STREAM

STREAMING FLEXIBILITY TO THE POWER SYSTEM

D5.1 DEMONSTRATION ACTIVITIES REPORT

Delivery Date: June 2026

STREAM

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Abstract

This deliverable presents the results of the deployment and demonstration activities carried out within the STREAM project. The four pilot sites have successfully integrated the STREAM tools with the underlying physical systems to operationalise the local flexibility market ecosystem and have validated their deployments under real operating conditions.

Keywords

Local flexibility markets, low-voltage grids, flexibility services, flexibility service providers, end users, deployment, demonstration, pilot validation, data collection, mFRR, FCR-D, traffic light system, device registry

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EXECUTIVE SUMMARY

This deliverable provides the documentation of the deployment, integration and demonstration activities performed within Work Package 5 across the four STREAM pilot sites. It reports the implementation of the STREAM ecosystem in real operational environments, the execution of the demonstration experiments (hereafter referred to as test cases), and the datasets collected during the pilot activities.

Overall, the STREAM demonstrations have validated the technical feasibility and operational value of leveraging distributed energy resources (DERs) to provide flexibility services supporting grid operation (both at transmission system operator (TSO) level through ancillary services and distribution system operator (DSO) low voltage (LV) level) and the development of local flexibility markets (LFM). The results demonstrate how DSOs, aggregators, energy communities (EnC), prosumers and industrial actors can actively contribute to congestion management, voltage control, optimisation of renewable energy integration and reduction of grid reinforcement needs.

The **Slovenian pilot** site focused on the use of industrial flexibility and electric vehicles (EVs) to provide services both to LFMs and to TSO manual frequency restoration reserve (mFRR) ancillary services. The pilot demonstrated an integrated ecosystem of tools covering the full flexibility value chain, including sDATA for data management, sFLEX for asset monitoring and flexibility activation, the Device Registry for asset prequalification, sGRID for grid monitoring and congestion management, sPLAN for investment planning, and sMART as the local flexibility market platform. The pilot validated end-to-end flexibility workflows from asset registration to market participation and grid operation support through ten different test cases.

The **Spanish pilot** site demonstrated the role of EnCs as key enablers of local flexibility markets. The pilot combined sENC for aggregation of small-scale prosumer flexibility, sFLEX for management of larger community assets such as batteries and EV chargers, sGRID for distribution grid monitoring and flexibility request generation, and sMART as the market platform enabling flexibility exchange. In addition, peer-to-peer flexibility mechanisms within the EnC were demonstrated, showing improved utilisation of local renewable generation and increased economic welfare. The Spanish pilot results were validated through nine test cases covering congestion management, voltage control, market interaction and optimisation of community assets.

The **Italian pilot** site focused on flexibility provision from EV charging infrastructure and additional distributed assets. The pilot demonstrated EV charging station onboarding and registration into the flexibility platform, validation of EV charging flexibility activation through sMART, and end-to-end processes from DSO flexibility requests to bid submission and activation. It also included digital twin-based modelling of water pumping systems and heating, ventilation and air conditioning (HVAC) consumption estimation, enabling flexibility potential assessment. Furthermore, optimisation of distributed flexibility was demonstrated using sENC supported by sFLEX and sGRID inputs. The pilot validated asset registration, flexibility activation, optimisation and remuneration workflows through eleven executed test cases.

The **Finnish pilot** site focused on the provision of explicit flexibility for frequency containment reserve for disturbances (FCR-D) services using residential loads. The pilot demonstrated the potential of residential flexibility aggregation to deliver FCR-D up and down services. This included multiple activation scenarios based on grid signals sampled at 10 Hz, under both simulated and real load conditions, as illustrated through three test cases. Following the definition and initial execution of the demonstration activities, the pilot sites identified the need to reevaluate the originally defined key performance indicators (KPIs), including the addition, modification, and in some cases removal of some of the KPIs with respect to those initially established in D2.2 [1], in order to better assess the impact of the demonstrations.

Across all four pilot sites, the STREAM ecosystem has demonstrated its applicability under different regulatory, technical and operational contexts. The results confirm that coordinated flexibility activation through platforms such as sGRID, sMART, sFLEX, sENC, sPLAN and sDATA can significantly enhance grid observability, support system operation, and enable new market-based flexibility services.

The demonstrations highlight the key role of end users, aggregators and energy communities in enabling scalable local flexibility markets and supporting DSOs in grid management. Overall, the STREAM results provide strong evidence of the potential of flexibility-based solutions to reduce grid reinforcement needs, improve system efficiency, and accelerate the transition towards a more decentralised and digital energy system.

To reduce the length of the main body of the deliverable, the detailed results of the test cases and datasets are included in the annexes.

Response to the recommendations from the review

The pilot sites describe in Sections 3.1.2, 3.2.2, 3.3.2 and 3.4.2 their **stakeholder engagement activities**, which was essential to keep end users engaged in order to support impactful demonstrations and validate the solutions under real operational conditions.

Furthermore, Sections 3.1.5, 3.2.5, 3.3.5 and 3.4.5 present the **main innovations and advancements beyond state-of-the-art demonstrated in each pilot site**, emphasizing the different approaches adopted across STREAM to leverage flexibility services at low-voltage level.

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The purpose of this deliverable is to report the activities carried out in the four pilot sites (Slovenian, Spanish, Italian and Finnish) within Work Package (WP5) Demonstration and integration, covering its three tasks: Task 5.1: Overall coordination and deployment, Task 5.2: Pilot sites and Task 5.3: Demonstration monitoring. In particular, this deliverable reports on:

- The definition of the deployment plans and the detailed deployment activities process to integrate the STREAM ecosystem in the four pilot sites. This includes the integration of the tools developed in WP2 (sENC), WP3 (sDATA, sGRID and sPLAN) and WP4 (device registry, sFLEX and sMART).
- The demonstration activities conducted in each pilot site, including the end-user engagement activities which streamlines the active participation of end user within the demonstrations. A set of experiments (hereafter referred to as test cases) have been defined, executed and analysed in each pilot site to demonstrate the use cases described in deliverable D2.2 “Use cases and requirements definition”. The test cases are named following the nomenclature AA-UC.XX.YY, where:
    - AA: Identifier of the pilot site where the test case was executed.
    - UC.XX: Identifier of the use case, following the nomenclature defined in D2.2.
    - YY: Sequential number of the test case within the corresponding use case.
- The results of these test cases, together with the datasets gathered and reported in the final chapter of this deliverable, will be used to calculate the KPIs defined in D2.2 and updated in this document, supporting the impact assessment activities under WP6.

This report is the result of collaborative work between pilot site partners, who provide the datasets and operate the tools during the test case execution, and technical partners, who deploy and integrate their tools within the pilot sites’ data, infrastructure and flexibility assets.

1.2 SCOPE OF THE DOCUMENT

This deliverable provides the documentation of the activities carried out within the scope of WP5 Demonstration and integration. It provides a detailed description of the implementation and deployment of the STREAM ecosystem across the four pilot sites and reports the results of the test cases and the datasets collected to enable the calculation of the KPIs for the impact assessment under WP6.

1.3 STRUCTURE OF THE DOCUMENT

The document is structured as follows:

- **Section 2** describes, for each pilot site, the details of the **integration and deployment of the assets and tools** (sENC, sDATA, sFLEX, sGRID, sPLAN and sMART) developed in the completed work packages WP2, WP3 and WP4. Each pilot site subsection includes:
    - **Sections 2.X.1, introducing the pilot sites**, their scopes, operational context and main objectives and use cases, and contextualizes the deployment and demonstration activities.
    - **Sections 2.X.2,** presenting the **risk analysis** for each pilot site, expanding the risks listed in the Grant Agreement and defining mitigation measures. Probability ranges

from low (1) to high (3) likelihood of occurrence, while impact ranges from minor effects on the pilot (1) to critical issues that could jeopardise deployment and demonstration activities (3). The final risk priority is calculated as the product of both values, providing a straightforward way to rank and prioritise risks for monitoring and mitigation.

    - **Sections 2.X.3,** detailing the **deployment plans**, including timelines, Gantt charts, and a comparison between planned and actual deployment milestones.
    - **Sections 2.X.4,** describing the **new assets and hardware deployed** in the pilot sites, where applicable.
    - **Sections 2.X.5,** explaining the **implementation of the STREAM ecosystem** in each pilot site.
    - **Sections 2.X.6,** outlining the **challenges and limitations** encountered during the integration of the STREAM ecosystem in each pilot site.
- **Section 3** documents the **demonstration activities** carried out in each pilot site **and their results**, including:
    - **Sections 3.X.1,** providing the **planification of the demonstration activities** and the deviations from the planning.
    - **Sections 3.X.2,** listing the **stakeholder engagement activities,** which were essential to ensure successful and impactful demonstration of the STREAM ecosystem**.**
    - **Sections 3.X.3**, **updating the list of KPIs** for each pilot site based on the experience gained during deployment and demonstration.
    - **Sections 3.X.4,** summarising the executed **test cases** with their key results, providing a list and justification of the descoped use cases (the ones that the pilot sites had not demonstrated finally).
    - **Sections 3.X.5**, highlighting the main innovations demonstrated in each pilot site and the progress beyond the state of the art (SOA).
    - **Sections 3.X.6,** reporting the **challenges and limitations** encountered during the demonstration activities.
- **Section 4** lists the **datasets gathered** during deployment and demonstration activities.
- **Section 5**: provides the **conclusions** of the document, summarising the main findings and results obtained across the pilot sites.
- **Annex A**: provides the detailed description of the updated set of KPIs of each pilot site, aligned with sections 3.X.3.
- **Annex B**: provides the detailed documentation of the test cases executed per pilot site, including their detailed description, results and qualitative analysis.
- **Annex C**: provides the detailed documentation of the datasets gathered per pilot site, including if the dataset is public or confidential, the URL to Zenodo where the dataset has been uploaded (in the case of public datasets) and graphical support if possible.

2 INTEGRATION AND DEPLOYMENT OF THE STREAM ECOSYSTEM

2.1 SLOVENIAN PILOT SITE

2.1.1 Pilot site scope, operational context and objectives

The Slovenian pilot is located in an industrial zone in Ajdovščina, in the southwest of Slovenia. The area is characterised by predominantly industrial electricity demand, ranging from small and medium-sized enterprises to large industrial customers with connected power of 1 MW and above. A key feature of this part of the distribution network is the high pace of industrial development, which has led to a continuous increase in electricity demand. Consequently, Elektro Primorska (EPR), as the local DSO, must regularly adapt and reinforce the network to keep up with this growth. For this reason, the site was selected as a relevant test environment for assessing the value of flexibility for both network planning and operational purposes.

The industrial zone is mainly supplied from the 110/20 kV primary substation RTP Ajdovščina via two 20 kV medium voltage (MV) feeders (Mirce and Tale) (see Figure 1). In addition, some loads are supplied through two further feeders (Čistilna naprava and Fructal). The area includes several MV/LV secondary substations, seven of these are owned by the DSO and supply customers connected to the LV network, while larger industrial customers operate their own dedicated transformers. All MV and LV feeders in the pilot area are underground cables. For customers supplied through private transformers, metering is performed on the MV side.

All consumers within the pilot site are equipped with smart meters providing measurements of active and reactive power, as well as voltage values. Additionally, selected transformers are equipped with dedicated control measurements at the secondary (LV) side, recording active power, reactive power, and phase voltages. Both measurement sources are integrated into the Advanced Metering Infrastructure (AMI) system. EPR receives AMI data on a D-1 basis through concentrators installed in MV/LV substations, with communication performed via power line communication (PLC).

On the MV level, measurements are available via the SCADA system. For MV feeders, SCADA provides active power, reactive power, and current measurements. For the primary substation transformer, SCADA provides phase-to-phase voltages as well as active and reactive power measurements.

Before the start of the project, a Letter of Intent (LOI) was signed with 10 companies from the pilot area. During the initial phase, KOL, EPR, and AVA conducted a series of meetings and workshops with these companies to assess their assets and potential participation in the flexibility-related activities. Based on these discussions, some companies declined to participate in the demonstration activities, while some assets were deemed unsuitable for further analysis and market participation. As a result, the detailed work proceeded with 5 companies, highlighted in red in the grid topology figure below. The final list of assets is described in more detail in Section 2.1.5.



Figure 1: Visualization of Ajdovščina pilot site

The overall Slovenian pilot scheme is shown in Figure 2. It summarises the tools deployed in the pilot and their interactions with the main actors (flexibility providers, DSO, market operator, and TSO/wholesale markets).

At the pilot site, flexibility is provided by two groups of assets: (i) pilot site flexibility devices (described in Section 2.1.5) and (ii) EV charging stations operated by the e-mobility provider AVANTCAR. These assets are connected to sFLEX, which acts as the flexibility management layer. sFLEX provides the interface between flexibility assets and market processes and supports key functions such as asset monitoring/control, forecasting, and preparation of flexibility bids. In parallel, EV charging station data are shared via sDATA, enabling secure and transparent data exchange and making the relevant datasets available to authorised users and applications for further analysis and operation.

sFLEX exchanges flexibility information with sMART, the LFM platform, by submitting bids and receiving market signals (e.g., auction requests and outcomes). The short-term grid management tool sGRID is positioned upstream of the market process: it uses the required operational data provided through sDATA (grid topology and measurement data) to forecast the grid state in advance (day-ahead and shorter horizons). When sGRID detects or forecasts congestion, it triggers the opening of an auction in sMART. The auction request specifies (i) the location of the constraint, (ii) the required flexibility volume to mitigate it, and (iii) the Traffic Light System (TLS) stage, which determines the type of action and urgency depending on whether planning or operational limits are exceeded.

Once the auction is closed and the market is cleared, sMART selects the most suitable assets based on the submitted bids and the auction requirements. The clearing results (awarded assets and activation setpoints/volumes) are then communicated to sFLEX, which sends the corresponding activation signals to the selected assets and ensures the execution of the requested flexibility.

On the DSO side, sPLAN supports network planning by explicitly considering flexibility as an additional option alongside traditional reinforcement measures.

In addition to local congestion management, the pilot assets can also contribute to system-level balancing: through sFLEX, flexibility can be aggregated and offered to the wholesale/TSO context (ELES) (e.g., mFRR ancillary services), supporting overall system balance alongside the local sMART auctions.

A key enabling component is the device registry, which maintains the list of flexibility assets eligible to participate in LFMs. The registry includes, in particular:

- the asset's location (critical for local products),
- its prequalification status (i.e., whether it can provide a specific service/product),
- relevant asset parameters (e.g., technical capabilities and bidding/activation-related attributes), and
- the aggregator assignment (i.e., under which aggregator the asset is registered and represented in the market).

The registry interacts with sFLEX to support communication and test activations during prequalification and commissioning, and with sMART to validate bids and verify eligibility and consistency during auctions (e.g., correct product, location, and aggregator association).

All these interactions are illustrated in Figure 2.

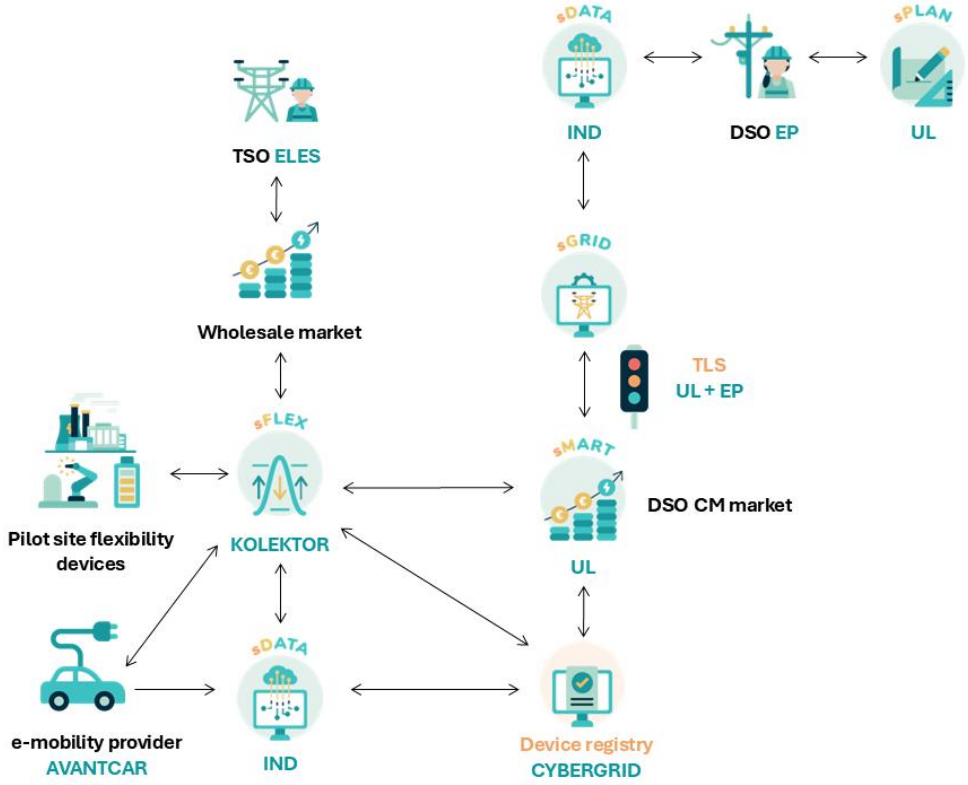


Figure 2: Slovenian pilot site scheme

The main objectives of the Slovenian pilot are:

1. Demonstrate end-to-end operation of the STREAM ecosystem in the Ajdovščina pilot, integrating the deployed tools and validating the complete workflow from data acquisition and forecasting to market execution and real asset activations.
2. Validate congestion forecasting and congestion mitigation workflow by demonstrating that sGRID can anticipate network constraints (day-ahead / intraday) and trigger the appropriate mitigation process via sMART (auction opening) and sFLEX (bid submission and activation of selected assets).

3. Demonstrate the TLS as an operational decision layer, showing how the TLS stage determines the type/urgency of actions (planning vs operational limits) and how this information is communicated to the market process (auction request requirements).
4. Demonstrate the role of the device registry as a market-enabling component, ensuring that only eligible assets can participate through: prequalification status, location mapping for local products, technical parameters, and showing how registry checks support bid validation and auditability.
5. Assess the value of flexibility-aware planning by demonstrating how sPLAN supports grid planning decisions by considering flexibility as an option complementary to conventional reinforcement measures, using data-driven insights from the pilot.
6. Demonstrate multi-asset flexibility utilisation through sFLEX, showing aggregation and control of heterogeneous assets (e.g., PV, industrial cooling, industrial processes such as mills) and their provision of flexibility services to both local DSO congestion management via sMART and system-level services or markets.
7. Demonstrate secure and controlled data exchange via sDATA, including governed access to key datasets (measurements, topology, metadata), user authorisation, and traceable data usage to support reliable operation across the toolchain.

2.1.2 Risk analysis

Apart from the risks included in the Description of Action, seven additional potential risks were identified in the pilot site as listed in Table 1: Slovenian pilot site risk analysis. Mitigation measures were defined in order to reduce the impact of the risks if materialized:

Table 1: Slovenian pilot site risk analysis

Ref ID	Risk description	Probability	Impact	Priority	Mitigation measures
SI_01	Asset owners are not willing to activate their assets for DSO ancillary services simulation. Low end-user participation	1	1	1	Aggregator (KOL) will try to maintain good relationships with asset owners, explain to them the benefits of the project in general and try to find the monetization possibilities in the already established markets.
SI_02	The complexities of measurement data from individual energy assets may lead to challenges in accurately calculating the baseline, potentially resulting in penalties from TSOs due to not meeting activation expectations in ancillary services.	3	1	3	Aggregator (KOL) will emphasize the evaluation of the baseline of individual assets and choice of the appropriate ancillary services products to avoid potential penalties.
SI_03	Real-time measurements not available	3	2	6	If RT measurements are not available, we will simulate the acquisition of data in RT by using past data.
SI_04	The complexity of modelling the LV grid in sGRID and sPLAN causes the functionalities developed within the pilot site to behave incorrectly	2	2	4	Continuous coordination between technical and pilot partners to ensure the correct and optimal modelling of the LV grid, which will be critical for the correct functioning of the services deployed in the pilot.
SI_05	Failed integration between the developed tools that leads to issues with data transfer and failures in the operation of sMART	2	3	6	Bilateral calls are being conducted between the developers of the tools to align on the protocols and formats that will be exchanged.

SI_06	Local flexibility market design not aligned with the stakeholder needs	**1**	**3**	**3**	To ensure the local flexibility market design meets stakeholder needs, people-centric approach is used to involve all important stakeholders in the specification and design phase.

2.1.3 Deployment plan

Figure 3 provides the Gantt chart of the Slovenian pilot site deployment plan:

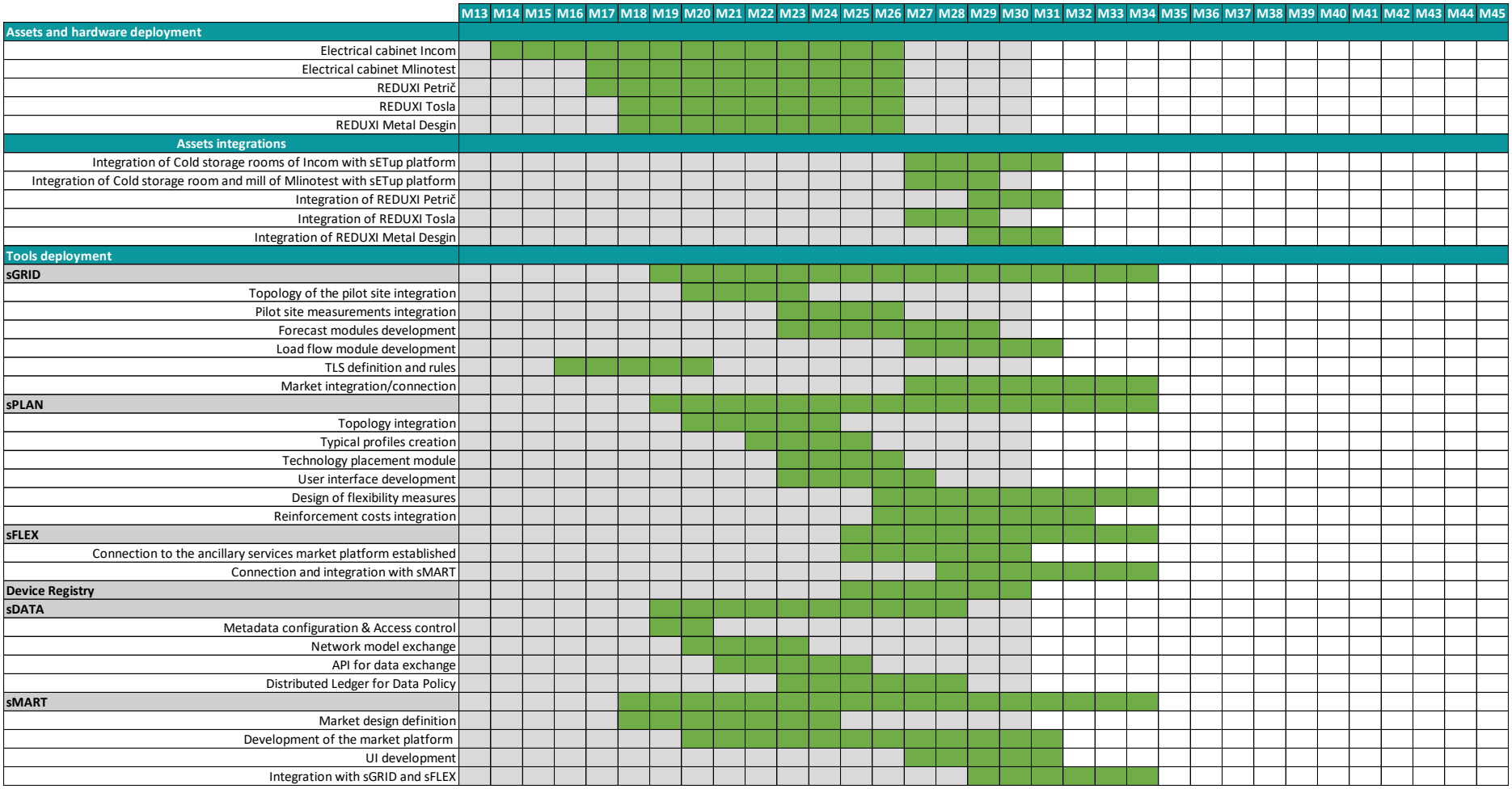


Figure 3: Slovenian pilot site deployment plan

Table 2 presents the deviations suffered during the deployment of the tools and the integration of the pilot site assets in the Slovenian pilot site and the reason for the deviations (please note that the features not listed did not suffer any deviations):

Table 2: Final deployment deviations in the Slovenian pilot site

Tool and feature	Expected deployment date	Final deployment date	Reason
sGRID: Market integration/connection	July 2025 (M34)	November 2025 (M38)	API communication with sMART was validated in a development environment before M34. Full integration was finalised in M38 when sGRID was deployed on server infrastructure, which also depended on the resolution of measurement data availability issues (see below).
sGRID: Pilot site measurements integration	November 2024 (M26)	November 2025 (M38)	The M26 milestone covered historical data for model training, which was completed on time. Establishing a reliable pipeline for fresh D-1 smart meter data via sDATA took longer due to a high rate of missing values caused by retrieval timing. After approximately one month of debugging (including coordination with the DSO on data propagation from field concentrators) sDATA's retrieval frequency was increased, resolving the issue.
sPLAN: Design of flexibility measures	July 2025 (M34)	September 2025 (M36)	Power flow convergence issues were encountered in edge cases involving high peaks in input profiles and BESS modelling. Resolving these required corrections to input profiles and modifications to the flexibility asset models.
sMART - Integration with sGRID and sFLEX	July 2025 (M34)	November 2025 (M38)	sMART was deployed and ready by M34. The delay was caused by the later finalisation of sGRID's operational deployment, which was a prerequisite for end-to-end integration.

2.1.4 Deployment of new assets and hardware

In the scope of the pilot site, KOL deployed and installed several pieces of equipment to enable the integration of the assets to the sFLEX and execution of activations. KOL included the following equipment:

- Tosla: REDUXI device (Figure 4)
- Petrič: REDUXI device
- Metal Design: REDUXI device
- Incom Leone: Edge device (Siemens controller) for integration of existing measurements and establishment of the activation signals.
- Mlinotest: Edge device (Siemens controller) for integration of existing measurements and establishment of the activation signals.



Figure 4: REDUXI device

In addition to the equipment deployed by KOL, EV charging infrastructure was installed at two company sites in the Ajdovščina area through a collaboration with the e-mobility provider AVACAR. The engagement with these companies was the result of several rounds of meetings with local company representatives conducted during the pilot preparation phase, aimed at identifying willing participants for the demonstration of the LFM. Two companies: SLO-car and Knauf agreed to have EV charging stations installed on their premises.

Both installations are dual-socket AC charging stations, each equipped with two Type 2 connectors (IEC 62196) and capable of delivering up to 2 × 22 kW of three-phase charging power (3 × 32 A at 400 V). The stations support adjustable charging current (from 6 A to 32 A), include built-in ground fault protection, and are connected via Wi-Fi (IEEE 802.11b/g/n) with Modbus TCP/IP support for remote monitoring and control. The two installations differ in form factor: the SLO-car site uses a freestanding tower enclosure (stainless steel, 1400 × 300 × 200 mm), while the Knauf site uses a wall-mounted wallbox variant. They are shown in Figure 5.



Figure 5: EV charging station installed at SLO-car (left) and Knauf (right)

The charging stations are integrated into the STREAM ecosystem through the AVACAR API, which provides near-real-time operational data (charging power, session status) to sDATA at 5-minute intervals. This data is subsequently made available to sFLEX for flexibility forecasting and bid preparation, and is used in the demonstration of the local congestion management market operated through the sMART platform.

2.1.5 Pilot site assets and STREAM tools integration and deployment

Following the meetings and workshops conducted with companies in the Ajdovščina pilot area, a set of flexibility assets was identified for participation in (i) system-level services (TSO ancillary services) and (ii) the local congestion management market operated through the sMART platform. The selected assets represent a heterogeneous portfolio of industrial and prosumer resources, including flexible industrial processes, cooling loads, PV generation, battery storage, and EV charging infrastructure.

All assets included in the pilot have been onboarded and connected to sFLEX, which acts as the flexibility management layer. sFLEX collects asset-level operational data (e.g., active and reactive power measurements, operational status, and other relevant signals) and enables the preparation and submission of flexibility bids.

However, for the battery energy storage systems (BESS) and EV charging stations operated by Tosla, sFLEX is limited to monitoring and bid preparation only. The execution of activations (i.e. real-time control and dispatch following market clearing or service requests) is not possible, as these assets are controlled by an external flexibility/portfolio management system.

Table 3 summarises the assets included in the Slovenian pilot, their nominal capacity, and whether a contractual agreement for participation in mFRR ancillary services is in place.

Table 3: Flexibility assets in the Slovenian pilot

Asset	Company	Nominal power	Contractual agreement for mFRR ancillary services
Cold storage rooms	Incom Leone	1.500 MW	YES
Mill	Mlinotest	0.450 MW	YES
PV	Petrič	0.150 MW	NO
PV	Tosla	0.150 MW	NO
Cold storage rooms	Mlinotest	0.215 MW	YES
PV	Metal design	0.150 MW	NO
BESS	Tosla	0.08 MW/0.2 MWh	NO
E-charging stations	Tosla	0.044 MW	NO
E-charging stations	AVAcar	0.088 MW	NO

The STREAM ecosystem deployed in the Slovenian pilot site includes several tools developed and integrated during the project. The role, functionality, and deployment status of each tool are described in the following subsections.

2.1.5.1 sDATA

sDATA is the central data management, exchange, and governance platform for the STREAM project. Its primary role is to create a secure, reliable, and interoperable environment for data flow between various stakeholders, such as DSOs, e-mobility providers, aggregators, and the analytical tools developed within the project (sGRID, sFLEX, sPLAN).

2.1.5.1.1 Data Access and Security

Security and data sovereignty are fundamental to sDATA's design. Access is managed through a multi-layered approach to ensure that data is only shared with authorized parties according to the data owner's rules.

- Authentication & Authorization:
  - MDM Portal: Human users access the Master Data Management (MDM) portal via a secure login (username/password). The system features a detailed user and user group management system where an administrator assigns specific roles (Editor or Viewer) for each data record system.
  - API Access: Programmatic access for tools and services (like sGRID or sFLEX) is secured using API keys. Data exchange endpoints with partners are protected with specific

credentials, such as a JWT token for the Elektro Primorska API and a dedicated API key for the AVAcar integration.

- Access Control and Governance:
  - Data Provider Control: The data providers (e.g., Elektro Primorska, AVAcar) remain the data owners. They define the conditions under which their data can be accessed and used.
  - Access Granting Process: Data recipients, such as other project partners (KOL, UL), must be granted access. This is managed within the sDATA user rights system. An administrator, in accordance with the data owner's policies, configures the access rights for a user or user group. This ensures there is a formal, controlled process for granting access.
- Transparency and Auditing:
  - Audit Trail: The MDM portal features a comprehensive Audit trail for every record, logging all actions (creation, edits, views), the user who performed them, and the timestamp.
  - Distributed Ledger: As defined in use case UC sDATA.02, all access events across the platform are recorded on a distributed ledger, creating an immutable and transparent history of data access and ensuring full accountability.

2.1.5.1.2 Deployment in the Slovenian Pilot Site

In the Slovenian pilot, sDATA serves as the central data hub for the Ajdovščina industrial zone. It integrates data from multiple sources to provide a unified, quality-controlled dataset for other STREAM tools.

- Grid Topology Integration: sDATA integrates the complete distribution network model for the Ajdovščina area, provided by Elektro Primorska (EPR) in a CIM-compliant format. This model is highly detailed and includes:
  - 1 HV/MV primary substation transformer (RTP Ajdovščina, 2x31.5 MVA).
  - 4 MV feeders (Tale, Mirce, Fructal, Čistilna naprava).
  - 48 MV/LV secondary substations.
  - 184 cable segments across both MV and LV networks.
  - 141 load points, of which 12 are large industrial customers connected directly to the MV level and 129 are connected to the LV network.
- Measurement Data Integration:
  - From Elektro Primorska (DSO): sDATA performs a daily pull (D-1) of measurements from the AMI system, including smart meter data (power and voltage), MV/LV transformer measurements, and SCADA data (current, power).
  - From AVANTCAR (E-Mobility Provider): It connects to the AVANTCAR API to fetch near-real-time data from EV charging stations at 5-minute intervals.
- Visualization and User Management: The MDM web interface is the single point of management.
- Metadata Management: It stores and manages all metadata for the assets mentioned above, including measurement points, devices, and EV chargers.

- User and Access Rights: Administrators use the MDM to control which users and tools can access specific datasets.
- Data Visualization (Grafana): The MDM provides direct, pre-configured links to Grafana dashboards. For instance, the record for a specific EV charging plug or a measurement device contains a "Link to chart" field. Clicking this link opens a Grafana dashboard that visualizes the actual, time-stamped measurement data (e.g., power, voltage) for that specific asset, enabling users to analyze its operational history without needing separate login credentials for Grafana.

2.1.5.1.3 Partner Roles and Data Flow

The following user roles exist in sDATA:

- Data Providers:
  - Elektro Primorska (EPR): Provides detailed grid topology and D-1 measurement data.
  - AVANTCAR (AVA): Provides near-real-time EV charging data.
- Data Recipients:
  - University of Ljubljana (UL): Uses the grid model and measurement data from sDATA as the primary input for its sGRID and sPLAN tools to perform congestion forecasting and network planning.
  - Kolektor sETup (KOL): Uses the EV charging data from sDATA for its sFLEX platform to perform user profiling and flexibility forecasting.

2.1.5.1.4 Scope of Data Storage

The sDATA platform is designed primarily to ingest, store, and provide data from the pilot sites for analytical purposes. This includes raw and processed time-series measurement data, the grid topology model, and all associated metadata.

It serves as a unified source of truth for other STREAM tools. It is not designed to store the outcomes or analytical results produced by tools like sGRID or sFLEX. Instead, sDATA provides the quality-controlled input data that these tools require to perform their analyses.

2.1.5.2 sGRID

sGRID is a short-term grid management tool designed to support operational forecasting and congestion anticipation on day-ahead and near real-time horizons. In the Slovenian pilot it produces a day-ahead forecast for the current day and short-term updates every 15 minutes with a one-hour-ahead horizon, feeding congestion signals to sMART to initiate flexibility auctions.

2.1.5.2.1 Grid model and topology integration

The sGRID grid model covers the distribution network in the Ajdovščina industrial zone at both MV (20 kV) and LV (0.4 kV) levels, comprising one HV/MV primary substation transformer (110/20 kV, 2×31.5 MVA) representing RTP Ajdovščina, 48 MV/LV secondary substations, four MV feeders (Tale, Mirce, Fructal, Čistilna naprava) as underground cables, 184 cable segments across the MV and LV network, and 141 load points across MV and LV buses.

Of the 141 loads, 12 are connected directly at the MV level, representing larger industrial customers metered on the MV side. The remaining 129 are LV-connected. The representation of LV-connected loads depends on whether the underlying LV network falls within the pilot area and what measurement data is available at the transformer level.

Load points belonging to the pilot site area are included in the grid model with full topological detail — their feeders, nodes, and individual loads are explicitly represented in the network.

For LV networks outside the pilot area boundary, the full LV topology is not modelled. Instead, each such subnetwork is replaced by a single equivalent load placed at the LV bus of the corresponding MV/LV transformer, preserving correct power balance at the MV level and above while avoiding unnecessary complexity in parts of the grid that are not the focus of the pilot. The load profile assigned to this equivalent load is determined by data availability at the transformer level. Where transformer control measurements are available (active and reactive power recorded at the secondary side of the MV/LV substation), these are used directly as the profile for the equivalent load, and forecasting models are trained on this measured time series. Where no transformer control measurements exist, the consumption profiles of all individual smart meter loads connected under that transformer are retrieved and aggregated into a single composite profile, which is then used as the equivalent load profile for both model training and forecasting.

The grid topology was provided by EPR as a GeoPackage export. A dedicated extraction script was developed as part of the project and is now also used operationally at EPR to extract the relevant Ajdovščina subnetwork from their database. The resulting export is then processed locally using a transformation script that parses the GeoPackage layers for nodes, lines, transformers, loads, and switches, and converts them into the pandapower network format, handling voltage level mapping, cable parameter assignment, and load placement. This process is triggered manually each time EPR provides an updated topology export, which has occurred at several points during the project to reflect network changes and keep the model aligned with the current grid configuration.

The visual representation of the topology is shown in Figure 6, with the triangles representing transformer substations, blue lines the MV feeders and red dots the loads.

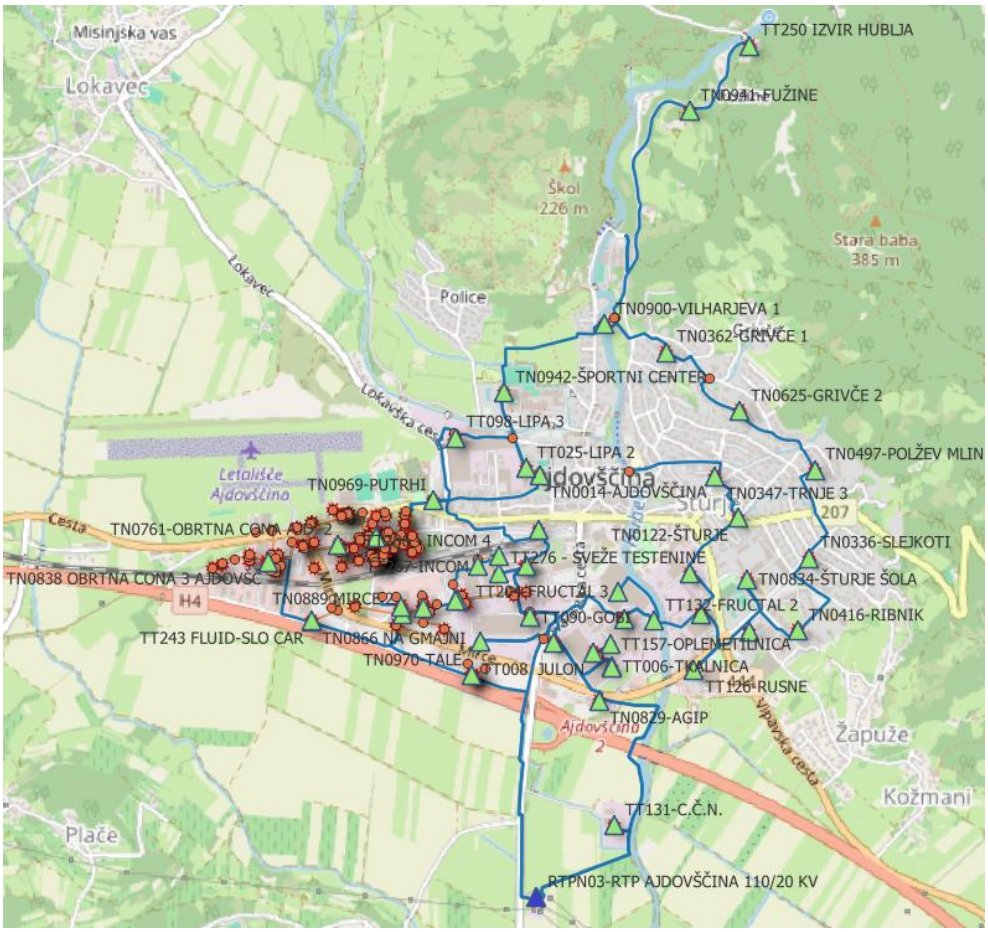


Figure 6: Visual representations of the Slovenian pilot grid topology

2.1.5.2.2 Data ingestion

sGRID draws on two external data sources: weather data from the Open-Meteo API and grid measurement data from the sDATA API.

Weather data is fetched from the Open-Meteo API for the Ajdovščina area at hourly resolution and resampled to 15 minutes — using linear interpolation for temperature and global horizontal irradiance (GHI), and a stepwise approach (same value for all four 15-minute intervals within an hour) for wind speed. The variables retrieved are air temperature at 2 m, wind speed at 10 m, and GHI. Weather data is fetched on every run of the day-ahead (DA) and short-term (ST) functionality for the required forecast horizon. For current and near-future timestamps the standard forecast API endpoint is used; for historical timestamps beyond the forecast API's coverage window the historical forecast API endpoint is used instead, with the selection made automatically based on the target timestamp.

Grid measurement data is retrieved through the sDATA API and is used exclusively in the ST functionality as input for lag features. The data available via sDATA includes consumer smart meter readings, transformer control measurements (active and reactive power at 15-minute resolution) from selected MV/LV substations in the pilot area, and aggregated consumer profiles for composite load representations. SCADA measurements from MV feeders and the primary substation RTP Ajdovščina are also available via sDATA and are used for evaluation and validation of sGRID outputs. In the ST run, sGRID calls three sDATA endpoints (prosumers, transformers, and prosumers_aggregated) for the date range required to cover the lag window.

Data arriving from sDATA may contain missing values for some timestamps. sGRID handles short gaps through linear interpolation; for longer gaps where interpolation is not reliable, the tool falls back to the DA forecast value for the affected load and timestamp, retrieved from the sGRID database. If the sDATA API is entirely unavailable for a given run, the same DA fallback is applied across all affected loads, allowing the ST run to complete using DA values in place of measured lags. If the Open-Meteo API is unavailable, the run cannot proceed, as weather features are a required input for all forecast models; however this dependency is common to any operational forecasting system and is not specific to sGRID.

2.1.5.2.3 Operational workflow

An important context for understanding sGRID's operational setup is the data availability constraint at the pilot site. Measurements from EPR's AMI metering system (both individual smart meter readings and transformer control measurements) are only available on a D-1 basis, meaning data for a given day becomes accessible the following day. This precludes the use of truly real-time inputs and means that sGRID operates with a one-day lag in its measurement inputs. To preserve meaningful validation of forecast outputs against actual grid conditions, results are stored in the database under the original D-1 timestamps. When congestion messages are sent to sMART, a one-day offset is applied so that they reference the corresponding delivery day (D), allowing sMART to process them as forward-looking flexibility requests.

All internal processing in sGRID uses UTC-naive timestamps following a consistent UTC backbone convention. Conversion to local time is applied only when constructing JSON messages for sMART, including the assignment of imbalance settlement period (ISP) numbers.

sGRID operates two complementary forecast runs. The DA run executes once per day, currently scheduled at 12:00 local time, and produces a full 96-step forecast covering 00:00–23:45 local time at 15-minute resolution for the current day. For example, a DA run executed on April 3rd produces forecasts stored under April 3rd timestamps in the database, while the corresponding sMART messages reference April 4th. The ST run executes every 15 minutes around the clock, producing a single-step updated forecast for the timestamp one hour ahead. Because the most recent available sDATA measurements are from D-1, each ST run's effective forecast target also falls on D-1; the

corresponding sMART messages again apply the one-day offset to reference the correct delivery timestamp.

Run execution is managed through Windows Task Scheduler. Both runs produce structured logs: a detailed text log capturing per-load forecast outcomes, power flow convergence, and any fallback events, and a summary record written to the PostgreSQL database capturing the number of successfully forecast loads, whether the power flow converged, and the overall run status. These logs are reviewed periodically to monitor operational health. In the event of a failed run, no automatic recovery or alerting mechanism is in place; the missed run can be replicated manually by specifying the target date or timestamp directly in the script configuration.

2.1.5.2.4 Load forecasting functionality

sGRID forecasts active power for all load points in the network individually using XGBoost gradient boosting models. Each load point has one model for DA forecasting and one for ST forecasting, with the two model sets maintained as separate experiments in an MLflow model registry, allowing the tool to always retrieve the latest available model for each load at runtime.

For DA models the feature set comprises cyclical time features (time of day, day of week, month of year encoded as sine and cosine pairs), a binary flag for Slovenian public holidays, and weather features (air temperature, wind speed, and GHI). Models are trained on approximately two years of historical metering data and are retrained manually as new data accumulates to keep them representative of current consumption patterns.

For ST models the feature set is extended with lag features derived from D-1 measurements retrieved from sDATA. Specifically, the model uses measured active power at lag steps 4 through 8, corresponding to measurements from 60 to 120 minutes before the forecast target — noting that since sDATA data carries a one-day delay, these lags represent the equivalent historical interval from D-1 rather than live measurements. In cases where lag values are missing or cannot be reliably interpolated, the tool falls back to the DA forecast for that load point and timestamp, as described in Section 2.1.5.2.2.

Reactive power is not forecast directly. Instead, it is derived from the forecasted active power using a per-load power factor estimated from historical measurements and stored in the sGRID database, applying the relationship $Q = P \cdot \tan(\arccos(pf))$.

2.1.5.2.5 Congestion detection and TLS assignment

Following the power flow simulation, which uses the forecasted active and reactive load profiles as inputs, sGRID evaluates results against predefined loading limits for each monitored network element. The monitored set includes the HV/MV primary substation transformer, all MV/LV secondary substation transformers, MV feeder cables, and LV feeder first sections — the first cable segment on each LV feeder, which typically experiences the highest loading. The conceptual framework and the methodology for deriving the limits for each element type are defined in Deliverable D4.1 and the following summarises the operational interpretation.

The traffic light system (TLS) assigns one of four stages to each monitored element at each timestep based on its loading relative to two threshold levels: a planning limit and an operational limit, which vary by element type and account for factors including thermal ratings, the N-1 criterion for MV feeders, and a security factor reflecting the pace of local load growth.

- Green: loading below the planning limit — normal operation, no action required.
- Yellow: loading between the planning and operational limits — sGRID calculates the required flexibility volume and direction to bring loading back within the planning limit, and sends a congestion message to sMART to initiate a flexibility auction.

- Orange: loading between the operational and emergency limits — in addition to the flexibility auction initiated via sMART, the DSO may activate non-firm connection agreements.
- Red: loading above the emergency limit — direct load management or protection device activation may be required as a last resort to avoid grid failure.

It should be noted that for Orange and Red stages, sGRID's role is limited to detection and signaling via sMART; the subsequent DSO actions are external to the tool. For the purpose of the pilot demonstration, planning limits have been set conservatively relative to current load levels, enabling congestion scenarios to be triggered and validated under realistic operating conditions without waiting for load growth to naturally reach operational limits.

For each element and timestep where the TLS stage is Yellow or above, sGRID calculates the flexibility volume required to reduce loading back to below the planning limit, expressed in kW, together with the activation direction — downward (reduce consumption or increase generation) or upward (reduce generation or increase consumption).

2.1.5.2.6 sMART communication

Congestion results are translated into structured JSON messages and transmitted to sMART via its REST API. Each message corresponds to one monitored element at one timestep where the TLS stage is Yellow or above, and specifies the congested element identifier, the required flexibility volume in watts, the activation direction, the imbalance settlement period number (ISP, in local time, 1–96), the auction date, and the TLS stage. All messages for a given run are sent as a single JSON array. An example message generated by sGRID is shown in Figure 7:


```
{
  "CongestionDetails": {
    "CongestedElementID": "7022105",
    "OrderAmount": 31841,
    "OrderDirection": "Downward",
    "ISPNumber": 29,
    "AuctionDate": "2026-03-31",
    "AuctionID": "7022105_2026-03-31_29"
  },
  "TLS": {
    "Stage": "Yellow"
  }
}
```


Figure 7: Example message generated by sGRID

In this example, the monitored LV feeder with identifier 7022105 is forecast to exceed its planning limit during ISP 29 (07:00–07:15 local time) on 31 March 2026. The message requests a downward flexibility of approximately 31.8 kW (a reduction in net consumption on that feeder) to bring loading back within the planning limit.

The complete set of messages produced by each run is also stored locally in JSON format as a record of the congestion signals generated. Following the completion of end-to-end integration testing in November 2025 (M38), the sMART transmission step is fully active: congestion messages generated by sGRID are sent to sMART and used to open flexibility auctions, as demonstrated in Section 3.1.

2.1.5.3 sPLAN

sPLAN is a distribution grid planning and analysis tool developed solely for the Slovenian pilot site. Its main purpose is to support the DSO's decision-making in medium to long-term grid development and planning by comparing traditional reinforcement solutions (grid upgrades) with solutions that also consider the impact and potential value of flexibility through power flow simulations. As a potential source of flexibility new evolving technologies (e.g., PV, EVs, heat pumps (HPs), and BESS) are considered.

The sPLAN tool is designed as a standalone tool that consists of three core components: a database, a graphical user interface (GUI), and the engine (back-end calculation layer).

- **Database**: stores the pilot grid topology and element parameters, historical measurements used to build typical seasonal load profiles, and cost-related inputs for reinforcement measures. The database is updated when new real-network information becomes available.
  As the sPLAN is designed as a standalone independent tool with no direct connection with other tools being part of the STREAM ecosystem, the sPLAN database has been designed mainly with the purpose of serving as data storage for all sPLAN related data. However, as sPLAN is still part of the STREAM ecosystem that enables integrated data sharing, the relevant data that are regularly updated, e.g. measurements from the real network provided by EPR, are imported into the sPLAN database in the same way as in the case of sGRID. Data synchronisation (import) is initiated manually by the user. As mentioned, the role of the sPLAN is to support medium to long-term decision-making on the network development and planning, meaning that constant updates of the measurements from the real network are not a matter of high importance, as in the case of day-to-day operation, such as in the case of sGRID.
  Network modelling based on the considered topology was part of the pre-processing phase. The sPLAN tool requires a comprehensive model of the network in question. The tool design also enables its usage for other distribution networks if a comprehensive network model and all relevant data are provided.
- **GUI**: enables interactive scenario definition and results analysis. The user configures the simulation inputs and the simulation period. The latter is due to computational complexity limited to one week at 15 minutes time granularity in each meteorological season. The sPLAN GUI is presented in Figure 8.

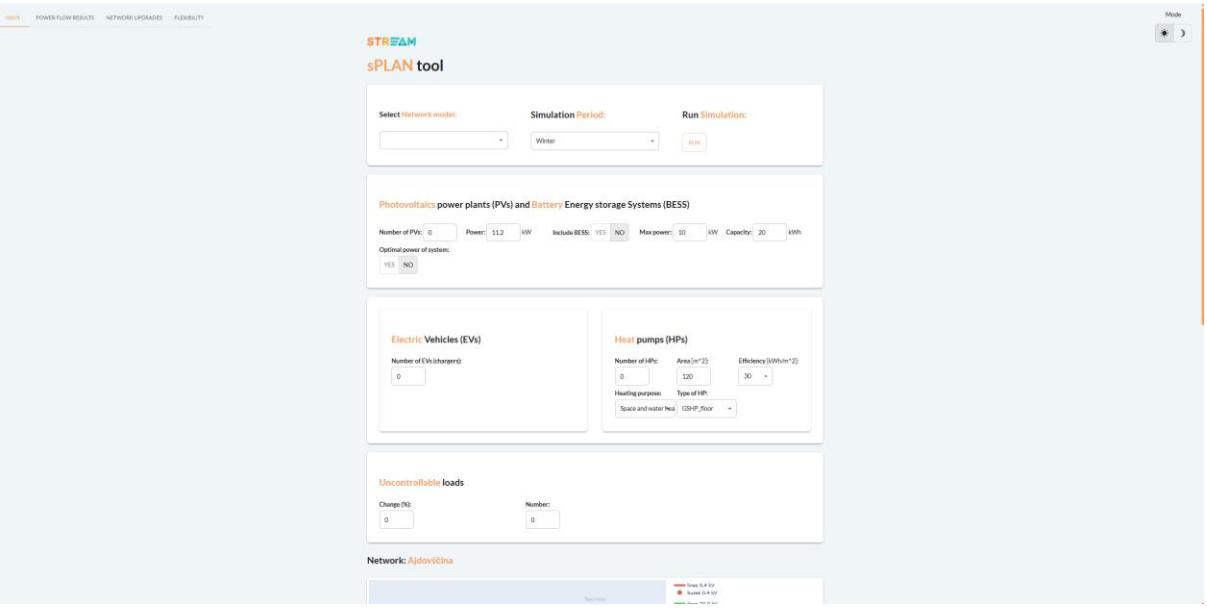


Figure 8: sPLAN graphical user interface.

- **Engine**: runs the entire workflow from initial profile preparation, initiating technology placement to modifying the profiles serving as main inputs for power flow simulations.

  The workflow consists of the following steps:

  - The user in the GUI on the first page first selects the simulation meteorological season and defines the inputs for the simulation. These inputs are:
    - Number of newly installed PVs in the network – The power of each newly installed PV is set based on the connection power or set by the user. In the latter case, the power is the same for all newly installed PVs.
    - Possible combination with BESS – If the option is selected, then all newly installed PVs are combined with BESS.
    - Number of newly installed EVs (chargers) – while generating the profiles of EVs charging, each user's connection power is considered.
    - Number of newly installed heat pumps – for generating the HPs profiles, the user can also define the average heating area and building efficiency used for generating HPs power profiles. If these parameters are not defined by the user, the algorithm in the background generates profiles based on random sampling.
    - Optional parameter is also a change of uncontrollable load in percentage.
    - Placing new technologies in the network is done by Technology placement module described in D3.3 [2].
  - Once all the inputs are defined, the user can run a power flow simulation with the original network model and power profiles generated based on measurements from the real network, combined with power profiles of newly installed technologies. Simulations are performed using pandapower – an open source tool for power system modelling, analysis and optimization with a high degree of automation.
  - After the simulation is completed, the user can evaluate the results presented in graphs and tables directly via GUI.

- To consider and compare different options for the network development and planning defined based on the needs identified based on initial simulations, users have the option to deploy the Optimal reinforcement module and Flexibility module. The first one determines which elements in the grid model need to be replaced with more powerful ones. The threshold of the loading factor is set by the user. For all upgrades made, the tool provides an indicative calculation of the cost of the investment based on the data provided by EPR. The Flexibility module allows the adaptation of profiles of flexibility resources during periods of increased load, i.e. when the loading factor of network elements exceeds a certain value, or when voltages are outside the allowed limits. As mentioned, the primary flexibility resources are devices added to the grid in the context of the definition of the initial parameters of the simulation, i.e. PVs and BESS, HPs, EVs. The module allows the adjustment of power profiles during periods of increased load, thus simulating the flexibility services that could be offered to the grid operator as an alternative to grid upgrades. The network conditions assessment is based on parameters such as the line loading factor and voltage deviations, where, in addition to absolute values, their temporal distribution is also taken into account (the proportion of time during which the values exceed the permissible limits).

Through all of the tool's features listed above, user of the tool can compare expected network conditions based on the current network configuration, implemented identified network upgrades, or utilisation of flexibility for different combinations of simulation inputs.

sPLAN is deployed on UL infrastructure and relies on (i) the tool's database storing pilot site network topology with all the parameters and (ii) typical seasonal profiles derived from historical measurements. It is designed primarily for planning studies, rather than scheduled operational runs. The implementation of the tool at the pilot site Ajdovščina, is carried out indirectly through the integration of data collected directly from the pilot site in the database used by the tool. The use of the sPLAN tool will enable the responsible DSO -EPR- the efficient, technology-neutral, and cost-effective development of the pilot site's network in the future.

2.1.5.4 sFLEX

sFLEX serves as the central technical and economic engine for the planning and real-time management of aggregated energy assets in the pilot. The platform determines how flexibility can be allocated across market opportunities while strictly respecting unit-specific technical, operational and security constraints, such as ramp rates, availability, state-of-charge limits, minimum operation times, and process requirements (e.g., defined response times for thermal loads).

The system continuously acquires real-time measurements from controllers or communication devices installed at connected assets, including active and reactive power, operational status and availability signals. EDGE controllers establish a connection to sFLEX using the MQTT communication protocol. In this architecture, the EDGE controller operates as the client, while the platform acts as the MQTT broker. Communication is bidirectional: operating schedules are sent from the platform to the controllers, while measurement data is transmitted from the controllers back to the platform. The communication link is provided via a 4G connection using a private APN, through which the EDGE devices securely connect to the platform. Redux controllers establish the connection in a similar way, also using the MQTT protocol. However, instead of a dedicated 4G connection, they rely on the internet connection available at the customer sites.

Building on this live data layer, sFLEX generates a baseline forecast (expected operation without intervention) and a flexibility forecast (upward and downward potential available for market

participation). An optimization module evaluates these forecasts against accessible market products and identifies economically optimal bidding strategies for individual assets and for the aggregated portfolio. On the DA basis, sFLEX performs an optimization for each of the connected assets and decides in which market or markets an asset can gain the most in the next day.

Within the STREAM framework in Slovenia, sFLEX considers participation in:

- Ancillary services, in particular mFRR;
    - To provide balancing services on the balancing market, balancing service provider (KOL) has communication channels established with the TSO, namely:
        - Business communication channel for sending market, billing and historical data, as well as for mFRR activation.
        - Operational communication channel for exchanging operational data and for automatic frequency restoration reserve (aFRR) activation.
    - The following protocols are used for data exchange between the balancing service provider and the TSO:
        - IEC 60870-6 TASE.2 communication protocol (ICCP): Exchange of operational data and data related to the implementation of aFRR and mFRR balancing services.
        - AMQPS communication protocol: Exchange of messages for sending market, billing and historical data and mFRR activation, implemented in the form of the ECCoSP communication platform (ENTSO-E Communication and Connectivity service Platform).
- sMART, covering both long-term and short-term flexibility products.

In the STREAM case, all assets are participating either in the ancillary services market or sMART market, which means that there is no decision making (at the moment sMART is not operational). However, in the future, sFLEX will decide in which market it should place bids for each of the asset based on maximal potential gain.

The tool provides an UI and different types of communication in the background (for example, API), enabling manual operation as well as automated integration with other STREAM tools. The UI offers an overview of the baseline forecast, the flexibility forecast, and activations (see Figure 9).



Figure 9: Slovenian pilot sFLEX UI overview.

Within the Slovenian pilot, sFLEX is integrated with the following STREAM components:

- sMART: the LFM platform to send the bids in the LFM sessions, offering flexibility from the assets.

2.1.5.5 Device Registry

The Device Registry (DR) is a web-based platform used in the Slovenian pilot for registering and prequalifying devices participating in LFMs. It serves as the central registry of flexible assets, maintaining key information such as device characteristics, location, and prequalification status, which are essential for bid validation within sMART.

The platform provides a graphical user interface that supports core workflows, including device registration, aggregator assignment, and the submission of prequalification requests. Through the interface, authorised users can view device details and access operational time series related to the prequalification.

The registration UI is asset-type agnostic: all assets follow the same registration workflow, regardless of asset type. During registration, the following parameters are collected: asset name, operational status, type, voltage level, installed capacity and flexibility, metering point ID.

The device registry supports multiple communication protocols for data exchange with assets including Reduxi MQTT, AVA Car API, IEC 60870-5-104, Modbus, IEE2030.5 and others. The connection to each asset is established based on the supported communication protocol. Within the pilot, PV plants were connected via Reduxi MQTT, while EV charging stations were connected via the AVA Car API.

Once the connection between an asset and the device registry is established, the platform can collect monitoring data and perform prequalification tests. During these, the DR verifies whether the device activation was performed within the tolerance limits. The prequalification test consists of a 15-min activation with tolerated deviation of +/- 10%.

The resulting prequalification outcome is available to users through the DR user interface and can also be retrieved via the DR REST API.

Within the STREAM architecture, the Device Registry is directly integrated with sDATA, which retrieves device information and operational time series data for use by other tools, including sMART.

2.1.5.6 sMART

sMART is the LFM platform deployed in the Slovenian pilot to enable DSO-led congestion management through auction-based procurement of flexibility. It acts as the central coordination layer between (i) the DSO's flexibility needs (derived from grid forecasts produced by sGRID), (ii) flexibility bids provided by aggregators and FSPs via sFLEX, and (iii) eligibility checks based on asset location and prequalification status maintained in the Device Registry. sMART is implemented as a web-based platform with a backend developed in .NET, a frontend built using Angular, and PostgreSQL for data storage. Communication with other STREAM tools is handled through HTTPS and JSON-based REST APIs.

sMART implements two market products, each serving a different purpose in the congestion management workflow:

- **Short-term flexibility product (energy market)**: the primary mechanism for congestion management, operating at a 15-minute resolution. This product is triggered automatically based on sGRID outputs when the TLS indicates that forecasted loading exceeds planning or operational limits. Its purpose is to procure flexibility that brings network loading back within the applicable limits, whether planning limits (to support network planning objectives) or operational limits (to maintain safe grid operation and avoid accelerated asset degradation). The short-term product combines new energy bids from sFLEX with capacity bids already contracted through the long-term market.

- **Long-term flexibility product (capacity market)**: designed to provide the DSO with assurance that sufficient flexibility resources will be available during critical periods identified through long-term network analysis. The DSO publishes a tender manually, and flexibility service providers (FSPs) commit to providing the requested capacity and standing ready for activation during the designated readiness period (weekly or monthly). This product serves as a safety net: by contracting flexibility availability in advance, the DSO reduces the risk of facing congestion situations with insufficient market liquidity, and can use flexibility as an alternative to conventional grid reinforcement.

The key differences between the two products are summarised below. The long-term product is initiated manually by the DSO, operates on weekly/monthly time horizons, and uses a two-component remuneration model (reservation price in €/kW/week plus activation price in €/kWh). The short-term product is triggered automatically via sGRID's congestion messages, operates on 15-minute intervals, and is priced purely on an energy basis (€/kWh). In both cases, bids must satisfy location and prequalification requirements validated against the Device Registry.

2.1.5.6.1 Asset eligibility via Device Registry

Before any asset can participate in sMART auctions, it must be registered and prequalified in the DR. The DR maintains key information for each asset, including its location in the distribution network (metering point ID, LV feeder, MV/LV substation, MV feeder, HV/MV substation), its prequalification status for specific market products, its technical flexibility parameters (active import/export capacity, response time, activation duration limits), and the aggregator assignment. This asset data is provisioned from the DR to sMART via sDATA, so that sMART holds a local copy of all relevant asset information. When bids are submitted, sMART performs eligibility checks internally against this pre-loaded data, verifying that the assets referenced in each bid are prequalified for the relevant market product, located in the correct part of the network, and that the bid quantities fall within the asset's registered technical capabilities. Bids that do not satisfy these criteria are considered void. The asset data within sMART is updated when changes are made in the DR.

2.1.5.6.2 Long-term flexibility product workflow

The long-term flexibility product follows a manual auction process initiated by the DSO to secure committed flexibility capacity for anticipated critical periods. The workflow proceeds as follows:

The DSO identifies, through long-term network analysis, grid elements (transformers or feeders) where forecasted demand may exceed planning limits during specific periods. Based on this analysis, the DSO publishes a tender on the sMART platform specifying the readiness period (weekly or monthly), the amount of flexibility required (in kW), the location of the expected congestion, the maximum reservation price (€/kW/week) and the maximum activation price (€/kWh), and optionally the minimal lead time (time between contract signature and first possible activation).

FSPs respond by submitting capacity bids via the sMART platform. Each bid must specify: the reservation price (€/kW/week, granularity 0.01), the activation price (€/kWh, granularity 0.01), the direction (upward or downward), the quantity (in kW, granularity 1 kW, range 1–9999 kW), whether the bid is divisible or indivisible, the asset location (validated against asset data held within sMART), the minimum rest time between consecutive activations (0–720 minutes), and the maximum number of consecutive activations before rest time is required.

The clearing algorithm constructs a Common Merit Order List (CMOL) sorted first by price and second by timestamp. The pricing method is pay-as-cleared (marginal pricing): all accepted bids receive the price of the last activated bid that satisfies the DSO's demand. The algorithm maximises welfare for the given set of orders and demands while minimising the total amount of activated flexibility. Only bids from eligible assets (correct location and valid prequalification) are considered.

Following the clearing, the results, which include the list of activated bids, the clearing price, and the satisfied demands, are published on the sMART platform in the market sessions view. The awarded FSPs commit to providing the contracted capacity during the readiness period and standing ready for activation by the DSO.

Settlement for the long-term product comprises two components: (i) reservation remuneration, compensating the FSP for keeping the asset available during the service window, and (ii) activation remuneration, paid when the DSO requests and the FSP delivers an actual activation. The activation baseline is defined as the average 15-minute measurement prior to the activation period. To encourage early participation in this nascent market, an activation delivering 80% or more of the agreed flexibility volume is considered successful.

2.1.5.6.3 Short-term flexibility product workflow

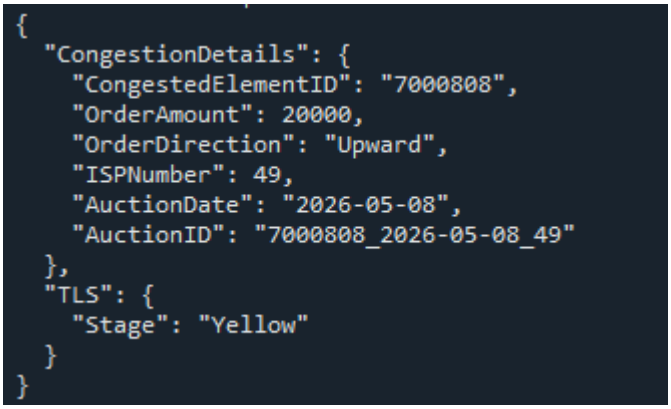
The short-term flexibility product is the primary congestion management mechanism, operating through an automated workflow driven by sGRID's congestion forecasting and the TLS. Its purpose is to procure flexibility to keep network loading within both planning and operational limits.

sGRID runs two forecast cycles: a DA run executed once per day producing a full 96-step forecast at 15-minute resolution, and a ST run executed every 15 minutes producing a single-step updated forecast one hour ahead. For each monitored element (transformer or feeder), sGRID evaluates the forecasted loading against two sets of limits and assigns a TLS stage:

- **Green**: loading within planning limits —> no market action required.
- **Yellow**: loading exceeds planning limits but remains below operational limits —> sGRID calculates the required flexibility volume and direction to bring loading back within the planning limit and sends a congestion message to sMART to initiate an auction. Both short-term energy bids and long-term capacity bids are considered.
- **Orange**: loading exceeds operational limits —> the same auction mechanism is triggered with increased urgency, and the DSO may additionally activate non-market-based measures such as non-firm connection agreements.
- **Red**: loading exceeds emergency limits —> rules-based emergency intervention by the DSO, outside the market mechanism.

Each TLS state is resolved independently using a bottom-up approach, starting at LV feeders and proceeding up to the HV/MV substation level.

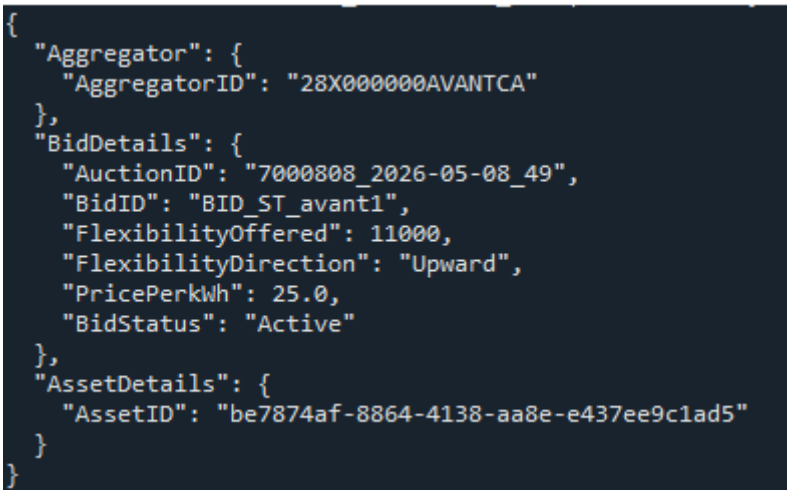
When sGRID identifies a Yellow or Orange condition, it transmits a structured JSON message to sMART via its REST API. Each message corresponds to one monitored element at one 15-minute timestep and specifies: the congested element identifier (CongestedElementID), the required flexibility volume in watts (OrderAmount), the activation direction Upward or Downward (OrderDirection), the imbalance settlement period number in local time, 1–96 (ISPNumber), the auction date (AuctionDate), a unique auction identifier (AuctionID), and the TLS stage. All messages for a given sGRID run are sent as a single JSON array. An example of a JSON message coming from sGRID is shown in Figure 10.



```
{
  "CongestionDetails": {
    "CongestedElementID": "7000808",
    "OrderAmount": 20000,
    "OrderDirection": "Upward",
    "ISPNumber": 49,
    "AuctionDate": "2026-05-08",
    "AuctionID": "7000808_2026-05-08_49"
  },
  "TLS": {
    "Stage": "Yellow"
  }
}
```


Figure 10: Example of a JSON message from sGRID to sMART (congestion signal)

FSPs submit energy bids to the short-term market via the sMART API. Each bid must specify: the bid price (€/kWh, granularity 0.01), the direction (upward or downward), the quantity (kWh, granularity 1 kWh, range 1–9999 kWh), and the asset location (validated internally by sMART against pre-loaded asset data). The preparation period, which is the time between the activation request and the start of the ramping period, is fixed at 2.5 minutes. Example of a JSON bid message is shown in Figure 11.



```
{
  "Aggregator": {
    "AggregatorID": "28X000000AVANTCA"
  },
  "BidDetails": {
    "AuctionID": "7000808_2026-05-08_49",
    "BidID": "BID_ST_avant1",
    "FlexibilityOffered": 11000,
    "FlexibilityDirection": "Upward",
    "PricePerkWh": 25.0,
    "BidStatus": "Active"
  },
  "AssetDetails": {
    "AssetID": "be7874af-8864-4138-aa8e-e437ee9c1ad5"
  }
}
```


Figure 11: Example of a JSON message from sFLEX (flexibility bid)

The clearing algorithm for the short-term product follows the same pay-as-cleared merit order logic as the long-term product. The CMOL includes both short-term energy bids and long-term capacity bids. The algorithm maximises welfare and minimises the total flexibility activated, subject to location and prequalification eligibility constraints.

Once the clearing is complete, the auction results (including the list of activated bids, the clearing price, and the satisfied demands) are published on the sMART platform in the market session's view. sFLEX consults the auction outcomes and sends the corresponding activation signals to the selected assets, ensuring the execution of the requested flexibility. On the sGRID side, no auction results are communicated back and the validation of whether the activated flexibility effectively mitigated the forecasted congestion is performed by the DSO using subsequent measurement data.

2.1.6 Deployment challenges and limitations

During the development of the tools and the deployment activities, the Slovenian pilot site partners encountered several challenges and limitations that needed to be overcome in order to meaningfully demonstrate STREAM solutions:

- **Limited availability of real-time (or near real-time) data from the DSO (EPR):**

The absence of real-time measurement streams required adaptations, in particular for sGRID, which is intended to support short-term operational forecasting. In the pilot setup, sDATA provides metering data on a D-1 basis (data become available one day later through DSO concentrators). Consequently, the short-term forecasting in sGRID relies on lag-based features derived from this D-1 dataset. For demonstration purposes, sGRID therefore performs its forecast and grid-state simulation for the previous day (D-1), while the resulting congestion information is forwarded to sMART as if it referred to the current day. This approach still enables a meaningful validation in two steps: (i) forecast accuracy evaluation, by comparing the simulated grid state against the measured state for D-1 (where measurements are available), and (ii) activation impact validation, by performing real activations and assessing their effect on a "congestion" scenario emulated by temporarily lowering element limits in the model.

- **Variable quality of consumer measurement data:**

  Metering data from consumers may contain outliers, gaps, and missing values, which required careful data cleaning and preprocessing to avoid propagating errors into forecasting and simulation results.

- **Difficulty in onboarding asset owners for flexibility services:**

  Asset owners' willingness to participate in flexibility services depended primarily on the presence of adequate financial incentives. If the expected remuneration did not compensate for the additional operational effort, internal coordination and perceived risks, participation was typically declined. For instance, the combined heat and power (CHP) unit at the Fructal site showed the highest theoretical revenue potential for mFRR, yet the operator chose not to engage, considering the benefit insufficient compared to the required commitment. In parallel, the lack of commercially available products on sMART meant that activations would have been performed purely for demonstration purposes, without real payment. This further reduced motivation and made asset recruitment more difficult.

- **Topology modelling effort and limitations:**

  The available grid topology model initially contained inconsistencies and modelling errors, making the topology preparation time-consuming and requiring substantial manual corrections to ensure simulation readiness. Due to the effort required and the available input data/model detail, the pilot implementation focused on a single-phase representation of the network rather than a full three-phase model.

- **Data inconsistency:**

  During the implementation of the sPLAN tool, a discrepancy was identified in the data regarding network elements. This discrepancy is not the result of negligence or improper procedures, but rather the fact that the networks, including the one in Ajdovščina, were planned and built decades ago. Digitisation was much less widespread at that time, which means that certain errors likely occurred during the subsequent conversion of data into digital form, as evidenced by the fact that the network model does not always reflect the exact actual conditions. While this may impose certain limitations on the project's results, it also raises the important question of how to properly address such challenges so that the solutions developed in the scope of the project will be as useful as possible in real-world situations.

2.2 SPANISH PILOT SITE

2.2.1 Pilot site scope, operational context and objectives

The Spanish pilot site is located in Crevillent, a municipality located in the southern part of the Valencian Region. In this municipality, Enercoop has established an EnC composed by 10,000 members. The EnC integrates the following flexibility-relevant assets:

- Hybrid PV + BESS installation: 120 kWp/242kWh
- Community buildings PV installations: 687 kWp
- EV chargers: ~20 kW (2 chargers)

In addition, 8 prosumers equipped with PV and battery systems actively provide flexibility services, representing a total battery capacity of 90 kWh and an installed PV capacity of 43 kWp.

Although these assets provide the highest flexibility potential, aggregated clusters of consumers across the municipality have also been considered within the demonstration activities. Due to their negligible individual flexibility capacity and the lack of automated control capabilities, these consumers mainly participate in the peer-to-peer market demonstration. This allows showcasing how LFMs can generate economic benefits for EnC members even when their individual flexibility potential is limited.

The distribution grid in the municipality is managed by Distribución Eléctrica Crevillent, SLU, owned by Enercoop Group. The network supplies more than 14,000 consumers (including over 13,000 households and 1,300 industrial and commercial customers) connected to the low voltage network; and 30 medium-voltage consumers. All households are equipped with smart meters, enabling detailed monitoring of electricity consumption. The local grid is supplied through a 40 MVA substation, and electricity is distributed through more than 150 transformers (20/0.4 kV). A visualization of the grid is provided in Figure 12.



Figure 12: Enercoop's grid representation

Within the STREAM project, the pilot focuses on the deployment and demonstration of the integration of the energy community into an LFM to provide flexibility services to the DSO, including congestion management and voltage regulation.

Although congestion is not currently observed in the distribution network, the available hosting capacity at Enercoop's substation is currently zero (see Figure 13). This situation indicates that congestion situations are likely to occur in the near future due to increasing electrification and

distributed generation. Furthermore, voltage deviations represent a relevant operational risk due to the high penetration of PV generation in the local grid. In this context, the hybrid PV+BESS installation plays a key role in the El Sala low-voltage grid by providing voltage support and contributing to grid stability.

								Capacidad tramitada	
Subestación	Localidad	UTM	Nivel de tensión	Posición	Capacidad Total MW	Capacidad Disponible MW	Capacidad Ocupada MW	SOLAR MW	EÓLICA MW
ST Crevillent	Crevillent	ETRS89, USO 30 x: 693.879 y: 4.233.793	132/20 kV	1	28	0	23,22	4,78	0

Figure 13: Capacity availability report for Enercoop's substation

The flexibility ecosystem deployed in the pilot site is composed of several interoperable tools that enable grid monitoring, flexibility forecasting, aggregation of distributed assets and market-based procurement of flexibility services. The grid is constantly monitored through sGRID, which communicates with the SCADA and AMI systems. With this data, sGRID calculates the power flows and creates forecasts every 15 minutes for the next 24 hours. Through these forecasts, sGRID detects potential grid congestions or voltage deviations in the grid, creating a flexibility requirement which identifies the zone affected by the grid issue, the flexibility quantity required to address the issue and the maximum price the DSO is willing to pay. This requirement is sent to sMART, which creates an auction to enable FSPs to offer flexibility services. FSPs can provide offers in two different ways:

- **Individually through sFLEX:** sFLEX monitors and forecasts the flexibility availability of the medium- to large-scale assets in the pilot site, which are the PV+BESS installation, the municipal buildings with rooftop PV installations and the EV chargers. These larger assets can provide flexibility individually to sMART through sFLEX.
- **Aggregately through sENC:** sENC monitors and clusters all the members of the EnC. Additionally, sENC includes the data from sFLEX assets. This enables the tool to offer aggregated flexibility of the clusters of the small prosumers (EnC members) and also the flexibility from the large assets included in sFLEX, as long as no flexibility offer has been sent by sFLEX previously for that session.

Once the auction is closed, sMART clears the market and communicates the result to sGRID, which assesses whether the problem would be effectively addressed with the market solution, and to sENC and sFLEX to generate the setpoints to ensure the flexibility provision by the assets.

These interactions of the pilot site are depicted in the pilot site scheme in Figure 14.

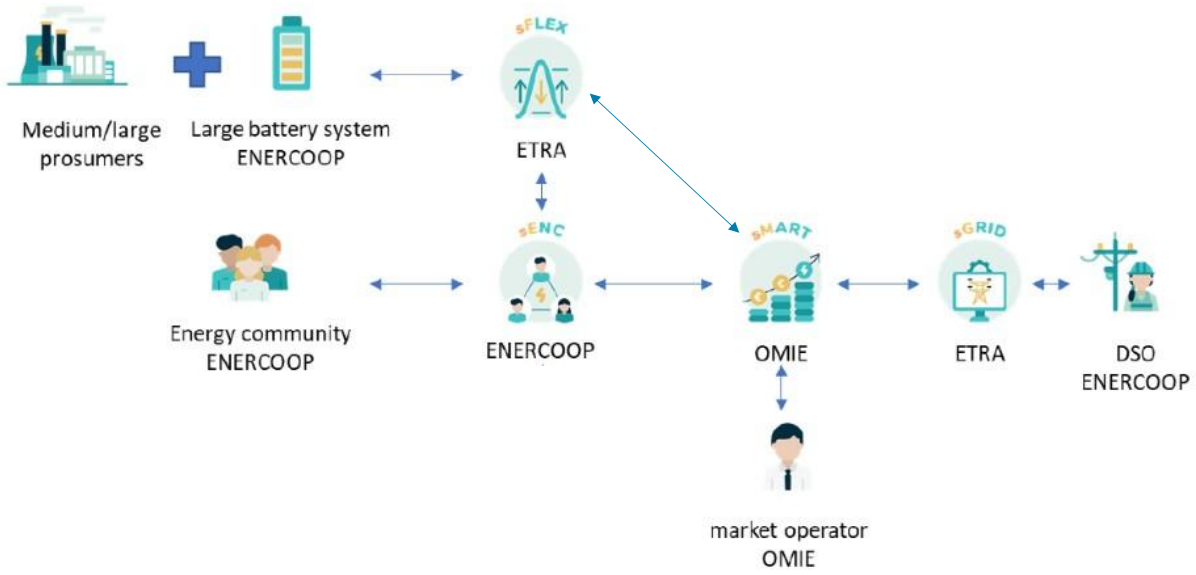


Figure 14: Spanish pilot site scheme

With the integration of this ecosystem, the objectives of the pilot site are:

1. Deploy and integrate a flexibility ecosystem that connects grid monitoring, flexibility aggregation and LFM mechanisms, demonstrating that EnCs are key actors to enable and support the roll-out of LFMs.
2. Demonstrate the provision of flexibility services to the DSO for congestion management and voltage regulation in local distribution grids.
3. Demonstrate the aggregation of small prosumers within the Energy Community, enabling them to participate collectively in flexibility services despite their limited individual flexibility capacity.
4. Validate the interaction between forecasting, grid monitoring and market-based procurement, using predictive analytics to detect potential grid issues and trigger flexibility requests.
5. Evaluate the economic and operational benefits of LFMs for energy community members through mechanisms such as peer-to-peer trading and the provision of flexibility services.
6. Assess the role of hybrid PV+BESS systems in supporting grid operation, particularly in mitigating congestion and voltage deviations in areas with high PV penetration.

2.2.2 Risk analysis

Apart from the risks included in the Description of Action, seven additional potential risks were identified in the pilot site as listed in Table 4. Mitigation measures were defined in order to reduce the impact of the risks if materialized:

Table 4: Spanish pilot site risk analysis

REF ID	RISK DESCRIPTION	PROBABILITY 1 – 3	IMPACT 1 – 3	PRIORITY	MITIGATION MEASURES
ES_01	No congestions occur in the LV grid during the demonstration phase, making impossible to test the tools functionalities and use cases	1	2	2	If there is no congestion during the demonstration phase, the capacity of the transformers of the LV grid will be modified in sGRID to simulate the event.
ES_02	Low end-users' participation, leading to lack of liquidity in the LFM	1	3	3	Workshops are being organized in the Spanish pilot site to engage end-users and ensure their participation. The pilot site will be in constant contact with end-users. In the event of lack of liquidity in the LFM, during the pilot stage, additional liquidity will be simulated.
ES_03	Failure of communication with devices	2	3	6	The technical partner and the pilot site are constantly communicating to coordinate communication tests. The prequalification and qualification processes will test ultimately the correct communication. What is more, the technical partners and the pilot site have already worked along in various projects in which the communication with most of the devices have already been tested.
ES_04	Incorrect definition of flexibility zones, which subsequently will create inefficiencies of the functioning of the STREAM ecosystem	2	3	6	A deep analysis of the LV grid topology of the pilot site will be performed in order to ensure that the DSO zones are correctly defined to identify the grid issues .

ES_05	The complexity of modelling the LV grid in sGRID causes the functionalities developed within the pilot site to behave incorrectly	2	2	4	Continuous coordination between technical and pilot partners to ensure the correct and optimal modelling of the LV grid, which will be critical for the correct functioning of the services deployed in the pilot.
ES_06	Failed integration between the developed tools that leads to issues with data transfer and failures in the operation of the flexibility market	2	3	6	Bilateral calls are being conducted between the developers of the tools to align on the protocols and formats that will be exchanged.
ES_07	The automatic use of the flexibility assets of the end-users leads to discomfort of the prosumers	1	2	2	The tools will include analytics that ensure the provision of flexibility within given comfort boundaries.

2.2.3 Deployment plan

Figure 15 provides the Gantt chart of the Spanish pilot site deployment plan:

Year	2022			2023											2024												2025												2026					
Month	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
Assets and hardware deployment																																												
Cloud infrastructure commisioning																																												
Additional SLAMs commisioning																																												
Assets integrations																																												
Community battery																																												
3 x 6 kWh BESS in industrial premises																																												
EV Charging stations																																												
Collective self-consumption installations																																												
Industrial end-users integration																																												
Active consumers self-consumption installations																																												
SLAMs																																												
FTP smart metering data from 15k EnC members																																												
Smart plugs (heating control in the local school)																																												
SCADA																																												
Tools deployment																																												
sGRID																																												
sGRID: Measurements integration																																												
sGRID: End user feedback implementation																																												
sGRID: Grid topology modelling																																												
sGRID: Grid management services																																												
sGRID: Market integration																																												
sFLEX																																												
sFLEX: Measurements integration																																												
sFLEX: Asset actuation tests																																												
sFLEX: Flexibility calculation																																												
sFLEX: Market integration																																												
sENC																																												
sENC: Measurements integration																																												
sENC: Functionalities for the Energy Community																																												
sENC: Integration with sFLEX assets																																												
sENC: Flexibility calculation																																												
sENC: Market integration																																												
sENC: Functionalities for participation in Local Flexibility Markets in the mobile app																																												
sMART																																												
sMART: functionalities for participation in Local Flexibility Markets																																												
sMART: Application Connection																																												
sMART: Market Integration																																												

Figure 15: Spanish pilot site deployment plan

Table 5 presents the deviations suffered during the deployment of the tools and the integration of the pilot site assets in the Spanish pilot site and the reason of the deviations (please note that the features not listed did not suffer any deviations):

Table 5: Final deployment deviations in the Spanish pilot site

Tool and feature	Expected deployment date	Final deployment date	Reason
sGRID: Grid topology modelling	July 2025 (M34)	November 2025 (M38)	Since all LV grids ultimately were fully modelled in sGRID, the completion of the deployment required more time than initially anticipated. The process also proved more challenging than expected, particularly due to the complexity of correctly mapping SCADA measurements to the corresponding grid topology and the need to simplify the model (mainly of the busbars) until the power flows converged.
sGRID: Grid management services	July 2025 (M34)	December 2025 (M39)	As the deployment of this feature was highly dependent on the previous one, the finalization of this deployment was delayed.
sGRID: Market integration	July 2025 (M34)	February 2026 (M41)	As the deployment of this feature was highly dependent on the previous one, the finalization of this deployment was delayed.
sFLEX: Flexibility calculation	November 2024 (M26)	January 2026 (M40)	The first round of flexibility calculation was finalized on time for M26 with the community battery modelling. However, a second round was performed to enhance the model for collective self-consumption installations and household PV+BESS systems.
sFLEX: Market integration	July 2025 (M34)	February 2026 (M41)	The integration with the sMART market platform was carried out jointly for all tools. As a result, the delays experienced in sGRID also impacted the finalisation of the market integration timeline of sFLEX.
sENC: Flexibility calculation	November 2024 (M26)	January 2026 (M40)	Since sENC aggregates the flexibility calculated by sFLEX for

			each asset, this feature was impacted by the delay experienced in sFLEX.
sENC: Market integration	July 2025 (M34)	February 2026 (M41)	The integration with the sMART market platform was carried out jointly for all tools. As a result, the delays experienced in sGRID also impacted the finalisation of the market integration timeline of sENC.
sMART: Market integration with the other tools	July 2025 (M34)	February 2026 (M41)	Affected by the finalization of the market integration of the other tools.

2.2.4 Deployment of new assets and hardware

The flexibility assets that were an active part of the pilot site for the demonstration of the project were already commissioned when the project began. Only two additional assets were required:

- Cloud infrastructure: Required to deploy the cloud services of the tools that were part of the pilot site and to enable the communication with the assets and the data storage.
- Additional SLAMs commissioning: in order to enable real-time (RT) communication with the assets, additional smart meters with real time communication capabilities (SLAMs) were commissioned in the households that were actively participating in the demonstration activities. Additionally, miscommunicating SLAMs were sent to ETRA for fixing.

2.2.5 Pilot site assets and STREAM tools integration and deployment

As aforementioned, the Spanish pilot site relied on the EnC assets and the participation of members of the community.

Table 6: Flexibility assets in the Spanish pilot site

Asset	Nominal power	Capacity	DR type	Tool
Community PV and battery	120 kWp	240 kWh	Congestion Management	sFLEX and sENC
Community buildings PV installations	687 kWp	-	Congestion Management	sFLEX and sENC
EV chargers	1 x 7 kW 1 x 11 kW	-	Congestion Management	sFLEX and sENC
8 residential users with rooftop PV and batteries	35 kWp (total)	72 kWh	Congestion Management and peer-to-	sENC

		peer trading (P2P)	
200 EnC members	800 kW	P2P trading	sENC

2.2.5.1 sGRID

In the Spanish pilot site, sGRID is deployed as the grid monitoring and forecasting tool, giving the DSO the mechanisms to detect potential grid issues and send flexibility requirements to the LFM platform (sMART) in order to address them.

The detailed architecture and functionalities of the tool have been already provided in D3.3 [2]. As it was stated, sGRID is integrated with the DSO's SCADA and AMI systems. The different functionalities offered by sGRID require the deployment or use of a number of software artifacts and servers, as well as the integration of different data sets, that are described in the following sections.

2.2.5.1.1 MV and LV monitoring

The energy grid monitoring in sGRID is based on two main pillars: the access to up-to-date and accurate g**rid topological information** and the continuous availability of **grid measurements**. These datasets were obtained using different mechanisms.

The **grid topological information** was provided by the Spanish pilot DSO in the form of GIS (geographical information system) files. A dedicated RESTFul API was created by Enercoop for ETRA to gather the updated definition of the grid.

This topological information is the core of the sGRID application, and it is mandatory to keep it up to date to obtain reliable results. This implies the periodic update of the sGRID topology.

In order to simplify the topology handling pipeline, a general-purpose tool for topological model transformation has been used. The selected tool is *TopologyAlchemy*, that is one of the results of the OPENTUNITY innovation project [3], funded by the European Union's Horizon 2020 research and innovation programme.

The OPENTUNITY project aims to accelerate the energy transition by optimizing grid technologies and enabling flexibility through innovative digital tools, and one of such tools is precisely this *TopologyAlchemy* tool, that was developed and offered to the energy community in the form of an open source tool [4]. The tool allows for converting, manipulating and exchanging electrical grid topology data between multiple formats, and it has been used in STREAM for the data integration as follows:

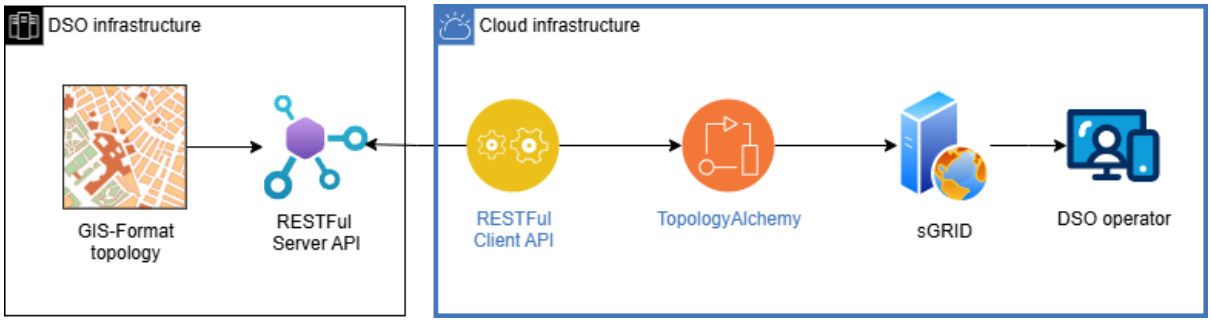


Figure 16: Spanish pilot grid topology integration

All the grid topology conversion and data transformation logic is carried out by the tool, including the adaptation to the specific sGRID data model. The process is triggered manually, when it is detected that grid topology needs to be updated. The resulting grid topology is stored in sGRID databases deployed at the cloud.

The other pillar of the sGRID grid monitoring is the management of **grid measurements**. These measurements may come from different types of assets and with different periodicity, granularity, level of quality, etc. The following artifacts have been developed and deployed within sGRID to obtain and integrate these grid measurements:

- Registers from the **MV and LV network** are read every 5 minutes using a SOAP web service and sent to sGRID through MQTT for grid monitoring purposes. The information includes measurements, statuses, and alarms from key monitoring points of the grid. This process requires a dedicated service deployed on-premise at the pilot site infrastructure for interfacing the local SCADA. MQTT sGRID server and database are deployed at the cloud:

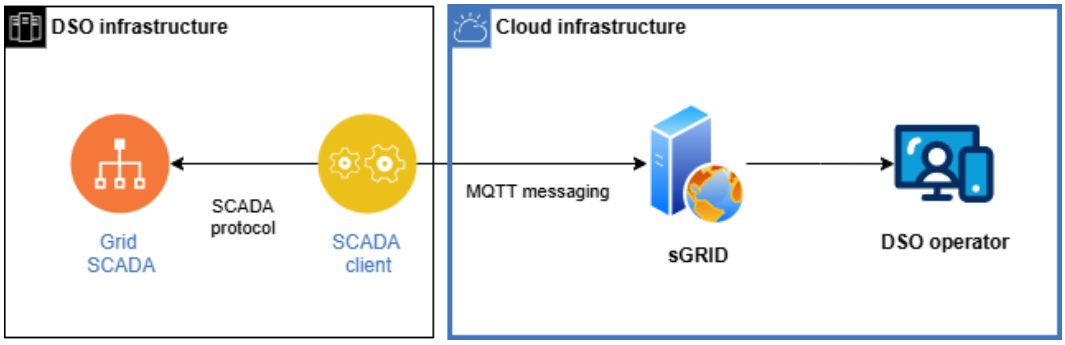


Figure 17: Spanish pilot SCADA data integration.

- Daily power curve data from **metering points** is collected by Enercoop's AMI system and automatically transferred to a dedicated FTP server. From there, a scheduled sGRID service retrieves these files and stores them in the sGRID database. Both the data transfer process and the FTP server are hosted at the cloud.

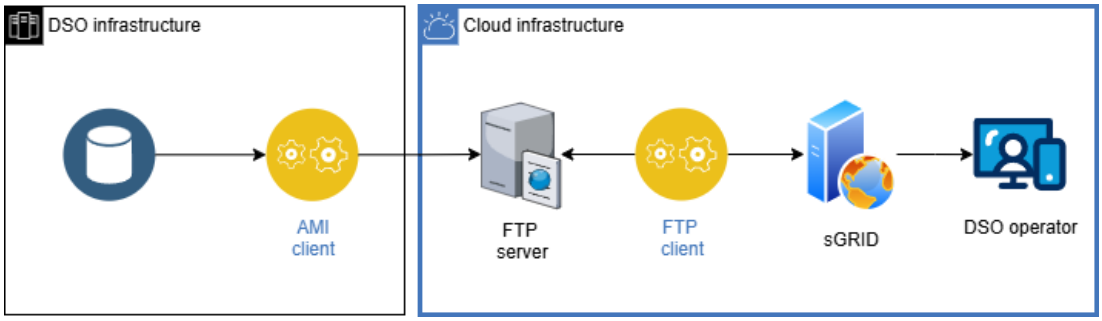


Figure 18: Spanish pilot AMI data integration in sGRID

2.2.5.1.2 Grid elements forecast

The extensive dataset of sensor and meter measurements stored by sGRID has been used to train deep learning models that analyse and predict the behaviour (consumption or generation) of the grid assets.

This consumption and demand forecasting of the grid elements enables different advanced sGRID functionalities like power flow calculation, grid security analysis or market participation.

The grid forecasting functionality in sGRID implies the cooperation of two different services:

- The **training service** is responsible of reading the sGRID data repository as well as some external sources of information relevant for the modelling (like weather forecast or calendar) and train deep learning models based on them. The resulting models are stored in a general-purpose model repository. As deep learning framework, NeuralProphet has been used. This

framework combines the power of a neural network like XGBoost, with the ease of use of a mathematical time-series prediction tool (like Prophet). The deep learning models generated are small and simple to use and can accurately predict the behaviour of the magnitudes modelled. For the model storage, MLFlow model repository has been used. This repository features functionalities for programmatically managing the models (create, update, download, delete, etc.) and a user interface for monitoring the results:

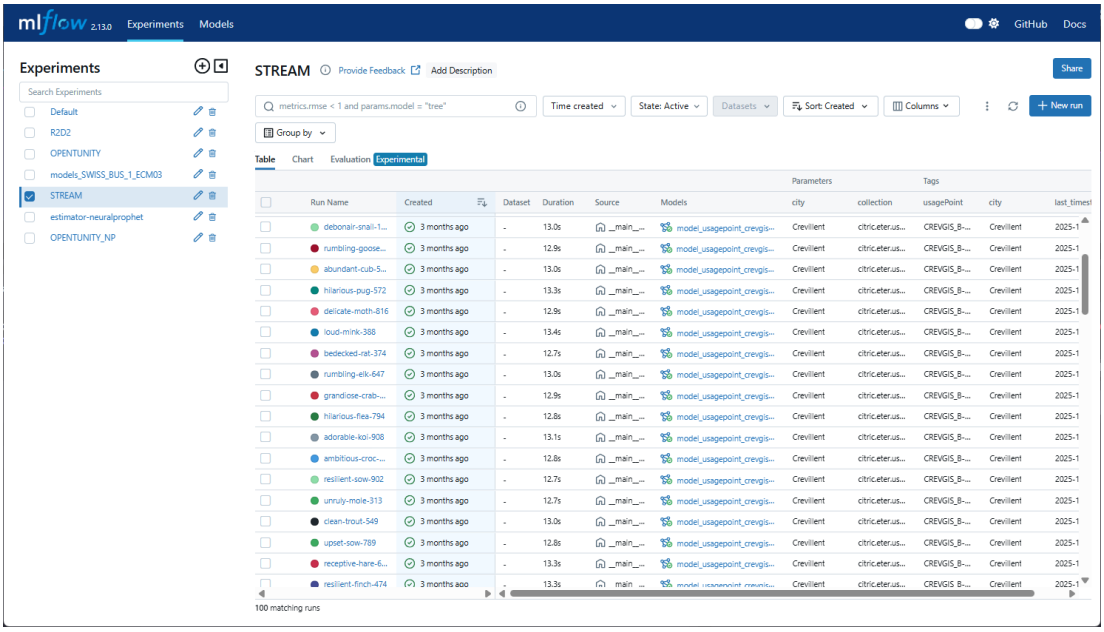


Figure 19: Spanish pilot MLFlow model repository

The training process is continuously running at the cloud reading the historical information of the considered assets (two years of data for each), training the models and storing them in MLFlow.

- The **forecasting process** provides a RESTFul API interface that let other processes query for forecasted measurements of specific elements. When invoked, the forecasting process accesses the appropriate neural network model and uses it to obtain the requested forecast. If not present, the neural network models are downloaded from MLFlow model repository. This service is deployed at the cloud, and it uses PyTorch for the execution of the models.

The next picture illustrates how the training and forecasting processes are integrated among each other and with other sGRID processes:

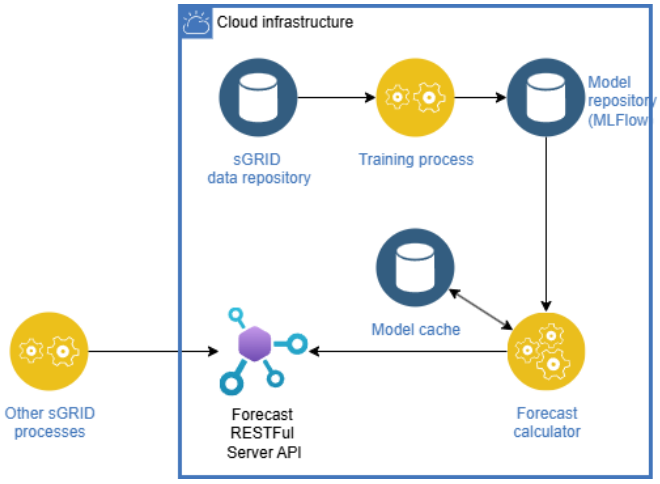


Figure 20: Spanish pilot forecasting process services.

2.2.5.1.3 Power flow analysis

By combining the topological grid information with the measured and forecasted grid measurements, power flows can be calculated for the grid in different situations.

sGRID features a continuous process that performs these steps:

1) Periodically, sGRID interfaces the **forecasting process** RESTFul API to obtain the forecast of consumption and generation of all the elements in the LV and MV networks for the next 24 hours. With these forecasts, the **power flow analysis service** calculates the forecasted power flow for the next 24 hours. Afterwards, security analysis is performed on the forecasted results, to identify congestions and other types of problems.
    - When **real time** data from grid assets is available (from Spanish pilot SCADA), this information is combined with the forecasted consumption and generation, and a more accurate power flow is calculated for every MV and LV network in the grid. The results will be more accurate because it will also consider semi real-time SCADA measurements (this is commonly known as state estimation). A security analysis also follows this process and the DSO operator is warned on any problem detected.
2) Every day, **D-1** power curves of meters are received by sGRID from the Spanish pilot AMI system. When received, a new power flow calculation for every MV and LV in the grid is performed, but in this case consumption and generation is not forecasted but based on data received from the meters.
3) For every time period, three types of power flows results will be available in sGRID:
    a. Results based on forecasts.
    b. Results based on forecasts plus real time data from selected elements (also known as state estimation)
    c. Results based on historical measurements obtained from AMI and SCADA

    sGRID will keep all these results independently to assess the accuracy of each one.

The power flow analysis service runs at the cloud infrastructure, gathering data from the respective data repositories and performing calculations according to the predefined schedule and available data:

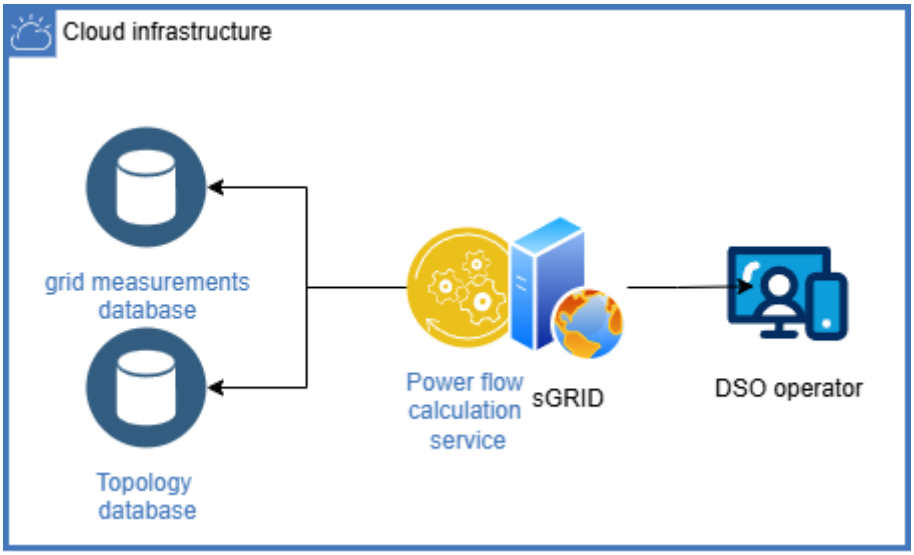


Figure 21: Spanish pilot power flow calculation service

2.2.5.1.4 Grid fault management

sGRID features an incident management system that centralises the reception and management of events and incidents.

These incidents can be described as a set of grid conditions (on single or multiple elements) that the DSO operator marks as potentially dangerous. The main purpose of identifying incidents is twofold:

- For the DSO operator to be automatically warned when such situations appear
- To prepare the software components to react to these incidents, either in an automatic way, or presenting DSO operators appropriate mitigation or corrective actions.

The incidents management system is composed of different elements:

- A RESTFul API event reception system
- A measurements database monitoring system
- A configurable rule set engine that can be used to define conditions on the data that will create incidents. The rules might be complex, combining data from multiple assets and considering hysteresis.
- A notification process that triggers actions on incident detection (or modification). The actions might be among others:
    - Data transfer to a notification platform (Email, Telegram, WhatsApp, etc.).
    - Activation of an external action (RESTFul api).
    - Changes in data.

In STREAM, the rule set engine have been configured to trigger incidents upon the detection or prediction of grid security issues by the power flow analysis. These incidents are prompted to the DSO operators for them to decide on the best solution.

The incident management system is deployed at ETRA's cloud environment.

2.2.5.1.5 Sensitivity analysis

The sensitivity analysis in sGRID allows determining the most appropriate element in the grid that can be used to solve an identified congestion incident in the grid.

This process is triggered manually by the DSO operator when a congestion incident is detected. The sensitivity analysis component has the form of a RESTFul API that receives requests for sensitivity analysis calculation of a certain grid element given a certain grid status, and answers with the influence coefficients of the rest of the elements in the grid.

2.2.5.1.6 Market integration

When the power flow analysis service detects a security issue, sGRID alerts the DSO operator and enables access to flexibility provider services to resolve it. The process unfolds as follows:

- Problem Identification: The sGRID graphical user interface presents the operator with detailed information about the detected issue.
- Solution Analysis: The operator evaluates potential solutions using sensitivity analysis and simulations.
- Flexibility Procurement: Once the optimal solution is identified, the short-term flexibility market is activated through a dedicated market session. The session defines the required flexibility parameters.
- Market Operation: Market participants receive the flexibility demand details and submit their offers, specifying available flexibility and pricing.
- Flexibility Allocation: After the market closes, the DSO procures the required flexibility from the most cost-effective provider offers.

sGRID product integrates with the market product by interfacing the RESTFul API developed for it and deployed at the grid. The next picture illustrates the whole process:

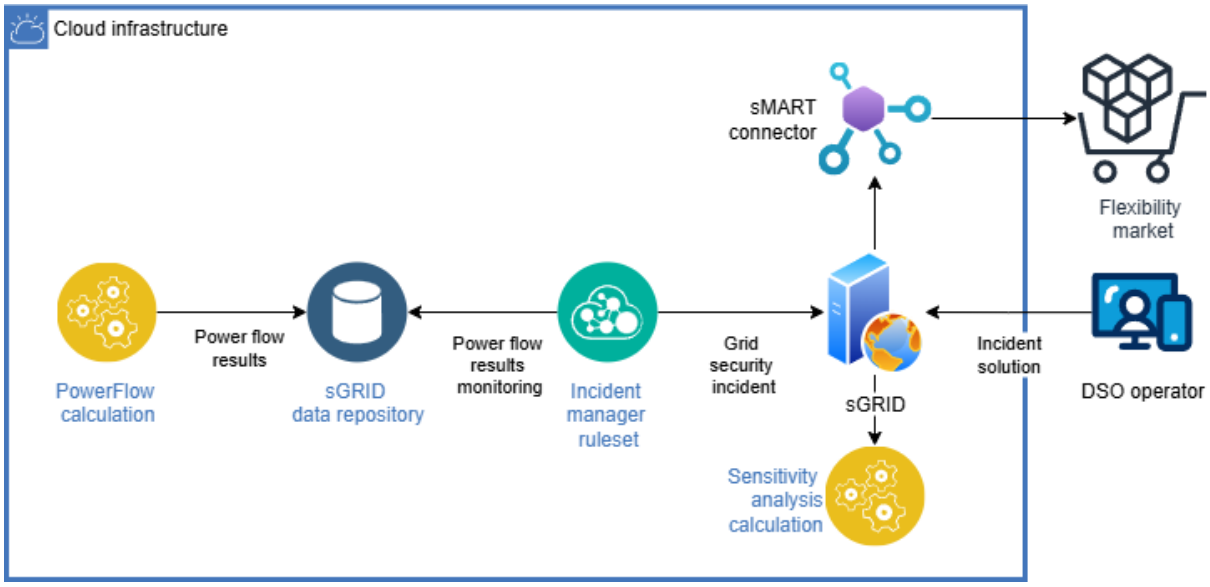


Figure 22: Spanish pilot market integration

2.2.5.2 sENC

In the Spanish pilot site, sENC is the tool for the management of the EnC member assets, thus providing services normally linked to an aggregator. The following sections provide a detailed explanation on how the different functionalities (described in D2.1 [5]), have been deployed in the pilot site:

2.2.5.2.1 Portfolio monitoring

The services of sENC are mostly linked to the monitoring of the energy community portfolio, as the main duty of the aggregator is to manage the portfolio in the most optimal way, either from a

monetary or environmental point of view. The main data gathered are the daily power curves from EnC members smart meters and PV panel meters. Different clients have been prepared for gathering these data:

- Similarly to the sGRID monitoring process, the daily power curve data from metering points is collected by Enercoop's AMI system and automatically transferred to a dedicated FTP server. From there, a scheduled sENC service retrieves these files and stores them in the sENC database. Both the data transfer process and the FTP server are hosted at the cloud.

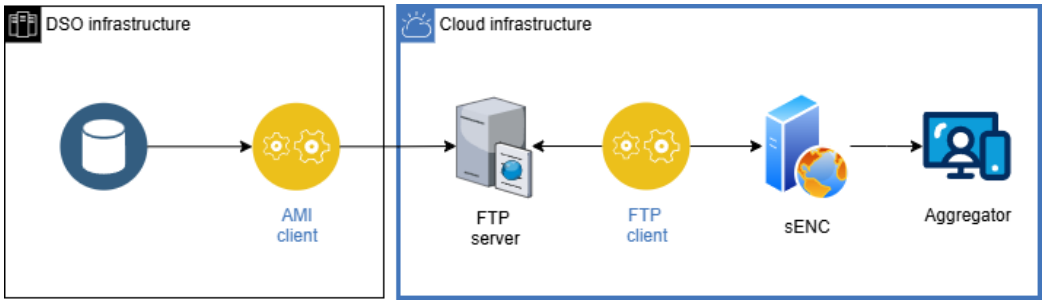


Figure 23: Spanish pilot AMI data integration in sENC

- Some households have installed ETRA manufactured smart meters with IoT capabilities. These meters have been configured to periodically send measurements to the sENC MQTT broker for being integrated into the sENC measurements database. No client is required for these meters.
- The PV panel generation is gathered from Huawei Fusion Solar platform using a dedicated client deployed at the cloud.
- Finally, the sFLEX flexible assets current state and status is directly obtained by the sFLEX services periodically sending this data to the sENC enterprise Bus. No specific client is required for this integration

2.2.5.2.2 Data analytics (baseline calculation and clustering)

When enough data from the portfolio assets is available, these assets can be categorized according to its observed behaviour in terms of energy consumption and generation over time. These categories or clusters contain assets that could potentially be aggregated for the market or for internal optimization of the EnC.

The clustering process is done manually by ETRA according to technical requirements. The process is off-line, takes as input the portfolio measurements time series and some clustering requirements, and the output is the calculated list of clusters with its linked assets.

2.2.5.2.3 Portfolio elements forecast

The consumption and demand forecasting of the elements in the portfolio is calculated with the same mechanism described in 2.2.5.1.2 - Grid elements forecast.

2.2.5.2.4 Flexibility management

The flexibility management of the different identified clusters is calculated upon request. For each cluster, the base line generation is calculated based on cluster characteristic and predicted consumption and generation. The calculation is done by the **flex asset optimizer service**, that is continuously running at the cloud.

2.2.5.2.5 Market integration

This functionality complements the market integration process described for sGRID in section 2.2.5.1.6. While sGRID's market integration is designed from the perspective of the flexibility-demanding actor (the DSO), which initiates market sessions to resolve grid congestions, sENC plays a more reactive role in this workflow.

sENC utilizes the same market platform but operates as follows:

- **Monitoring:** It continuously tracks the creation of new market sessions.
- **Flexibility Assessment:** For each session, sENC calculates the flexibility available across its clusters, assigns an economic value to it, and submits bids.
- **Bid Management:** If a bid is matched during market clearance, sENC must activate the committed flexibility. To ensure timely execution, it periodically checks the acceptance status of its bids.

This process runs continuously in the cloud, seamlessly integrating with sGRID through the bids and offers exchanged in the various auctions.

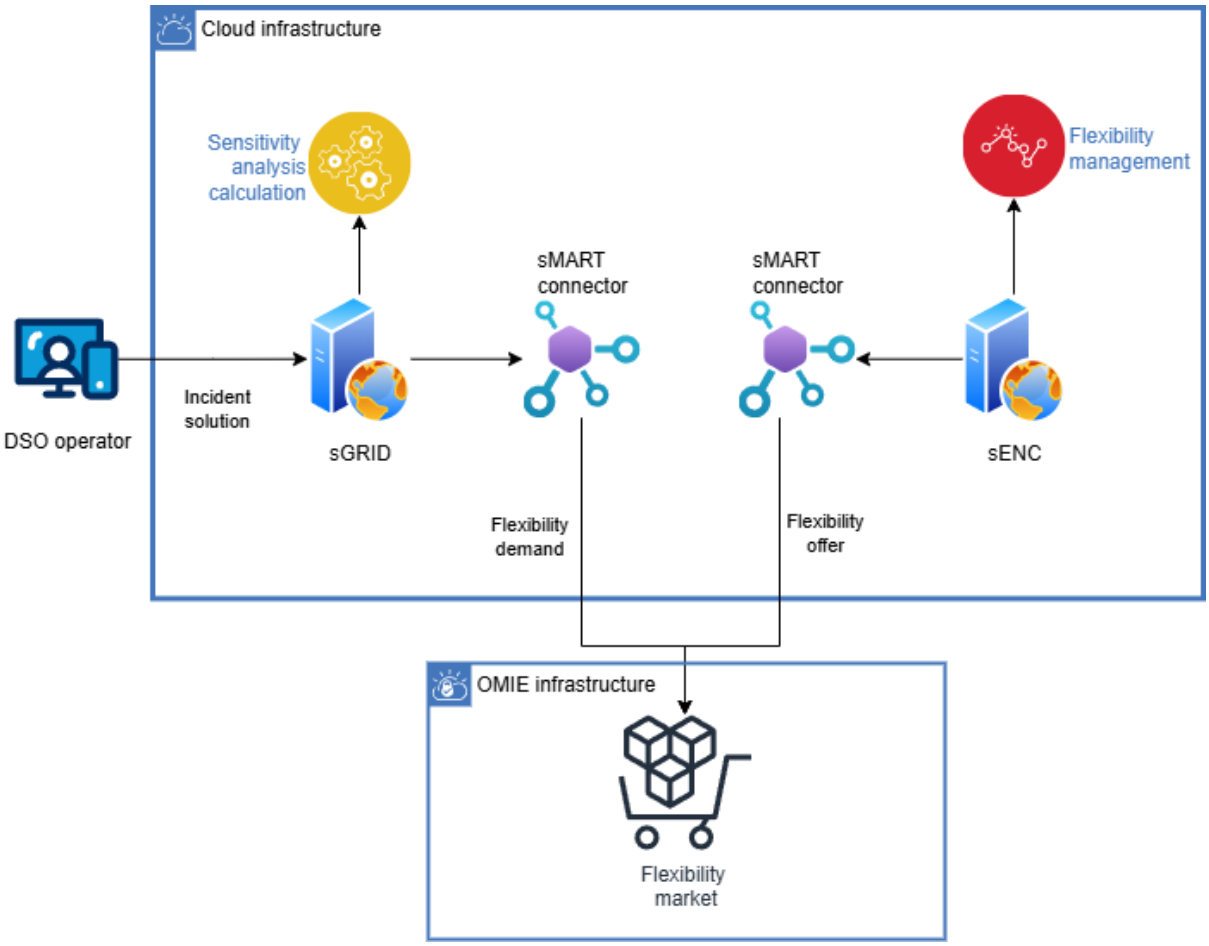


Figure 24: Spanish sENC components

2.2.5.3 sFLEX

The objective of the sFLEX tool is to optimize the use of the flexible assets in the pilot, with the purpose of optimizing the use of the energy resources and providing services to the DSO. The conceptual diagram of the sFLEX architecture is described in deliverable D4.1 [6].

2.2.5.3.1 Asset monitoring

The flexible assets in STREAM Spanish pilot are:

- The community battery
- The PV systems
- Some EV chargers

The monitoring of these assets requires specific connectors:

The **community battery** and **PV systems** are managed by a community energy management system (described in [6]). This system provides connectivity for external actors, like sFLEX. The process is the following

1) sFLEX client polls the energy management system RESTFul API.
2) The client transforms the raw API data into sFLEX data model.
3) Finally, the transformed data is published to the sFLEX data broker for being stored in sFLEX database

The ENERCOOP energy management system is deployed at the pilot site premises, whilst the sFLEX client is deployed at the cloud.

EV chargers installed at ENERCOOP premises have also been incorporated in sFLEX. Three of the chargers have OCPP connectivity, and they have been connected to an OCPP platform deployed for sFLEX. The data received into the OCPP platform from the chargers is transformed and submitted to the sFLEX data broker for being stored in the sFLEX database.

An additional EV charger does not have OCPP connectivity, and thus has been connected using a MODBus RTU client deployed at the pilot premises and periodically sending data to remote sFLEX platform.

The next picture illustrates how the different assets are interfaced:

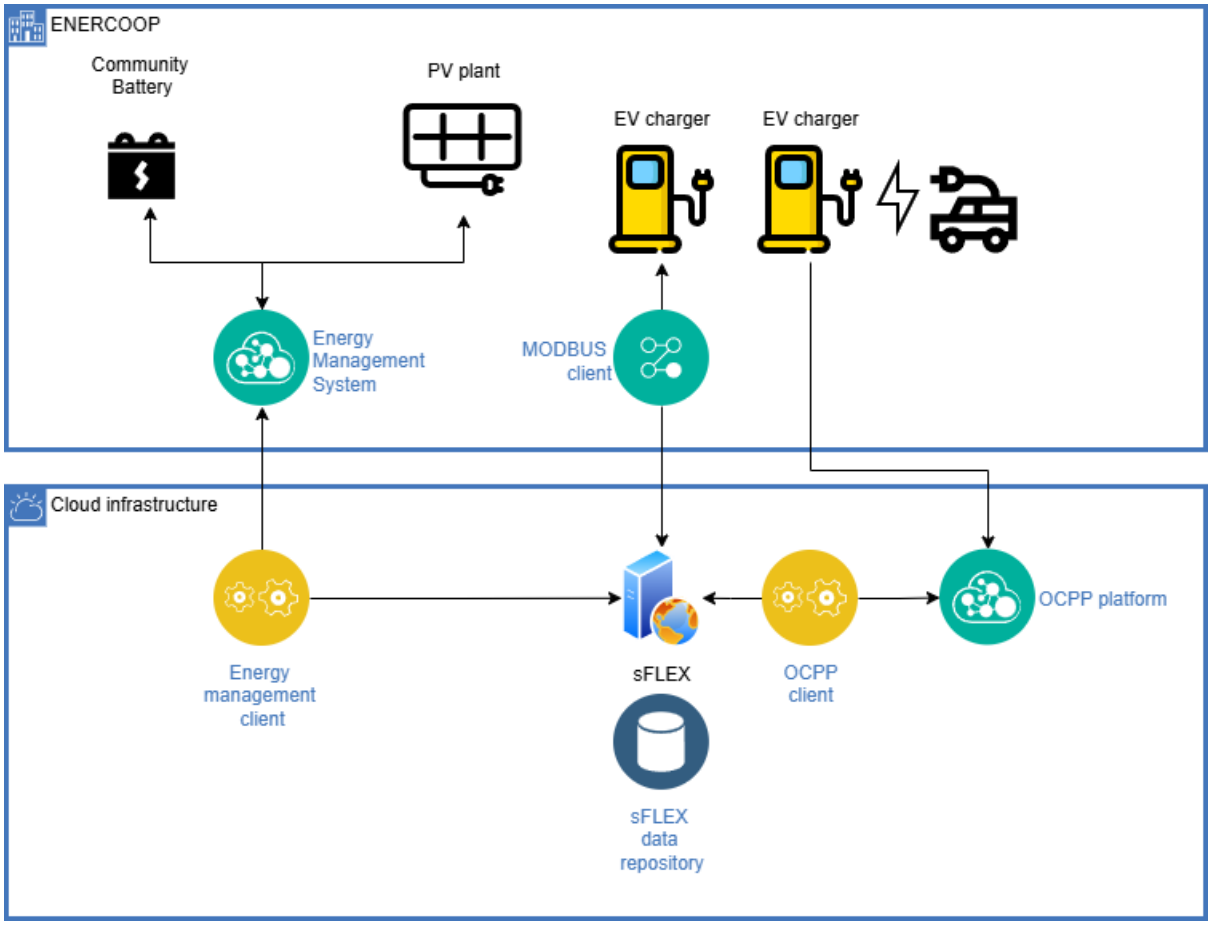


Figure 25: Spanish pilot sFLEX asset monitoring services

All the communication described here is bidirectional. Besides the data retrieval from the assets, these flexible assets are also controllable by sending them commands to modify its working parameters:

- For the battery, the charging or discharging set point can be established.
- For the PV plants, curtailment can be applied if needed.
- The EV charging points can be fully managed by defining the charging periods and the limits.

2.2.5.3.2 Asset scheduling for optimal use and flexibility provision.

In order to use the controllable assets as active flexibility providers, sFLEX needs to schedule and coordinate their operation, so that they can serve both their original functionality and advanced third-party purposes.

The **sFLEX asset optimizer** is the process responsible for the optimization. The process takes as inputs:

- The forecasted consumption of the EnC members. This forecasting is described in sENC product
- The forecasted generation of the PV plant, given the environmental conditions predicted
- The wholesale market prices, taken from ENTSO-E transparency platform
- DSO flexibility market requests, if any

With all this data, the algorithm tries to maximize the self-consumption of the EnC, using the battery as the most flexible asset to match solar generation and EnC demand.

The process is deployed at the cloud, with different client deployed to query all the data required by the algorithm:

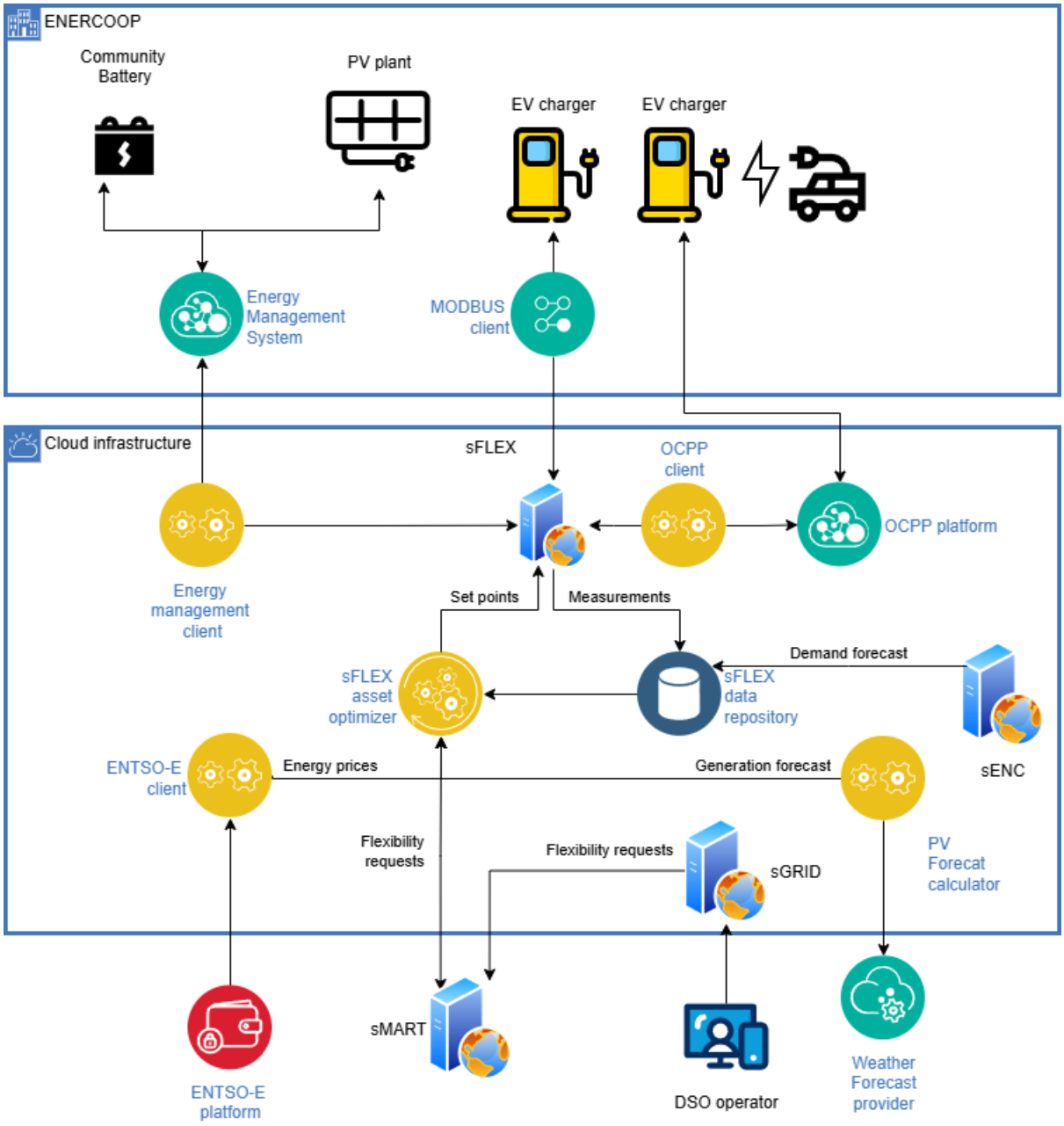


Figure 26: Spanish pilot site asset optimizer in context

The asset optimizer receives the input data from several sources, performs the optimization and contacts the sFLEX platform for the submission of individual set points to the flexible assets. Most of the software components are deployed at the cloud.

2.2.5.3.3 Market integration

The market integration for sFLEX is the same as described for sENC in section 2.2.5.2.5.

2.2.5.4 sMART

sMART is the LFM platform deployed in the Spanish pilot for the procurement of flexibility services through market-based mechanisms, with the aim of managing congestions in the distribution network. In the pilot, sMART was deployed in a test environment hosted by OMIE.

2.2.5.4.1 DSO and flexibility agent and assets registry

The deployment in the Spanish pilot site began with the registration of the DSO, which sends the flexibility requirements to the platform, and the agent, which offers flexibility services. Both roles are taken by Enercoop, acting as both Crevillent's DSO and energy community manager (aggregator).

Once both the DSO and the agent are registered on the platform, the agent is able to register its flexibility assets to trigger the prequalification process. After providing the required information to register the assets, both the market operator and the DSO receive a notification to prequalify the asset. Upon acceptance by the market operator, the flexibility unit is enabled to bid in local market sessions.

While the prequalification process on the market operator's side was directly approved, since it depends on financial warranties which are excluded from the project, the technical validation by the DSO is linked to sGRID, where the DSO validates the technical characteristics and the location of the assets by checking the grid topology.

The registration of the DSO, the agent, and the flexibility assets is further detailed in the execution of ES-UC.03.01 and can be found in ANNEX B — Test cases results reporting.

2.2.5.4.2 Flexibility market and procurement

Within the Spanish pilot, market sessions were triggered based on simulated grid conditions identified by the sGRID tool, which enabled the DSO to submit requirements to sMART. During the demonstration, a number of sessions were executed to validate the full market workflow, including requirement definition, bidding, clearing, and activation (see ANNEX B — Test cases results reporting).

The flexibility procurement can take place both in the short and in the long term:

- **Long-term**, as a complementary solution to new grid investments, ensuring the availability of flexibility during periods where DSOs have identified potential congestion issues (e.g., during peak local generation and low consumption periods, or vice versa). Long-term market sessions are arranged by the DSO with at least 48 hours' notice, specifying the service window, whether the service refers to firm delivery or availability, and the maximum price the DSO is willing to pay. When a session is open, flexibility providers can request the qualification of their unit(s) to participate in the bidding process. Similarly to the prequalification process, both the market operator and the DSO must qualify the asset for that specific session, with the DSO checking whether the flexibility of the unit would effectively impact the congestion. Once qualified, the assets can submit bids indicating their expected flexibility availability over the service window, as well as their availability and activation prices.
- **Short-term**, to address unforeseen congestions by activating flexibility at short notice, typically related to recently scheduled grid works, unexpected incidents, or similar situations. The requirements are sent by the DSO, indicating the service window and the maximum price, which enables flexibility providers to submit their bids. In the short-term market, the assignment of the service obliges the FSP to deliver the requested flexibility.

2.2.5.4.3 Integration with the STREAM ecosystem

There are two access technologies available for the connection to OMIE systems, depending on the platform used: Web Interface and API. sMART includes a Web Services–based access mechanism that complements browser-based access by providing an application-to-application interface.

For the connection to the Trading module, an executable component is used, which internally relies on Web Services technology and AMQP messages for communication. The public messaging interface allows clients to communicate with the SIMFLEX server and to perform all the operations required for participation in the local markets. To enable communication, each client must be assigned a unique identifier known as the *application identifier*, which must be included in all messages exchanged with sMART.

Three types of communication exist between clients and the sMART server:

- **HTTPS requests** (login), which are required only at client startup, using the HTTPS protocol with a client certificate and the corresponding URL.
- **AMQP messages** of type *Inquiry* or *Management* sent from the client to the server, together with their corresponding responses.
- **AMQP broadcast messages** sent from the server to all connected clients or to a specific group.

Communication with the server is mainly carried out through the AMQP protocol. The AMQP server used is RabbitMQ, and the content of the messages exchanged is formatted in JSON. In the case of *Management* messages, the content must be digitally signed, for which a utility class is provided within the API itself.

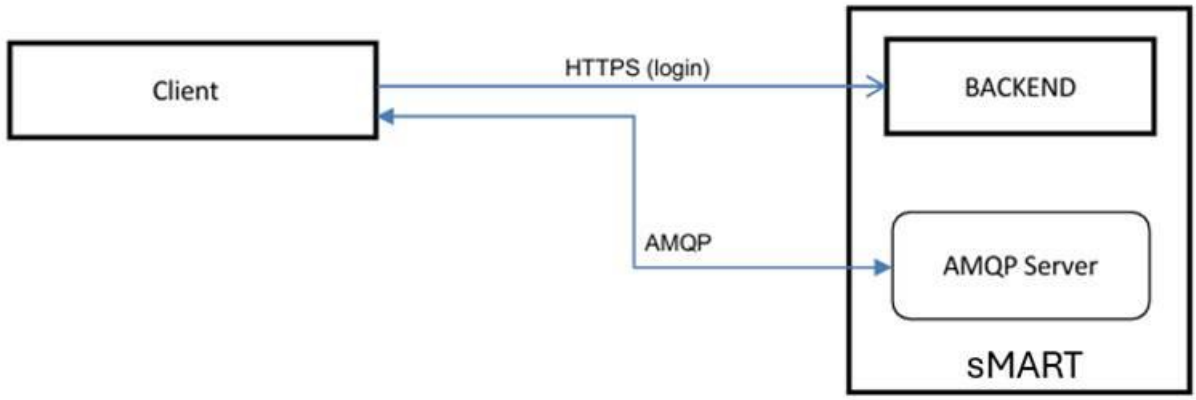


Figure 27: Spanish pilot site client connected to the sMART server

Within the Spanish pilot, sMART is integrated with the following STREAM components:

- **sGRID:** generates and sends the flexibility requirements to sMART, validates the proposed solution and validates the flexibility procurement.
- **sFLEX and sENC:** They continuously monitor the creation of new market sessions and, for each of them, evaluates the flexibility available across its clusters, assigns an economic value to it, and submits the corresponding bids. When a bid is awarded, it activates the committed flexibility and performs periodic checks to ensure proper acceptance and execution.

2.2.6 Deployment challenges and limitations

During the deployment phase in the pilot site, several challenges have been faced:

- **Complexity of the integration and development of the MV and LV grid model in sGRID:**
  As it has been stated in the previous section, sGRID integrates the network topology and measurements of 13,000 consumers. This posed a challenge to ensure that all the assets of the grid were correctly identified and modelled and that all the parameters were correctly correlated with the elements of the grid (lines, transformers, loads, generators, etc.).
- **Correct mapping of SCADA data with network topology:**
  Linked to the complexity of the grid, the measurements data coming from the SCADA system also introduced complexity since it was difficult to correctly correlate the measurements coming from the SCADA system with the actual grid elements.
- **Communication issues with the EV polycharger:**
  One of the flexibility assets that was initially considered in the pilot site was a polycharger that was connected through Modbus. Although connection with the SMX of the polycharger was possible, the measurements retrieved through Modbus always returned null values. Several wiring configurations were tested without any results, so the polycharger was finally dropped as flexibility provider.
- **Application of the user profiling to all the assets:**
  The user profiling algorithm was initially configured for the community battery (as indicated in D3.3 [2]). This algorithm needed several adaptations to be able to encapsulate the energy patterns of the different flexibility assets.
- **Communication with the community battery:**
  When testing the communication with the community battery, it was detected that the battery could not receive commands from two different tools at the same time, so sFLEX was causing interference with the energy management system (EMS) of the battery. To solve this problem, an API was developed and configured for sFLEX to send the commands to the EMS, and the EMS to the battery.
- **Heterogeneity of protocols and data models across systems (SCADA, EMS, Internet of Things (IoT) platforms):**
  The heterogeneity of the communication protocols and data models required custom integration efforts.

These challenges lead to some limitations:

- **Limited controllability of prosumer-owned assets due to lack of automation (absence of IoT devices):**
  Although the assets owned by the energy community (rooftop PV installations in municipal buildings and PV+BESS installation) were manageable, those owned by the prosumers presented several challenges when it came to activation. In the cases of the community members that do not have IoT devices, automatic activation was impossible and they were reluctant to activate their assets themselves manually. Therefore, due to the extremely reduced flexibility potential of these devices, for the demonstration activities it was agreed that only community assets and the batteries of the 10 prosumers with PV + BESS would be activated for congestion management services.

- **Assumptions are required to ensure power flows consistency:**
  The complexity of the modelling of the MV and LV grids led to some assumptions, since the power flows did not converge after finalizing the integration of the models (i.e., the power flows did not provide any results since the algorithm was not able to properly make sense the measurements). One of the issues faced was the near-zero impedance of elements such as busbars. Therefore, assumptions were required, such as considering the busbar as just a node to allow the algorithm to converge and provide accurate results.
- **Availability of real-time data for consumers:**
  Measurements of the consumers connected to the LV and MV grids are retrieved daily by the DSO. Therefore, no real-time data was available for these consumers, requiring the use of their forecasted consumption to approximate real-time conditions.

2.3 ITALIAN PILOT SITE

2.3.1 Pilot site scope, operational context and objectives

The Italian pilot site is located in the city of Terni in central Italy and is operated by ASM Terni, an Italian multi-utility company jointly owned by the Municipality of Terni, and a consortium of private stakeholders. The company operates across multiple sectors, including electricity generation and distribution, gas network management, water distribution and wastewater treatment, as well as environmental services.

The electricity distribution network acquires power at High Voltage (HV) through three primary substations and supplies residential and business customers via approximately 60 MV lines (10–20 kV and around 700 secondary substations. The network has a peak load of approximately 70 MW and a total line length of about 2,400 km, including roughly 600 km of MV and 1,800 km of LV lines. ASM Terni serves approximately 65,500 electricity customers, and the rollout of second-generation smart meters has been fully completed. The total annual energy consumption amounts to 400 GWh, of which 50% is supplied by renewable energy sources (RES). Currently, the local power distribution network integrates renewable generation from more than 3,000 PV installations, seven hydropower plants, and four biomass and waste-to-energy facilities.

The main objective of the Italian pilot is to explore how flexibility from different types of assets can support the operation of the electricity distribution network. In particular, the pilot investigates the potential of coordinating flexible loads and distributed resources connected to the grid. This includes the assessment of flexibility from the water distribution system and electric vehicle charging infrastructure, enabling the analysis of cross-sector interactions between the electricity, water and electric mobility sectors.

Several types of energy assets are considered within the pilot area of the company headquarters. These include distributed PV generation with an installed capacity of approximately 240 kW, controllable loads in buildings through a Building Energy Management System (including HVAC systems) with an estimated flexibility potential of 100–120 kW, and EV charging infrastructure operated by a Charging Point Operator (CPO), consisting of two charging points rated at 22 kW and one fast charger rated at 50 kW. In addition to these assets, the pilot also includes a group of end users equipped with smart meters that provide detailed electricity consumption data. These end users include residential households as well as several public buildings, such as schools, and small commercial facilities. The smart meters enable the collection of high-resolution consumption profiles, which are used within the STREAM ecosystem to analyse demand patterns, estimate flexibility potential and support forecasting activities.

The pilot also focuses on a selected portion of the distribution network where several power quality analysers (MBTs) have been installed to monitor the behaviour of the LV lines in real time. These monitoring devices provide detailed measurements of power flows and voltage conditions and enable the analysis of grid conditions and flexibility potential within the pilot area. This monitored part of the network also hosts the water distribution pumping station considered in the pilot, making it a relevant location to analyse the interaction between electricity demand from water pumping operations and the conditions of the distribution grid. The pumping station is equipped with 10 pumps, each with a nominal power of 30 kW, representing a significant controllable load within the pilot area.

To analyse and coordinate the flexibility potential of these assets, several tools from the STREAM ecosystem are implemented within the Italian pilot, as described below and depicted in Figure 28:

- The sGRID tool is used to analyse grid conditions and support congestion forecasting based on the measurements collected from the monitored part of the distribution network.
- The sFLEX tool is applied to evaluate the flexibility potential of the available assets, including the water pumping system and controllable building loads.
- Based on these inputs, the sMART tool supports the coordination between the DSO and external flexibility actors, such as the CPO managing the EV charging infrastructure.
- Finally, the sENC tool performs multi-objective optimisation and generates day-ahead scheduling proposals that consider grid conditions, renewable generation and operational constraints.

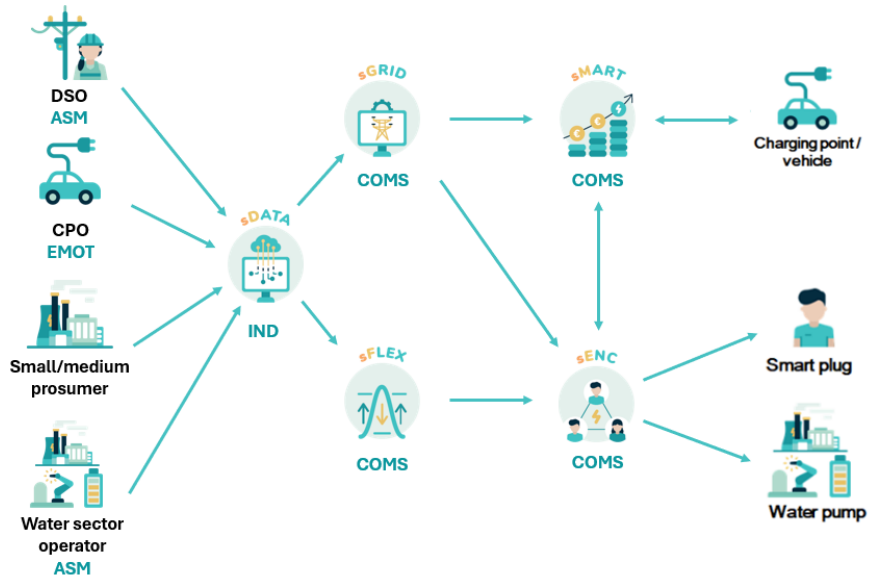


Figure 28: Italian pilot site scheme

Through the integration of these tools and the execution of the defined use cases and test cases, the Italian pilot aims to demonstrate how the STREAM ecosystem can support the assessment, coordination and scheduling of flexibility resources at the distribution level while enabling cross-sector interaction between electricity and water infrastructures.

2.3.2 Risk analysis

Apart from the risks included in the Description of Action, seven additional potential risks were identified in the pilot site as listed in Table 7. Mitigation measures were defined in order to reduce the impact of the risks if materialized:

Table 7: Italian pilot site risk analysis

REF ID	RISK DESCRIPTION	PROBABILITY 1 – 3	IMPACT 1 – 3	PRIORITY	MITIGATION MEASURES
IT_01	Low participation from end-users, resulting in minimal impactful contributions to grid management.	2	1	2	Encourage users to authorize the Energy Community Manager (EnCM) to aggregate flexibility from their assets on their behalf, enhancing their contribution to grid stability.
IT_02	Inability to collect the data due to failure of communication with the devices	2	3	6	Establish redundant communication channels where feasible to ensure robust data transmission.
IT_03	The LV grid reconstruction in sGRID does not allow for reliable congestion forecast and consequently suboptimal schedules optimization	2	1	2	The grid model reconstruction performance will be assessed and benchmarked to actual conditions via LV grid simulations.
IT_04	Lack of congestions in the LV grid during the demonstration phase prevents adequate testing of the tools' functionalities and use cases.	2	2	4	Implement stricter congestion criteria at secondary substations to simulate congestion scenarios, enabling effective testing of the principle and tool functionalities.
IT_05	The water distribution system has limited capacity to provide flexibility while maintaining uninterrupted water supply.	2	1	2	Explore flexibility provisioning capabilities of alternative water supply and treatment assets.

IT_06	User empowerment tools (such as apps) have limited effectiveness in incentivizing users to adopt grid-friendly behaviours.	2	1	2	Alternative motivation schemes beyond monetary compensation to encourage participation and behaviour change.

2.3.3 Deployment plan

To support the integration of the STREAM ecosystem within the Italian pilot, a deployment plan was defined to organize and prioritize the implementation of the different assets, data integrations, and software tools. The overall deployment plan and timeline cover both the deployment of hardware and the progressive integration of the STREAM modules ensuring a coordinated development across the different components, and is illustrated in Figure 29.

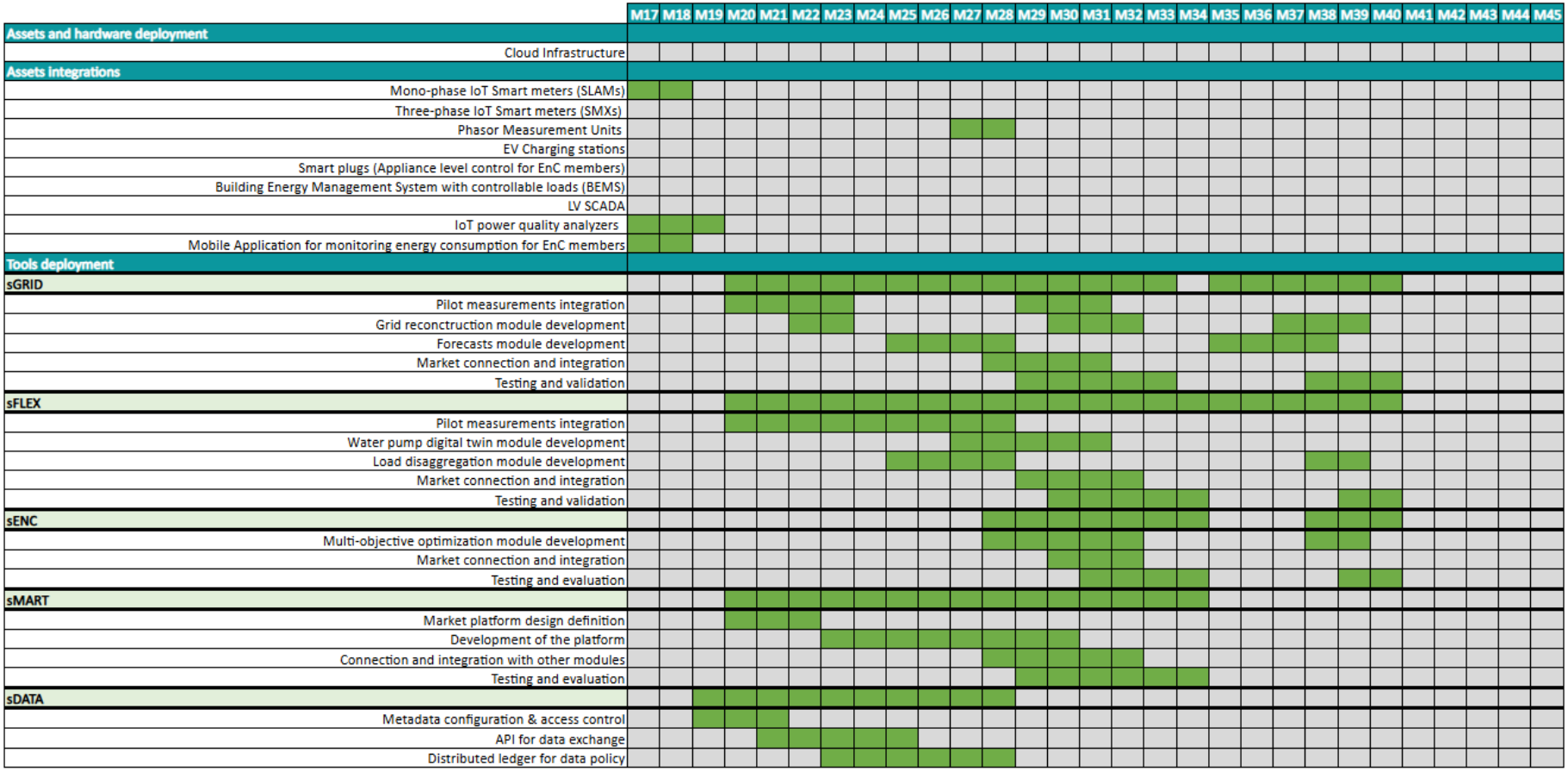


Figure 29: Italian pilot site deployment plan

Table 8 presents the deviations suffered during the deployment of the tools and the integration of the pilot site assets in the Italian pilot site and the reason of the deviations (please note that the features not listed did not suffer any deviations):

Table 8: Final deployment deviations in the Italian pilot site

Tool and feature	Expected deployment date	Final deployment date	Reason
sGRID grid reconstruction module	May 2025 (M32)	December 2025 (M39)	Incorrect wiring of MBT meters on MV/LV transformers lead to delays in the reconstruction of the grid
sGRID forecast module development	January 2025 (M28)	November 2025 (M38)	Similar as the previous one
sGRID testing and validation	June 2025 (M33)	January 2026 (M40)	Delayed due to delay in module development
sFLEX load dissagregation module	January 2025 (M28)	December 2025 (M39)	Initial module finished by M28, updated with the most recent data by M39
sFLEX testing and evaluation	July 2025 (M34)	January 2026 (M40)	Delayed due to delay in module development
sENC Multi objective optimization module development	May 2025 (M32)	December 2025 (M39)	Extended by additional optimization features
sENC testing and evaluation	August 2025 (M35)	January 2026 (M40)	Delayed due to delay in module development

2.3.4 Deployment of new assets and hardware

Within the Italian pilot, MBT devices are deployed as key monitoring components of the distribution network as shown in Figure 30. The MBT is a three-phase multi-stage power meter capable of measuring electrical quantities such as voltage, current, and active and reactive power on up to four three-phase lines connected to the same electrical node. By sharing a common voltage reference, the device enables the simultaneous monitoring of multiple feeders connected at the same point of the network.

The MBT measurements provide detailed information on power flows, load behaviour, and voltage conditions in the monitored part of the network. These data are used within the STREAM ecosystem to support several functionalities. In particular, MBT datasets are used as input for the analysis of grid conditions and power flow behaviour, supporting the identification of load patterns assessment and flexibility potential by providing a reference for baseline consumption and aggregated load profiles.

Furthermore, the MBT data are used in combination with other data sources to enable a comprehensive view of the network behaviour. Overall, the deployment of MBT devices enables enhanced observability of the distribution network at the monitored nodes and plays a central role in supporting the analytical and decision-making functionalities demonstrated in the Italian pilot.



Figure 30: MBT devices deployed in the Italian pilot site

2.3.5 Pilot site assets and STREAM tools integration and deployment

The Italian pilot includes multiple flexibility assets, covering residential, commercial, and utility-scale resources. Flexibility is activated through both implicit and explicit mechanisms. EVs participate via a flexibility marketplace, where the DSO requests specific amounts of flexibility, while end users are engaged and incentivised through a dedicated mobile application. Additionally, a water pumping station contributes to cross-sector flexibility by adjusting its operation according to day-ahead schedules, enabling grid-supportive behaviour while maintaining water service requirements.

The STREAM ecosystem deployed in the pilot environment consists of a set of tools developed and integrated throughout the project: sGRID, sENC, sMART, sFLEX, and sDATA, as previously explained. Each tool addresses specific functionalities within the overall architecture, contributing to the system's interoperability and operational objectives. The role, key features, and deployment status of these tools are described in the following subsections.

2.3.5.1 sDATA

The sDATA tool is the central platform for data management, exchange, and governance within the STREAM project, supporting both the Slovenian and Italian pilots. In the Italian pilot, it is operated in the context of ASM Terni, the local DSO, and integrates data from multiple sectors including electricity distribution, water infrastructure, electric mobility, and end-user consumption. sDATA acts as the single data hub enabling interoperability across STREAM tools (sGRID, sFLEX, sENC, and sMART).

2.3.5.1.1 Data acquisition and communication with stakeholders

sDATA integrates heterogeneous data sources through a combination of RESTful APIs, structured file exchanges, and system-to-system interfaces, depending on the maturity of each stakeholder's digital infrastructure.

- DSO data (ASM Terni):

- Grid measurement data are retrieved from the distribution network through REST API interfaces. These include voltage, current, and active/reactive power measurements from MV/LV transformers and monitored network branches equipped with MBT devices. Data are provided at native resolutions and harmonised within sDATA to a common 15-minute time step. In addition, static grid data (e.g. topology, line parameters, transformer characteristics) are exchanged in structured formats (CSV files), as no automated GIS export interface is available.

- Water system data (SII – water operator):
  - Operational data from the water distribution system, including pumping schedules, pump status, and power consumption of pumping stations, are integrated through structured data exchange mechanisms. These data enable the representation of cross-sector flexibility between water and electricity systems.
- CPO / e-mobility data (EMOT):
  - Data from electric vehicle charging infrastructure are retrieved via API-based communication with the Charging Point Operator platform. This includes charging session data, power profiles, availability status, and aggregated charging demand at near real-time resolution.
- End-user data (residential and commercial consumers):
  - Consumption data from smart meters and, where available, Building Energy Management Systems (BEMS) and IoT devices (e.g. smart plugs, HVAC controllers) are collected through API access or aggregator interfaces. These datasets are used for demand profiling, load disaggregation, and flexibility estimation.

2.3.5.1.2 Data formats and interoperability

sDATA ensures interoperability across all integrated systems by applying harmonised data models and standardised formats. All time-series measurements are aligned to a unified temporal resolution of 15 minutes and stored in structured formats (JSON/CSV) accessible via REST APIs.

Metadata describing assets (e.g. EV chargers, transformers, pumping stations, end-user groups) are structured in a consistent format to ensure traceability and cross-tool compatibility. Where applicable, grid-related representations are aligned with CIM-inspired modelling principles to ensure semantic consistency across the STREAM ecosystem.

2.3.5.1.3 Data governance and access control

Data governance in sDATA follows a data-owner-centric model. Each stakeholder (ASM, CPO, water operator, aggregators) retains ownership of its data and defines the conditions for access and usage.

Access is managed through a multi-layer security architecture:

- Authentication and authorisation: Human users access the MDM portal via secure login credentials, while STREAM tools access data via API keys or token-based authentication (e.g. JWT).
- Role-based access control (RBAC): Permissions are assigned based on user roles (e.g. viewer, editor, system interface), ensuring that only authorised entities can access specific datasets.
- Controlled access provisioning: Data access for STREAM tools (e.g. sGRID, sFLEX, sENC, sMART) is granted explicitly according to predefined data-sharing policies defined by the data owners.

- Auditability and traceability: All data access and modification events are logged to ensure transparency and accountability. This enables full traceability of how data are used across the ecosystem.

2.3.5.1.4 Role within the STREAM ecosystem

Within the Italian pilot, sDATA constitutes the foundational data layer of the STREAM architecture. It provides harmonised, quality-controlled datasets to all other tools:

- sGRID uses historical and near real-time measurement data for load forecasting and congestion detection
- sFLEX uses consumption, environmental, and operational data to estimate flexibility potential
- sENC relies on integrated datasets for optimisation of multi-sector flexibility coordination
- sMART uses processed data to support market operations, monitoring, and settlement processes
- sDATA therefore ensures consistency, interoperability, and reliability of all analytical and operational functions within the pilot.

2.3.5.1.5 Scope of data storage

The sDATA platform is designed to ingest, store, and manage raw and preprocessed data from the Italian pilot site, including time-series measurements, grid models, and asset metadata. It acts as the single source of truth for the STREAM ecosystem.

Outputs generated by analytical tools (e.g. congestion forecasts from sGRID or optimisation results from sENC) are not persistently stored in sDATA, but are accessed through dedicated interfaces when required for downstream processes.

2.3.5.2 sGRID

sGRID is a short-term grid management tool designed to support operational forecasting and congestion anticipation on day-ahead horizons. In the Italian pilot, the tool focuses on forecasting MV/LV transformer loading and identifying potential congestion in advance, enabling proactive operational planning and flexibility activation.

2.3.5.2.1 Data integration

The data ingestion layer of sGRID integrates multiple heterogeneous data sources required for the operation of the tool. These datasets are retrieved through API-based interfaces and structured data provided by the DSO, and are harmonised into a common format and temporal resolution.

Measurement data from sDATA

Grid measurement data is retrieved from the sDATA platform through a REST API interface. The available dataset includes voltage, current, and active/reactive power measurements from MV/LV transformers, as well as consumption data from loads directly connected to MV feeders.

The measurements available in sDATA span from 2024 onwards. However, it should be noted that active and reactive power measurements from MV/LV transformers were affected by incorrect wiring of measurement devices (MBTs) until May 2025. These issues resulted in physically inconsistent readings, including phase unbalances, unrealistic power distributions, and inconsistent relationships between active and reactive power. After the fixing of wiring, the transformer power measurements became physically consistent, exhibiting realistic electrical behaviour such as more symmetrical loading across the three phases, active power values consistently higher than reactive power, and the removal of previously observed anomalies such as single-phase overloading, simultaneous generation on one phase combined with consumption on another, and zero readings on individual phases under load conditions.

The native reporting frequency of MBT measurements is approximately one minute, while consumption data from loads connected to MV feeders follows a standard 15-minute reporting interval. Within sDATA, all measurements are already resampled to a common 15-minute resolution before being exposed via the API, ensuring consistency across datasets. Data quality issues such as missing values, NaNs, and unrealistically large values are handled within the sDATA platform itself through dedicated preprocessing procedures. As a result, the data retrieved by sGRID is already cleaned, filtered, and standardised, significantly reducing the need for additional correction at the sGRID level.

Weather data from Open-Meteo

Weather data is obtained from the Open-Meteo API for the Terni area. The dataset includes solar irradiance, ambient temperature, and precipitation, retrieved at 15-minute resolution. Two different API endpoints are used depending on the application context. The historical data endpoint is used to retrieve past weather observations for model training purposes, while the day-ahead forecast endpoint provides weather predictions aligned with the operational forecasting horizon of sGRID. Weather data is automatically retrieved for the required time intervals via API calls and temporally aligned with the electrical measurement data.

Grid data from DSO

In addition to time-series data, sGRID requires static grid information describing the electrical network. This includes parameters such as line impedances, line lengths, transformer characteristics, and network topology. In the Italian pilot, this information is not retrieved through automated GIS interfaces, as the DSO does not possess an automated API-based export from its GIS system for external tools. Therefore, grid data is exchanged as structured CSV files provided manually by the DSO. However, it is worth noting that within sGRID, these topology and line parameters are used solely as a reference for validating the results of the grid reconstruction module. Specifically, they are used to assess the accuracy of the impedance matrix reconstructed from measurement data, ensuring consistency between the estimated electrical representation of the network and the known physical characteristics provided by the DSO. The dataset is updated when relevant network changes occur and serves as a reference input for grid model validation.

2.3.5.2.2 Load forecasting module

The forecasting models are based on the XGBoost gradient boosting framework. A separate model is trained for each transformer, allowing the tool to capture local consumption characteristics and transformer-specific behaviour. In addition to load forecasting, the same modelling approach is also applied to forecast generation for transformers with a dominant share of distributed energy resources. In the Italian pilot, this includes one transformer where photovoltaic (PV) generation is the primary contributor and local consumption is negligible.

The feature set used for forecasting includes:

- Temporal features: hour of day, day of week, month of year, and weekday/weekend indicator
- Weather features: solar irradiance and ambient temperature

These features enable the models to capture both periodic consumption patterns and the influence of environmental conditions on both load and generation behaviour.

The forecasting models are retrained periodically on a weekly basis using the latest available historical data. This frequent retraining ensures that the models remain representative of evolving consumption and generation patterns, which may vary significantly due to seasonal effects, operational changes, or the integration of new loads and distributed energy resources. Once trained, each model is serialised and stored as a .pkl (pickle) file. This format allows efficient storage of the trained model objects and enables loading during the forecasting phase without requiring retraining. The models are stored in a structured directory, indexed by transformer identifier, ensuring traceability and version consistency

across training cycles. The day-ahead forecasting process is executed as a scheduled daily job. During each run, the latest trained models are loaded from the .pkl files and combined with day-ahead weather forecast data to generate transformer loading forecasts at 15-minute resolution for the following day. The resulting forecasts are stored in a dedicated forecast storage layer as structured .csv files. Each file corresponds to a specific transformer and contains timestamped forecast values for the full day-ahead horizon. The generated forecast results are made available to other STREAM components through a dedicated API interface.

2.3.5.2.3 STREAM integration and data provision

It is important to note that sGRID does not directly generate flexibility requests or trigger market actions. Its role is limited to producing day-ahead forecasts of transformer loading at 15-minute resolution and identifying potential threshold violations for each MV/LV transformer.

In the DSO section of the sMART graphical user interface, forecasts for all transformers are visualised so that the operator can assess the timing and duration of predicted constraints. Based on this information, the DSO manually defines and activates the corresponding flexibility request within sMART. In this process, the operator typically specifies the required flexibility in terms of the amount (kW) and the time window necessary to ensure that the forecasted loading does not exceed the defined threshold.

In addition to supporting operational congestion monitoring in sMART, the day-ahead transformer loading forecasts produced by sGRID are also provided to sENC. While the flexibility activation process in sMART is based on operational congestion identification and targeted requests for specific time windows, sENC requires the full day-ahead forecast profile as input to its optimisation framework, particularly when performing day-ahead scheduling of water pumps, where load shifting decisions are evaluated over the entire daily horizon. This requires a complete temporal representation of transformer loading conditions, rather than just information about congestion intervals, because the objective is to ensure that any planned shifting of flexible consumption does not unintentionally remove congestion in one time interval while creating new congestion in another part of the day.

2.3.5.3 sFLEX

sFLEX is the tool responsible for estimating and quantifying the flexibility potential of distributed energy assets within the pilot, as detailed in D4.1. It identifies how and to what extent consumption can be shifted or adjusted without compromising user comfort or operational constraints. In our pilot, sFLEX addresses two main categories of flexible resources: residential HVAC systems and a water pumping station, each requiring a distinct modelling approach, due to their distinct physical and behavioural characteristics.

2.3.5.3.1 Data integration

sFLEX integrates multiple data sources to construct and update its flexibility models:

- Historical residential consumption data is retrieved via MQTT from smart meters at individual household level. Each user profile is processed separately to identify HVAC-related consumption patterns before aggregation into community-level flexibility estimates.
- Weather data (temperature) is obtained via the Open-Meteo API using the same API interface as in sGRID.
- Water pumping station operational data, including pump operation states, power consumption, water reservoir level, and water inflow, is retrieved via MQTT at 1-minute resolution.
- Technical parameters of the pumping station (tank geometry, pump ratings, number of pumps, and static operational constraints) are provided as a one-time CSV input by the water

operator, as these parameters are not expected to change frequently in realistic operational settings.

2.3.5.3.2 Load disaggregation module

For residential users, sFLEX estimates flexibility by identifying the portion of electricity consumption attributable to HVAC systems. This is achieved by analysing the relationship between individual household consumption profiles and external temperature conditions. Each residential meter is processed independently in order to capture user-specific behavioural patterns. The model identifies a temperature-dependent baseline consumption level representing non-HVAC usage. Deviations from this baseline under varying temperature conditions are attributed to heating or cooling demand. Based on this decomposition, the tool derives a temperature-dependent flexibility profile representing the portion of HVAC-related demand that can theoretically be shifted or curtailed within short time windows without violating thermal comfort constraints.

Unlike water pumping flexibility, HVAC flexibility is not represented as a day-ahead schedule. Instead, it is expressed as an aggregated, temperature-dependent flexibility potential. This represents a best-case operational envelope indicating how much demand could be reduced if end users were willing to participate in short-duration flexibility activation events (typically below one hour). This formulation allows sENC to evaluate the upper bound of residential participation without assuming guaranteed activation.

2.3.5.3.3 Water pumping station digital twin

The water pumping station is modelled in sFLEX as a digital twin, based on its physical and operational characteristics. The system consists of a water reservoir and a set of ten identical pumps, each operating in a binary on/off mode with a nominal power of 30 kW. Each pump delivers a constant inflow rate of approximately 13 l/s when active. The reservoir is defined by its physical geometry, with a surface area of 800 m² and an operational water level range between 2 m and 3.4 m, which determines the usable volume for flexibility provision. While the pump inflow is measured directly, the water outflow (consumption) is not measured and is inferred from the inflow and changes in the water level of the reservoir.

Based on historical observations, sFLEX constructs a day-ahead water demand forecast. Due to the highly repetitive nature of consumption patterns within the same month, the current implementation uses a persistence-based approach, deriving the forecast from the average of the previous week's demand profiles. However, the same framework can support more advanced models, such as XGBoost-based forecasting, consistent with the approach used in sGRID for electrical load prediction. From the forecasted water demand, the evolution of the reservoir level over the day-ahead horizon is simulated together with the corresponding pump activation profile. In the current operational logic, pump activation is determined directly by reservoir level thresholds, meaning that the number of pumps in operation is a function of the current water level. This allows the derivation of an associated electricity consumption profile for the pumping station over the same horizon, which represents the baseline operating condition in the absence of any optimisation actions by the aggregator.

Consistent with the rest of the STREAM modelling framework, the simulation operates at 15-minute resolution, and pump operation is represented as discrete on/off states for each interval, aligned with the temporal granularity used in transformer load forecasting and other system components.

The resulting digital twin is implemented as a Python-based simulation module, which is exported and delivered to sENC. Within sENC, this model serves as the physical constraint layer for optimisation, enabling the generation of feasible pump schedules that fulfil the required objective function while respecting reservoir dynamics and operational limitations.

2.3.5.3.4 STREAM integration and data provision

The output of sFLEX is not a market signal or activation command, but a quantified representation of available flexibility that can be used by optimisation processes in sENC. For residential HVAC systems, the output consists of temperature-dependent flexibility curves that define the upper bound of controllable demand reduction at aggregated level. These profiles are made available to sENC via API-based data exchange, allowing them to be accessed as input parameters during the optimisation process. For the water pumping station, the output is a simulation-based digital twin that enables the derivation of feasible operational schedules. The digital twin is implemented as a Python-based module and transferred to sENC as a callable component, which is then used within the optimisation workflow to simulate system behaviour under different scheduling strategies. In practice, this allows sENC to translate flexibility into explicit on/off schedules for each pump over a day-ahead horizon. Each schedule ensures that operational constraints of the pumping system are respected while allowing sENC to evaluate different optimisation objectives such as cost minimisation, self-consumption maximisation, or congestion mitigation.

No direct control signals are sent from sFLEX to physical assets, and no feedback on execution is processed within sFLEX. Instead, the validation of implemented schedules is handled externally through operational monitoring of pump states and reservoir levels, which are compared against the generated schedules.

2.3.5.4 sENC

In the Italian pilot site, sENC is the tool responsible for coordinating and optimising flexibility resources at the energy community level, providing services typically associated with an aggregator. While the tool is currently operated within the project environment, its functionalities are designed to support an energy community manager in optimally managing distributed assets from both economic and operational perspectives.

2.3.5.4.1 Data integration

sENC integrates multiple data streams required for portfolio-level optimisation. The main inputs include:

- Forecasted transformer loading and PV generation from sGRID, retrieved via API
- Aggregated temperature-related flexibility estimates for residential users and digital twin of water pumps from sFLEX, accessed via API
- Electricity market prices, retrieved from the ENTSO-E platform via API
- Flexibility requests for congestion management issued by the DSO through sMART, when available
- Current water reservoir level, retrieved via MQTT, which serves as initial condition for the water system digital twin

These datasets provide a comprehensive view of both grid conditions and available flexibility within the energy community, enabling coordinated decision-making.

2.3.5.4.2 Optimisation of flexible assets

Based on the available inputs, sENC performs coordinated optimisation of electricity demand, local renewable generation, and water system operation. The optimisation is executed on a day-ahead basis and focuses primarily on the scheduling of water pumps, which represent the most significant and controllable flexible asset within the pilot.

Multiple optimisation objectives are supported, including:

- Maximising local renewable energy self-consumption

- Minimising costs based on electricity market prices
- Shifting load to mitigate forecasted grid congestion

Due to the potentially conflicting nature of these objectives, only one objective function is activated at a time. The optimisation is currently executed manually by the operator (acting as an aggregator), who selects the appropriate objective depending on operational priorities or market signals. The optimisation process generates a complete day-ahead operating schedule for water pumps, aiming to keep transformer loading within acceptable limits across all time intervals while respecting the selected objective.

The role of these objectives depends on the operational scenario. In portfolio management mode, the optimisation is driven by economic or self-consumption criteria and operates independently of market-based flexibility mechanisms. In congestion management mode, the optimisation is performed in coordination with flexibility requests issued by the DSO through sMART. In this case, the optimisation serves as a prerequisite for market participation, allowing the aggregator to estimate the cost and feasibility of shifting flexible loads before preparing and submitting an offer. The other optimisation modes (self-consumption and cost optimisation) are not directly linked to market participation.

The resulting optimised actions are communicated differently depending on the type of asset:

- Water pumps: sENC generates explicit day-ahead schedules, which are provided to the water system operator. At the current stage of the pilot, these schedules must be implemented manually by the water operator. The operation times of water pumps are monitored and recorded, allowing verification of whether the planned schedule has been followed.
- Residential users: sENC provides implicit control signals in the form of SMS notifications or incentives, encouraging users to shift or reduce consumption during specific periods. No direct control is exercised over these assets, and user response is voluntary.

2.3.5.4.3 STREAM integration and data provision

sENC operates as a decision-support and optimisation tool for the energy community manager, supporting both portfolio management and congestion management use cases. In portfolio management mode, the tool is used to optimise the operation of community assets based on economic or environmental objectives, such as minimising energy costs or maximising local self-consumption. In this case, the optimisation is performed independently of market-based mechanisms and serves primarily to improve overall portfolio performance.

In congestion management mode, sENC is used in coordination with flexibility requests issued by the DSO through sMART, which are based on congestion forecasts generated by sGRID. In this context, the tool supports the aggregator in assessing the available flexibility and determining how it can be deployed to address the identified constraints. The optimisation serves as a prerequisite for market participation, enabling the aggregator to evaluate the feasibility and cost of shifting flexible loads before preparing and manually submitting bids via the sMART platform, in a manner similar to other flexibility providers.

In practice, when addressing congestion events, priority is given to the optimisation of water pump operation. This is due to their higher flexibility capacity, greater controllability, and the ability to verify their activation, in contrast to residential loads, where response is uncertain and may affect user comfort. If no optimisation is executed, water pumps continue to operate according to their default control logic based on water level conditions, thereby ensuring continuous and reliable system operation.

2.3.5.5 sMART

The sMART tool serves as the platform for enabling LFM. It facilitates the exchange of flexibility services between DSOs and flexibility providers, supporting efficient grid operation and congestion management at the distribution level. The platform is implemented as a web-based solution comprising a graphical user interface, backend services and database storage. In addition to manual operation through the user interface, sMART exposes secure JSON-based REST APIs over HTTPS, enabling automated data exchange and integration with other STREAM tools and external systems used by market participants.

sMART integrates transformer loading forecasts generated by the sGRID tool, making them available to the DSO through an intuitive user interface, as shown in Figure 31.

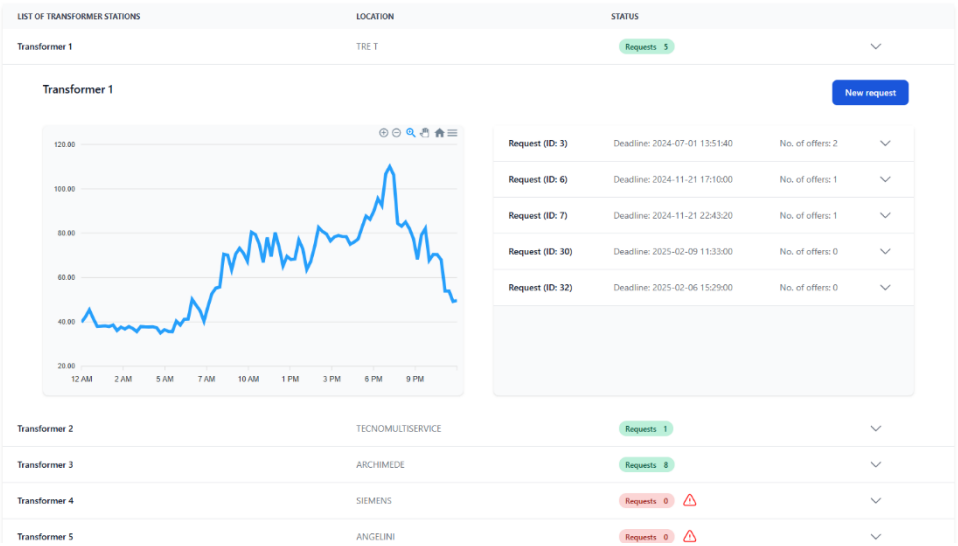


Figure 31: sMART – IT pilot – loading forecast

These forecasts provide a day-ahead view of potential grid constraints at transformer level, allowing the DSO to identify when and where flexibility is required. In the context of the pilot, the purpose of the market interaction is to support the DSO in preventing forecasted transformer overloads by procuring sufficient flexibility to reduce the expected loading below the nominal transformer capacity during the forecasted congestion interval. Since transformer congestion is directly related to loading, and the requested flexibility is also expressed in terms of loading reduction for a defined time interval, no additional simulations are required to verify the expected effectiveness of the bids. This differs from grid issues such as overvoltage, where the impact of flexibility may be more indirect and could require additional network analysis or simulation-based validation. The effectiveness of the accepted bid is therefore assessed through the comparison of the requested flexibility, the accepted commitment and the measured outcome after activation, using baseline estimation and metered data.

Based on forecasted loading information, the DSO can formulate and submit flexibility requests specifying key parameters such as the time window, required energy volume, maximum acceptable price, and the affected grid location, as shown in Figure 32.

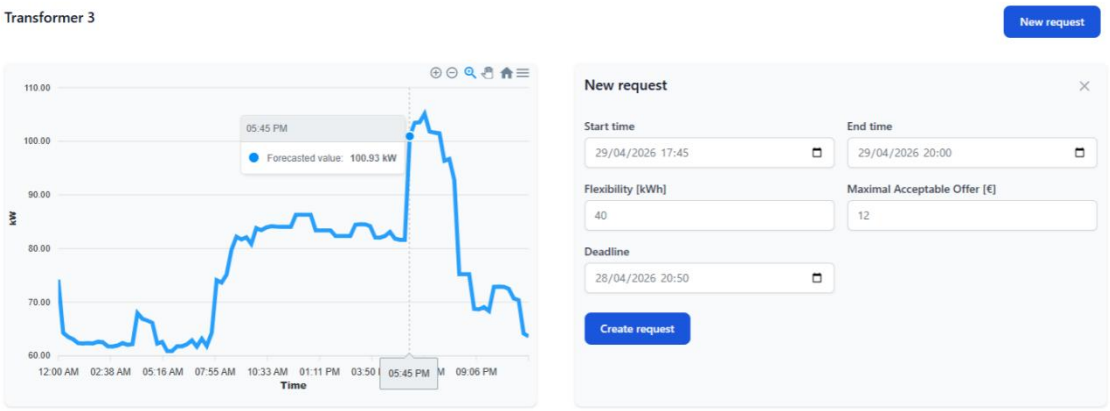


Figure 32: sMART – IT pilot – creating flexibility request

The flexibility provider prequalification process is carried out under the responsibility of the DSO and is performed outside the sMART platform. The DSO disseminates, through its communication channels towards relevant stakeholders, the opportunity to participate in the LFM enabled by sMART, together with the associated participation requirements. Interested flexibility providers are required to comply with predefined technical, operational, and locational criteria (e.g. available capacity, response time, and grid relevance), which are assessed by the DSO through external procedures. Once successfully prequalified, providers are registered within sMART and granted access to participate in LFM interactions.

In the IT pilot, two flexibility providers interact with sMART and can submit bids. The first is the CPO, which directly operates the EV fleet and can provide flexibility by adapting EV charging schedules. The second is the aggregator, which interacts with sMART through the sENC tool and aggregates flexibility from end-user HVAC systems and the water pumping station. Once a flexibility request is published by the DSO, it becomes available to these two registered and prequalified flexibility providers. The CPO and the aggregator can then manually submit bids for the corresponding request through their dedicated user interfaces connected to sMART, offering their available flexibility. sMART then supports the evaluation and selection process, in which the DSO assesses the submitted offers and accepts the most economically suitable one. Upon acceptance, the selected flexibility service is communicated directly back to the winning flexibility provider for the activation.

The platform also manages the full market lifecycle, including request publication, bid submission, result visualisation, and settlement. After the execution of the flexibility service, transactions are recorded and compensation is handled, ensuring transparency and traceability of market operations. Penalties for non-compliance (e.g. non-delivery, partial delivery, or delayed response) are defined by the DSO and are enforced outside the sMART platform. In the context of the pilot, the primary penalty mechanism consists of the temporary or permanent exclusion of non-compliant flexibility providers from participation in subsequent market activities. The assessment of flexibility activation is carried out through a measurement and verification process based on baseline estimation and metered data, ensuring that the delivered flexibility meets the required temporal, locational, and quantitative criteria. The sMART platform supports this process by recording commitments, activation events, and outcomes, ensuring transparency and traceability for settlement purposes.

More technical details about the sMART tool can be found in D4.2 [7].

2.3.6 Deployment challenges and limitations

This section outlines the main challenges encountered and limitations identified during the pilot implementation. These reflect practical constraints related to data quality, infrastructure characteristics, and user engagement, and should be considered when assessing the performance and scalability of the proposed solutions.

Challenges:

- **Transformer voltage measurement inconsistencies:**
  Voltage measurements were acquired on the secondary side of MV/LV transformers, which prevented direct comparison due to differing tap changer configurations across units. To address this, known power flows were used to simulate the missing voltages.
- **Initial misconfiguration of measurement devices:**
  During the early stages of the pilot, MBT devices installed on MV/LV transformers were incorrectly configured, resulting in inaccurate power measurements. This issue was identified and resolved during the project implementation phase (2025), restoring data reliability for subsequent analysis and tool operation.

Limitations:

- **Operational constraints of critical water infrastructure:**
  Due to the critical importance of water supply reliability, only one real-life flexibility activation was carried out at the water pumping station. The activation was performed manually under the supervision of the water operator to ensure that reservoir levels and service continuity were maintained at all times. The experiment nevertheless demonstrated that controlled deviations from standard pump operation can be implemented in real operating conditions and used to shift pumping electricity consumption in time.
- **Low penetration of distributed renewable generation:**
  The level of PV generation in the pilot area is currently insufficient to induce reverse power flows or significant voltage issues. To assess system performance under higher renewable penetration, simulated scenarios representing future RES deployment were introduced.
- **Indirect control of residential flexibility resources:**
  Residential end-user consumption cannot be directly controlled through automated devices (e.g. smart plugs or home energy management systems). Instead, flexibility depends on behavioural responses to incentives and SMS notifications, introducing uncertainty in participation rates and limiting the predictability and reliability of aggregated demand response.

2.4 FINNISH PILOT SITE

2.4.1 Pilot site scope, operational context and objectives

The scope of the Finnish Pilot in the STREAM project is **prototyping** an innovative **mechanism for incentive-driven flexible usage of active power (demand-response) to help stabilizing the transmission grid** in case of frequency anomalies. This prototype explores the possibility to use a pre-defined part of the load used for **heating** the buildings as a **Frequency Containment Reserve** (FCR).

The pilot site includes **7 residential buildings and 3 buildings that are part of a holiday resort**. The used flexible assets are **electric radiators and electric floor heating**. The solution is **fully scalable** to the full OptiWatti customer base.

Figure 33 shows the detailed locations of the pilot apartments.

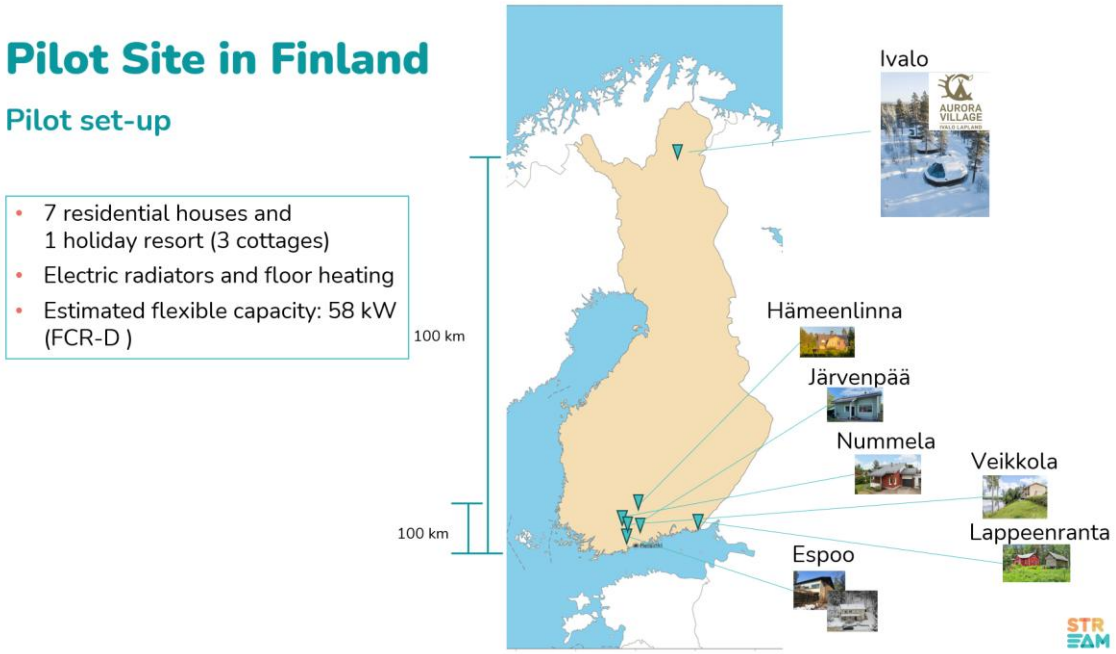


Figure 33: Finnish Pilot Set-up: pilot apartments and used flexible assets

The pilot has **three main objectives**.

- The first one is to study the **technical feasibility** of such a solution, by taking into consideration the challenging requirements set by the TSO on the aggregator in terms of accuracy of the amount of the offered flexible load in the bid, minimum amount of offered flexible load, activation time, etc. This includes also defining how to **integrate** the demand-response functionality **with the existing implicit flexibility**, that is, consumer reaction to price variations (spot-price based control). Demand-response and implicit flexibility could have an opposite effect on the same load since the first is connected to the grid frequency and the second one to the energy price. So, before doing any bid to the TSO in the demand-response, the aggregator shall take into account customer settings and the energy spot prices for the next coming day.
- At the same time, the **business feasibility** of the solution is studied both from the aggregator point of view and from the customer point of view by paying particular attention to the costs and benefits for the customer when his/her assets are part of an FCR.
- Finally, **customers' acceptance** aspects are investigated including the impact on the tenant's satisfaction by periodically collecting feedback from the pilot customers.

Figure 34 shows all the stakeholders and tools of the pilot project.

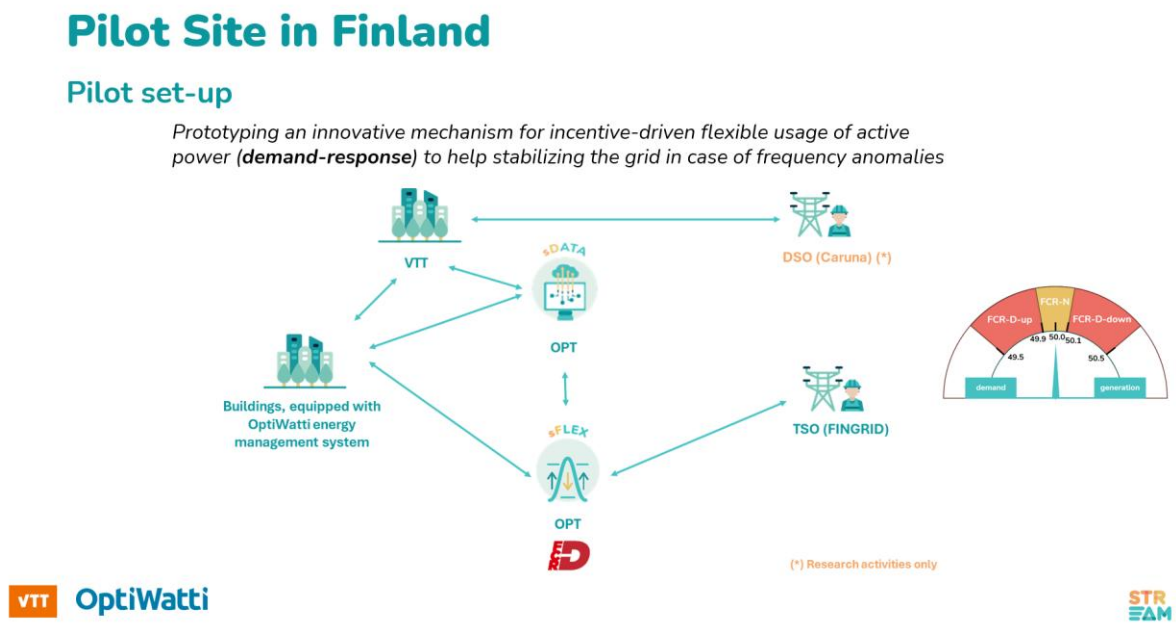


Figure 34: Finnish pilot site scheme

OptiWatti has specified, implemented, tested and demonstrated the functionality needed to offer **FCR-D** services to the TSO. The demand-response functionality is integrated into OptiWatti Buildings Management Control System. The sFLEX tool contains the logic to run FCR-D and the sDATA tool contains the needed data. sFLEX is designed to connect to the **Finnish TSO, Fingrid**. This interface is used to send bids and to report FCR data when a bid is active. sFLEX, which is located in OptiWatti Cloud, communicates with the **Edge computing units** called OptiWatti controllers located in customers' apartments. There is one of such unit for each apartment. OptiWatti controllers get information from the temperature sensors in each room and control the relays which are connected to the heating devices.

Most of sDATA is contained in OptiWatti Cloud. Part of it, the **data warehouse**, is located outside the Cloud in order to let the other Finnish partner, VTT access the relevant data sets.

Access to Optiwatti VPC is allowed only through Secure Shell (SSH) authentication. Access to data outside Optiwatti VPC is allowed only by Secure Sockets Layer (SSL) encrypted connections. SSL is used also in the connection with the TSO.

VTT contributes to the pilot through literature review, market status analysis, and customer research. In addition, VTT has organised customer engagement activities and validated the results using the datasets provided by OptiWatti. Finally, VTT conducted a study on the DSO perspective of demand response in Finland.

The operation of the FCR consists of **4 main phases**:

- Flexible power estimation
- Bid creation
- Frequency Monitoring
- FCR activation and deactivation (load cut / load connection)

The classic way to balance production and consumption of electric power is to modulate the production of energy. The new feature that OptiWatti is developing operates on the load: a decrease in grid's frequency will cause a decrease in load while an increase in grid's frequency will cause an increase in load.

The role of the aggregator will be to **estimate** how much flexible power can be promised to the TSO. Then, a **bid is created** for each hour of the next day, and it is sent to the TSO. Once the TSO accepts the bid, the **grid's frequency is monitored**.

The pilot focuses on FCR-D market, both FCR-D-up and FCR-D-down. In the case of **FCR-D-upward** service, if the frequency goes below 49.9 Hz, **heating load is cut** (see the left part of Figure 35**)**. The amount of load which is cut is proportional to the frequency deviation. For example, a frequency of 49.7 Hz causes cutting half of the load that is sold in the bid. A frequency of 49.5 Hz would cause cutting the full load in the bid. With **FCR-D-downward** service if the frequency is too high, heating load is added rather than cut (see the right part of Figure 35).

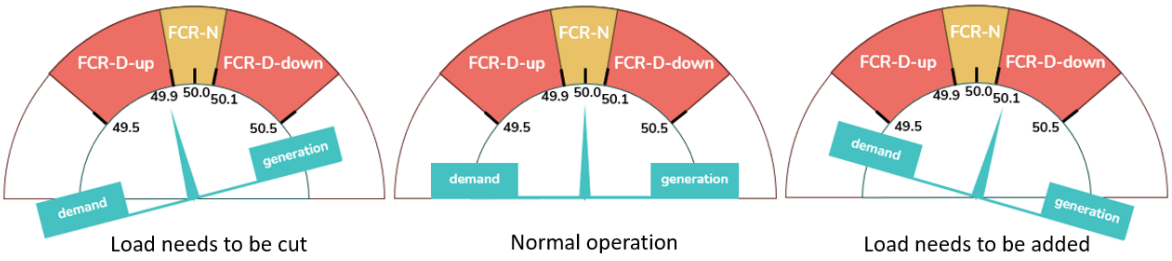


Figure 35: How Frequency Containment reserves help stabilizing grid's frequency

2.4.2 Risk analysis

Eight risks that are specific to the Finnish pilot have been identified when the project started. The estimated probability and the impact, as well as the mitigation measures, have been documented and are shown in Table 9.

Table 9: Finnish pilot site risk analysis

REF ID	RISK DESCRIPTION	PROBA-BILITY 1 – 3	IMPACT 1 – 3	PRIORITY	MITIGATION MEASURES
FI_01	The measurement database is not deployed in time for the project	1	3	3	1) In spring 2024 focus on the periodic measurement database development. 2) The tasks have been checked and re-scheduled in the OptiWatti project management tool. 3) In the worst case, the existing MySQL RDS instances can be used (separate database or at least separate table). 4) It would help a lot to get from deliverable tasks coordinators an estimation on how many hours are required for each task.
FI_02	The sFLEX functionality is not developed in time	1	3	3	1) The internal detailed SW design shall be completed asap. 2) As part of normal Agile methodology, a detailed plan for the core functionality will be done first.
FI_03	The product does not comply with the tight activation timing requirements	1	1	1	1) The most critical requirements are tested first. 2) FCR-N has less demanding requirements so, if needed, we could focus on that. 3) The DSO market have less tight requirements so in the worst case the productization could be re-directed towards that market.
FI_04	Some pilot customer drops from the project	2	2	4	1) Arrange regular meetings with them to keep them engaged. The first meeting could be in spring 2024. 2) There shall be a list of potential candidates and a plan to integrate them in a later phase of the project. Hawkhill could be an alternative to Aurora village (currently, they have no Calendar Integration so it would need more development compared to Aurora village).
FI_05	The amount of available resources decreases	1	3	3	The STREAM project shall have the highest priority in the company (OptiWatti).

FI_06	A lot of time is spent for the project documentation, communication and management and little time is left for developing the necessary functionality	1	3	3	1) A clear vision of the need for future documentation work is created. The reporting period is ending on March 2024 and the next one is on May 2025 so for one year it should be possible to focus on product development 2) The FI Project manager will screen the work and involve only the necessary team members. 3) Other OPT internal resources might be used, when available.
FI_07	Cutting load because of flexibility leads to a decrease of income for the entities providing electricity. Those entities might require monetary compensation	1	2	2	This risk is not going to materialize in the near future. However, if it were materializing, it would add complexity and it would make the business case more challenging. The mitigation action is lobbying the relevant entities.
FI_08	More opportunities for business development rise and slow down the product development	2	2	4	Focusing the development resources on the core functionality that has been defined in the use cases by March 2024 without adding any additional functionality for the full development year.

2.4.3 Deployment plan

OptiWatti develops its SW by using **Agile methodology,** which is an iterative project management approach that breaks work into small, manageable cycles (sprints) to allow for flexibility, continuous feedback, and rapid adaptation to change. Each cycle includes specification, implementation and verification. This approach allows high quality due to continuous testing and good visibility at each stage of the project. While the scope of the project is defined at the beginning of each project, this approach provides agility in changing the fine-tuned plans based, for example, on obstacles found during the implementation phase or to new important customer requirements received during the project.

The deployment plan has been updated quarterly in order to adapt to the actual status of development, integration and demonstration activities. Figure 36 shows the final version of the deployment plan.

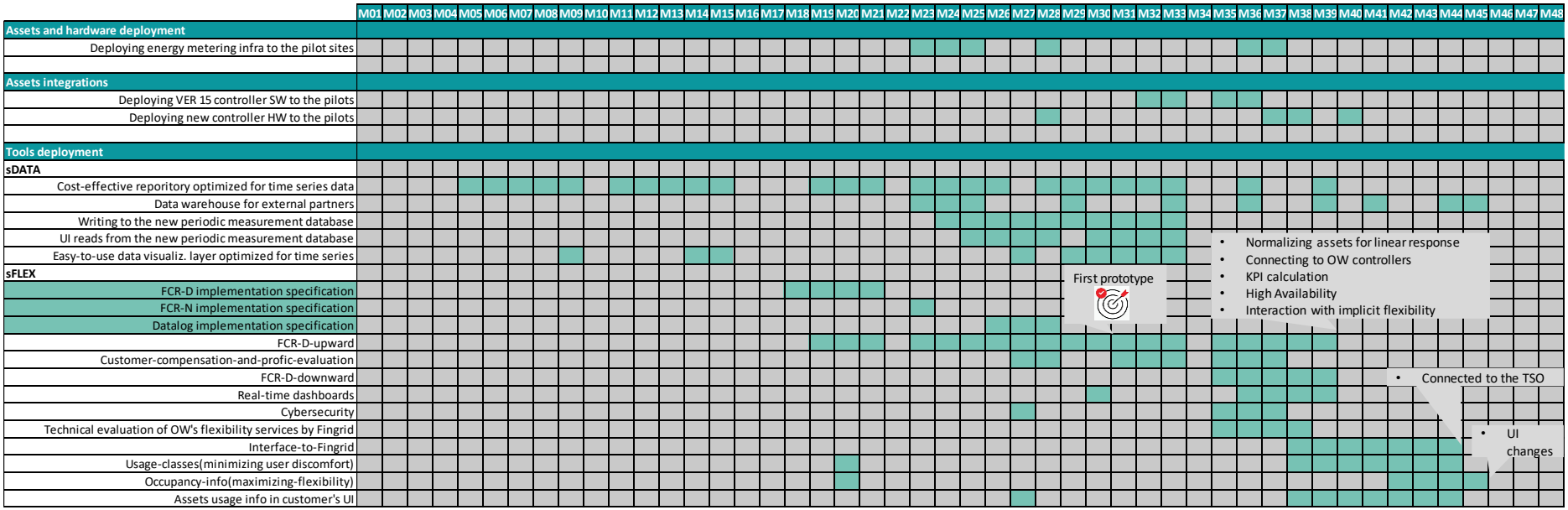


Figure 36: Finnish pilot site deployment plan

The deployment suffered the following deviations when compared to the plan:

Table 10: Final deployment deviations in the Finnish pilot site

Tool and feature	Expected deployment date	Final deployment date	Reason
HW deployment: new energy meters	October 2025 (M37)	Not deployed	Installation has been delayed by 1 pilot customer for a very long time due to delays in the work of their subcontractor on the distribution board where the energy meters were supposed to go. In May 2026 the work order has been cancelled.
HW deployment: new OW controller HW	January 2026 (M40)	Not deployed	The new SW version of OptiWatti controller has proved to be so efficient that it was not necessary any longer to upgrade the HW and therefore resources have been focused on the deployment of the sFLEX tool.
Assets integration: Edge device SW version	September 2025 (M36)	April 2026 (M43)	Getting a working version of sFLEX SW which reacts properly and quickly enough to frequent grid frequency changes has been challenging. Also, in the last couple of years OW has focused on core STREAM functionality and this has caused lower priorization of other projects related to the upgrade of Edge devices.
sFLEX: FCR-D-upward and FCR-D-downward	December 2025 (M39)	May 2026 (M44)	Getting a working version of sFLEX SW which reacts properly and quickly enough to frequent grid frequency changes has required re-designing partially the SW.
sFLEX: Customer compensation and profit evaluation	October 2025 (M37)	May 2026 (M44)	This item needed the previous one to be completed.
sFLEX: Cybersecurity improvements	October 2025 (M37)	June 2026 (M45)	FCR core functionality has been prioritized.
sFLEX: Modifications to customer UI (usage classes, occupancy info, assets usage info in customer UI)	June 2026 (M45)	Not deployed	Related to the descoped use case UC FI.02.
sFLEX: Real-time dashboards	December 2025 (M39)	Not deployed	Added in May 2025 and then descoped since part of the commercial version of the feature (the available GUI is enough for the prototype).

sFLEX: Interface to Fingrid (and technical evaluation of flexibility services by Fingrid – added on February 2025)	May 2026 (M44)	Not deployed	Descoped since part of the commercial version of the feature.

2.4.4 Deployment of new assets and hardware

The pilot customers have been selected among OptiWatti solar customers. Such customers, in addition to the standard OptiWatti HW (OW controller, OW temperature sensors and OW relays) have also 2 Carlo Gavazzi energy meters in each apartment in order to meter the energy produced by the solar panels and the energy bought and sold to the grid. However, this has been the case only for the residential customers.

The holiday resort customer has been selected because it has Calendar Integration feature which is integrated in the demand response functionality. Information about a certain apartment occupancy is used to decide whether or not to use the apartment's assets for demand-response. Installation of one **Carlo Gavazzi ET 340 energy meter** is needed for each of the three cottages of this holiday resort. Those energy meter types are already integrated with OptiWatti solution. Figure 37 shows the used device.



Figure 37: Carlo Gavazzi energy meter device

2.4.5 Pilot site assets and STREAM tools integration and deployment

sFLEX and sDATA are embedded in OptiWatti energy management system. Each apartment has an **OptiWatti controller**. The controller receives information from **the temperature and humidity sensors** located in each room and sends commands to the **relays** connected to each heating device. Electric radiators and electric floor heating are used as flexible assets. Each apartment has also an **energy meter** which is used by the aggregator to prove to the TSO that the reserved power has been maintained. The controller also receives customer settings from OptiWatti backend and sends periodic measurements to it. Customers can modify their settings and monitor the status of their apartment by using **OptiWatti UI**. OptiWatti backend uses weather forecast as well as energy spot prices for different kind of calculations.

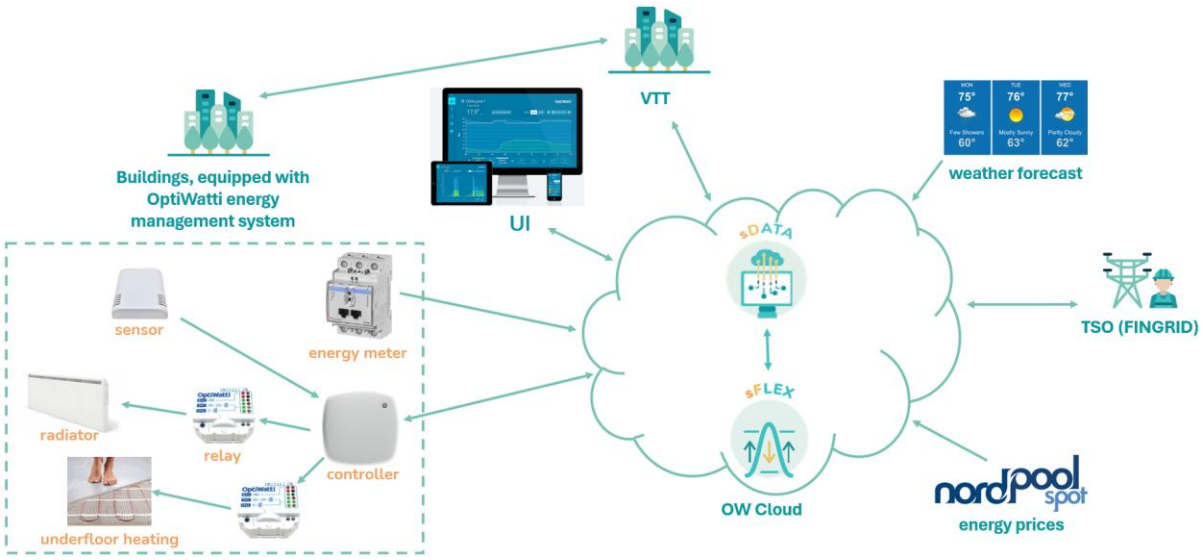


Figure 38: Deployment of STREAM tools in the OptiWatti system

2.4.5.1 sFLEX

The purpose of sFLEX in the Finnish pilot is to implement flexibility service for the TSO by aggregating heating assets into flexibility assets (Flex Groups). Its main functions are:

- **Estimate** the amount of flexible load and **create bids** to send to the TSO
- **Monitor grid frequency** and **activate and deactivate FCR-D** based on the frequency value
- Create and store detailed **logs** containing aggregate data about flexibility operations

The **sFLEX Simulator** uses measurements and control data (temperature settings, weather forecasts, spot prices, calculated room characteristics, current room temperature, outdoor temperature, etc.) to simulate heating of rooms. Those simulations are used by the **sFLEX Manager** which calculates how much flexibility can be offered to the TSO for each hour in a certain market. The sFLEX Manager prepares bids into the database.

The **sFLEX Server** monitors the grid frequency when there is an active bid and, based on the value of the grid frequency, activates and deactivates FCR-D. Also, it keeps detailed logs with a sampling interval of 1 second at aggregate Flex Group level and sends real time data to the TSO through the sFLEX TSO Connector. sFLEX will be integrated into TSO's market system by using **sFLEX TSO Connector** which has the task of reading the bids created by the sFLEX Manager from the database and of sending them to the TSO.

The **sFLEX Client** sends real-time data to sFLEX Server and receives flexibility activation commands from sFLEX Server. The **sFLEX Analyzer** compares the estimated and the actual power consumptions and adjusts system parameters for more reliable simulations.

sFLEX communicates with sDATA through a proprietary interface.

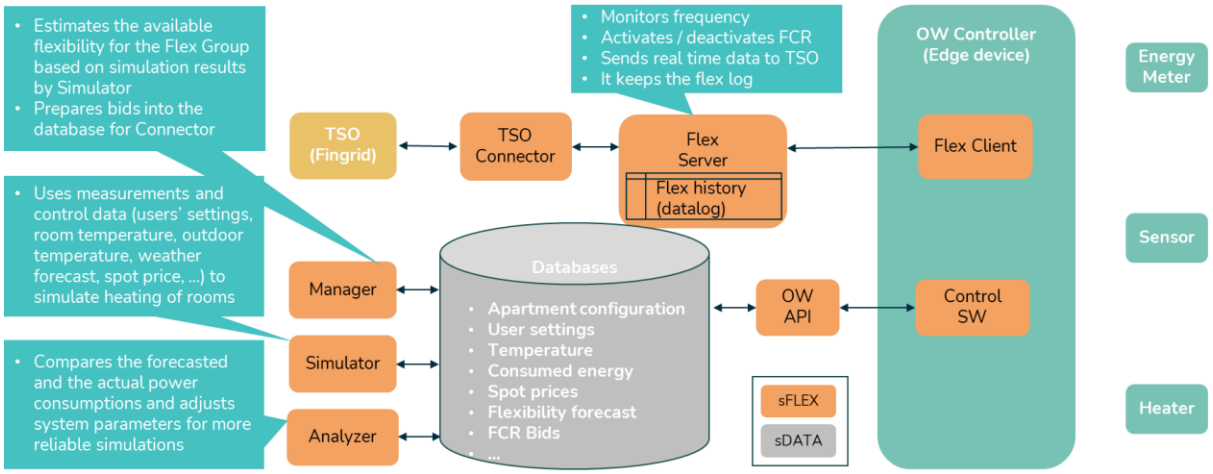


Figure 39: sFLEX in the Finnish Pilot

2.4.5.2 sDATA

sDATA contains two types of databases: **MySQL relational databases** in AWS Cloud which contain the control and configuration data and the **Timescale databases** which contain periodic measurements in time series format. In addition to the periodic measurements database, a new Timescale database has been added to contain demand-response specific data. Also, a separate Timescale server outside Optiwatti private cloud has been set up to exchange data with the Finnish partner in the STREAM project.

A **visualization layer** based on Grafana has been built to contain default dashboards for various analytical tasks. Also, an **ETL data pipeline layer** has been created to transfer data between different databases. This layer uses Apache Ni-Fi.

OW controllers get periodic measurements from the sensors and send periodically the result to sFLEX which updates sDATA.

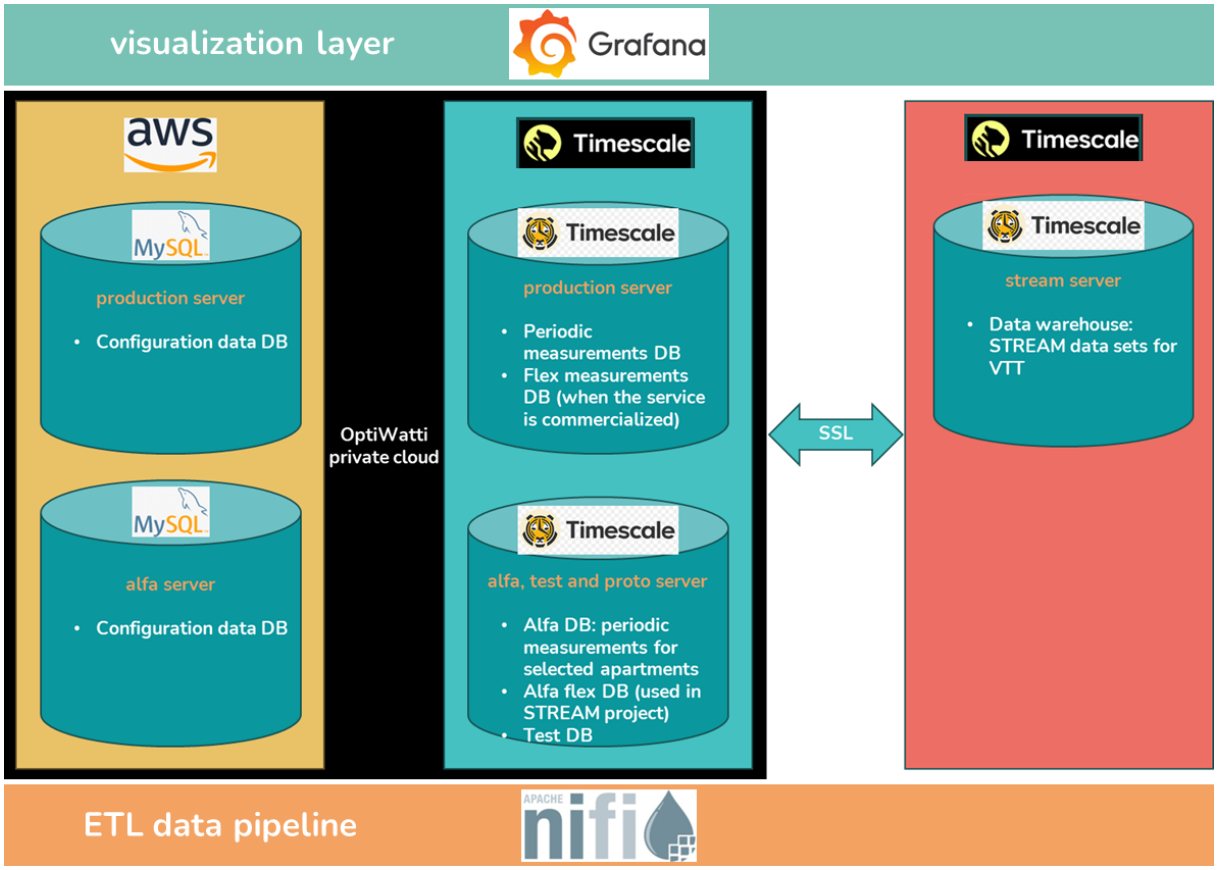


Figure 40: sDATA in the Finnish Pilot

2.4.6 Deployment challenges and limitations

Challenges:

- Extensive discussions have been held with the Finnish TSO (Fingrid) about **how to ensure the TSO that the aggregator is able to maintain the offered flexible power**. The solution that has been agreed is based on combining the measurement of the used power at apartment level with information about relays activities (timestamps).
- The SW needs the **capability to react to quick grid frequency changes**. This has required a partial redesign of the original SW.
- There have been **challenges in installing extra HW in pilot customer premises** due to practical problems (needed space in the electric cabinet of small wooden cottages) and to the coordination of the installation schedules with customer needs.
- It has been **challenging to find a good enough business case from customer's point of view**. The lack of financial motivations for the customer is balanced by benefits such as having more accurate information about the used energy (availability of measured information rather than calculated information).

Limitations:

- The scope of the pilot is limited to a **prototype**. The interface with the TSO is not yet fully tested. The bid process is not yet automatized.
- Tests with real load are limited to the pilot customers which offer **a limited amount of real flexible load**. This amount of load is not enough to test certain pieces of functionality like, for

example, the linear response of the amount of activated flexible power with the grid frequency deviation. Such functionality has been tested by using simulated load and an amount of power that is at least equal to the minimum flexible power required by the TSO for a single bid (1MW).

3 STREAM INTEGRATED ECOSYSTEM DEMONSTRATION

3.1 SLOVENIAN PILOT SITE

3.1.1 Demonstration plan

The demonstration plan for the Slovenian pilot site is shown in Figure 41 (majority of test cases) and Figure 42 (sDATA specific test cases).

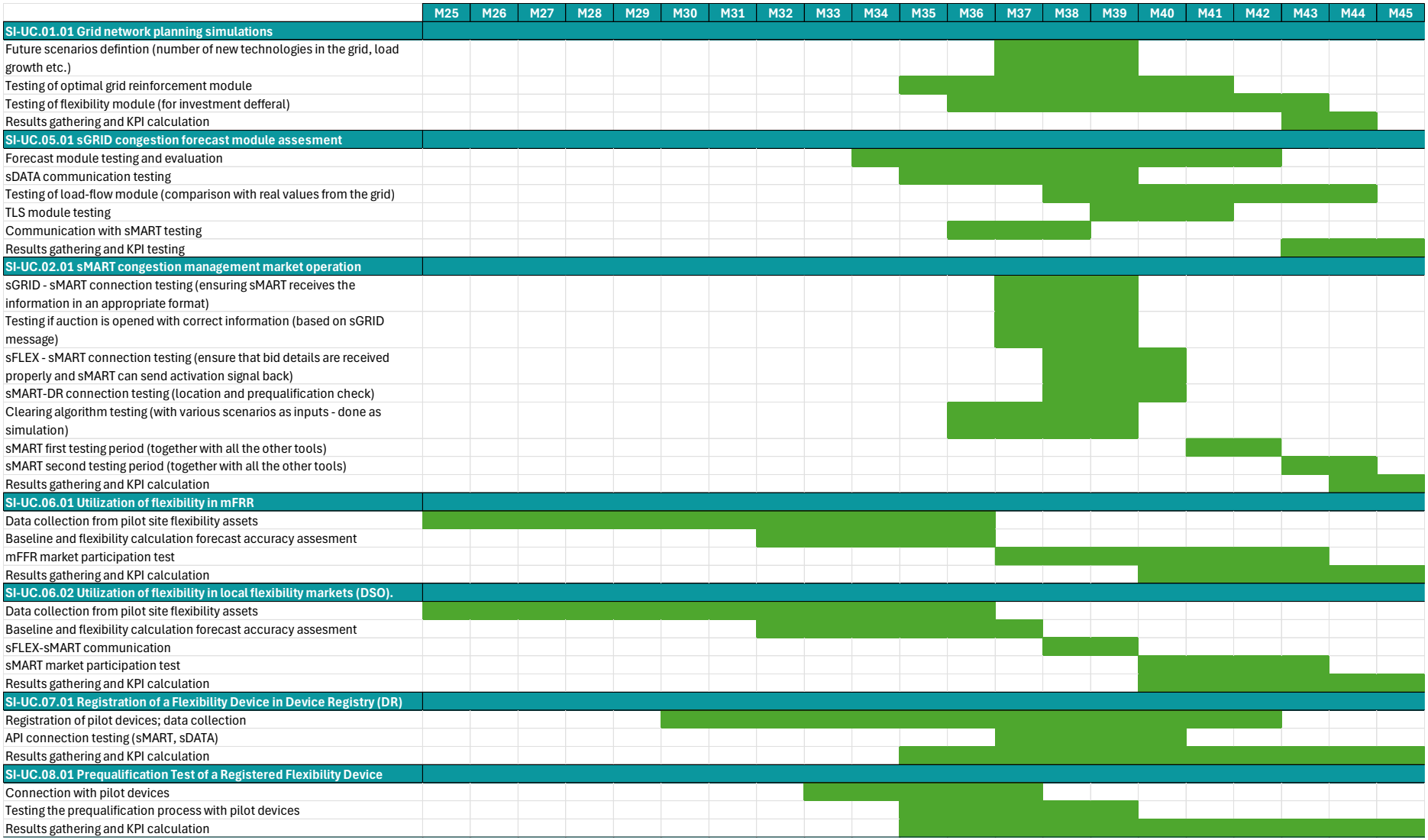


Figure 41: Slovenian pilot site demonstration plan (general test cases)

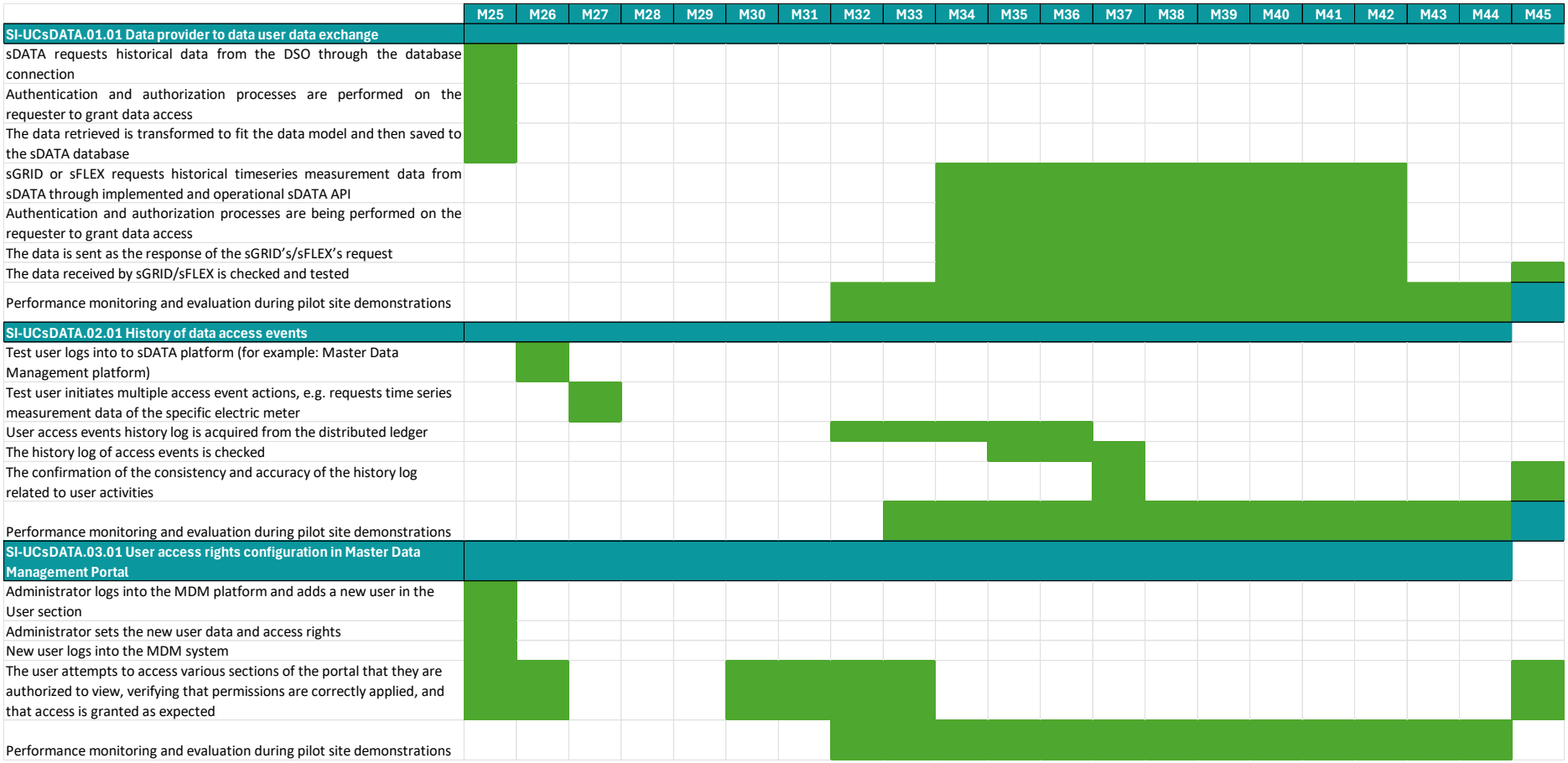


Figure 42: Slovenian pilot site demonstration plan (sDATA test cases)

Table 11 provides an overview of the main deviations in the execution of the test cases when compared to the plan:

Table 11: Slovenian pilot site demonstration deviations

Test case ID	Expected execution date	Final execution date	Reason

SI-UC.06.02 Utilization of flexibility in local flexibility markets (DSO).	M45	M45	The biggest challenge was to include assets with no real financial incentive.
SI-UC.01.01 Grid network planning simulations	M44	M45	Simulations were delayed due to key staff occupied with another project.
SI-UC.02.01 sMART congestion management market operation	M44	M44	• sMART-DR integration was delayed due to unavailability of some data in DR (measurement point IDs) • The testing periods were initially scheduled for M41-M42 (first testing period) and M43-M44 (second testing period). In the end, due to delays connected with prequalification, the test demonstration was performed on 24.4 and the two demonstrations in May (8.5 and 21.5)
SI-UC.05.01 sGRID congestion forecast module assessment	M45	M45	• sDATA communication was finalized in M42 (issues with missing data from EPR) • Consequently, the start of results gathering (both individual load forecasts and load flow results) was done in M43-M44
SI-UC.08.01 Prequalification Test of a Registered Flexibility Device	M45	M45	Prequalification experienced delays due to challenges related to device integration.

3.1.2 Stakeholder engagement activities for demonstration participation and validation

To ensure the participation of the stakeholders in the demonstration activities several activities were performed, which are presented in Table 12.

Table 12: Stakeholder engagement activities of the Slovenian pilot site

Date / activity / location	Focus	Consortium stakeholders	External stakeholders
23/01/2024 co-design workshop, Ajdovščina	**Stakeholder readiness assessment for flexibility market participation:** Project partners engaged flexibility asset owners from the Industrial Zone Ajdovščina to assess their readiness and willingness to participate in DSO ancillary services markets, with findings feeding into the development of STREAM flexibility services.	EPR, UL, KOL, IRI	Representatives from companies in the Industrial Zone Ajdovščina
02/10/2025 meeting, Nova Gorica	**Onboarding of pilot site companies ahead of live demonstrations:** STREAM project objectives and key distribution network challenges presented to local companies, confirming the participation of Tosla, Petrič and Metaldesign in flexibility demonstrations using solar PV and EV charging assets, with first test activations planned by end of 2025.	EPR, UL, KOL	Tosla, Petrič Metaldesign absent – later notified via phone call
October 2025 – May 2026	Following the meeting in Nova Gorica, KOL maintained regular contact with the participating company representatives to coordinate operational preparations. This included scheduling the initial test activations required for Device Registry prequalification and, subsequently, notifying asset owners of the planned demonstration activities in advance, in accordance with the coordination process agreed upon after the Nova Gorica meeting.	KOL, CYG	Tosla, Petrič, Metaldesing

3.1.3 Updated KPIs for demonstration

Table 13 provides a summary of the modifications of the Slovenian KPIs:

Table 13: Updated list of KPIs in the Slovenian pilot site

KPI ID	Original KPI name	Updated KPI name	Type of change	Reason for update
KPI SI.01	Data collection reliability	Data collection reliability	Scope updated	Clarified to report separately per data source (smart meters, transformer station control measurements, SCADA, flexibility asset measurements via sFLEX).
KPI SI.02	STREAM tools communication reliability	STREAM tools communication reliability	Definition refined	Adapted to demonstration-mode evaluation: reliability assessed based on integration tests and demonstration runs rather than continuous automated operation. Specific tool-to-tool connections are listed and individually assessed.
KPI SI.04	Generation forecast accuracy	Load and generation forecast accuracy	Scope updated / merged	Merged original KPI SI.04 (generation forecast) and KPI SI.05 (load forecast) into a single KPI covering all forecast types (consumption, generation, prosumer). Results reported separately for individual asset-level and aggregated transformer-level forecasts.
KPI SI.05	Load forecast accuracy	Grid state forecast accuracy	Definition refined / new scope	Repurposed to measure end-to-end grid state forecast accuracy — the accuracy of forecasted loading at transformer substations and MV feeders derived from the full pipeline (individual forecasts + power flow calculation), rather than individual load forecast accuracy.
KPI SI.12	Total Nominal Capacity of Prequalified Devices	Total Capacity of Prequalified Devices	Scope updated	Updated the KPI to include flexible capacity alongside nominal capacity, as both are relevant indicators of registered device capability.

3.1.4 Test cases results

Table 14 summarizes the test cases that were executed to validate the STREAM ecosystem in the Slovenian pilot site and their key results.

Table 14: Slovenian pilot site demonstration execution summary

Test case ID	Title	Status	Main results
SI-UC.01.01	Grid network planning simulations	Executed	Validation of sPLAN for scenario-based distribution network planning under different seasonal conditions and DER penetration levels. Identification and assessment of network constraints, including overloaded elements and voltage-related limitations. Technical and economic comparison between conventional grid reinforcement measures and flexibility-based mitigation strategies. Demonstration that flexibility resources can reduce network stress and potentially postpone selected reinforcement investments. Validation of a combined planning approach integrating both grid reinforcement and flexibility solutions to support more efficient network development.
SI-UC.02.01	sMART congestion management market operation	Executed	Validation of the end-to-end congestion management workflow, including congestion detection, auction opening, bid submission, market clearing, flexibility activation and grid-level verification. Successful integration and interoperability validation between sGRID, sMART, sFLEX and the Device Registry through multiple integration and eligibility validation tests. Demonstration of EV charging flexibility and PV curtailment activation through local flexibility market mechanisms operated via sMART. Validation of the pay-as-cleared market clearing mechanism under different supply-demand scenarios, including full and partial bid acceptance cases. Validation that flexibility activations produced measurable physical impact at both asset and grid level, demonstrating the capability of flexibility services to influence MV feeder power flows.

SI-UC.05.01	sGRID congestion forecast module assessment	Executed	Continuous operation and validation of sGRID forecasting functionalities on real distribution network infrastructure during the evaluation period. Validation of load forecasting capabilities across 147 load points with different load categories, including industrial consumers and aggregated transformer-level profiles. Demonstration of grid state forecasting through bottom-up power flow simulations, achieving meaningful accuracy at MV feeder and primary substation levels. Validation of the short-term forecasting approach, showing improved forecasting accuracy compared to day-ahead forecasting, particularly for large industrial loads. Identification and correction of topology modelling inaccuracies, demonstrating the importance of accurate grid topology and the capability of sGRID to support topology validation processes.
SI-UC.06.01	Utilization of flexibility in mFRR	Executed	Validation of sFLEX integration with the TSO platform for flexibility bid submission and activation management. Demonstration of real-time baseline and flexibility forecasting for industrial assets using high-resolution operational measurements. Successful activation of industrial flexibility assets, including the Mlinotest mill, achieving the required response time for ancillary service provision. Validation of flexibility activation workflows for cold storage facilities, confirming their technical capability to provide mFRR services. Identification of operational constraints affecting flexibility availability and activation performance, supporting improved bidding strategy definition for industrial assets.
SI-UC.06.02	Utilization of flexibility in local flexibility markets (DSO)	Executed	Validation of day-ahead and real-time baseline and flexibility forecasting for PV assets using high-resolution operational measurements. Demonstration of successful PV flexibility activations through controlled curtailment of generation output.

			Confirmation of fast response capability of PV assets, showing near-immediate reaction to activation signals. Validation of fine-grained PV power regulation without requiring complete disconnection of the assets. Identification of forecasting and baseline estimation challenges caused by short-term weather variability, highlighting limitations of PV assets for highly predictable capacity-based flexibility services.
SI-UC.07.01	Registration of Flexibility Devices in Device Registry (DR)	Executed	Successful registration of 13 flexibility devices in the DR system across 5 locations (PV installations and EV charging stations), confirming correct end-to-end functionality of the device onboarding process. Verification that each device was correctly assigned a unique identifier and properly linked to its corresponding FDO and FSP, ensuring full traceability within the flexibility ecosystem. Validation of the DR data model and registration workflow, demonstrating asset-type agnosticism, as both PV and EV charging assets followed the same process without requiring adaptations. Confirmation that all registered device data (including metering point IDs and technical parameters) was correctly stored and accessible via both the DR user interface and REST API.
SI-UC.08.01	Prequalification Test of Registered Flexibility Devices	Executed	Successful execution of the prequalification process for all 13 registered flexibility devices, confirming full operational readiness across PV installations and EV charging stations in different pilot sites (Petrič, Tosla, Metal Design, Knauf, and SloCar). Validation of device responsiveness to activation setpoints within the defined ±10% tolerance over the 15-minute testing window, demonstrating that all assets meet the minimum technical requirements for flexibility provision. Confirmation of reliable end-to-end communication through both Reduxi MQTT (PV assets) and AVA Car API (EV charging stations), with no communication failures or missing time-series data during test execution.

			Verification of complete and consistent time-series data acquisition by the DR, ensuring accurate monitoring, recording, and evaluation of device behaviour during activation tests. Establishment of full device readiness for downstream processes (market participation, bid submission, and activation), combining successful registration (SI-UC.07.01) and 100% prequalification success rate across all assets.
sDATA-UC.01.01	Data provider to data user data exchange in the Slovenian pilot site	Executed	Validation of end-to-end data exchange workflow between data providers (EPR, AVA), the sDATA platform (IND), and data users (sGRID, sFLEX), confirming correct ingestion, transformation, and provision of data through standardized APIs. Demonstration of high system reliability and robustness, achieving a 99.0% API success rate and stable performance under high-frequency requests, with correct handling of authentication, timeout, and data quality exceptions. Confirmation of strong interoperability and data integrity across heterogeneous systems, establishing sDATA as a reliable central data hub supporting downstream applications such as sGRID forecasting and sFLEX operations.
sDATA-UC.02.01	History of data access events in the Slovenian pilot site	Executed	Validation of distributed ledger-based logging mechanism for capturing and storing all user actions on the sDATA platform in a secure and immutable manner. Confirmation of full traceability and data integrity of user activity logs, with a 100% match between executed actions and recorded events, including correct timestamps and action types. Demonstration of system robustness and non-intrusiveness of the logging architecture, ensuring near real-time event recording and efficient log retrieval without impacting platform performance.
sDATA-UC.03.01	User access rights configuration in Master Data Management Portal in the Slovenian pilot site	Executed	Validation of end-to-end user management workflow in the MDM portal, including user creation, role assignment, and access rights configuration by the administrator (EPR).

			Confirmation of correct enforcement of access control policies, with accurate distinction between Viewer and Editor permissions and immediate restriction of unauthorized actions. Demonstration of system robustness and security compliance, including prevention of duplicate users, blocked unauthorized access attempts, and enforcement of session-based permission updates.

The detailed documentation of the execution of the test cases and their results can be found in Annex B under Section 8.1.

While initially eleven use cases were defined in D2.2 [1] for the pilot site, two use cases were finally descoped, as explained below:

- **UC SI.03 "Three phase grid topology creation and validation":** The creation of a three-phase grid model required a high-quality single-phase topology as its starting point. However, significant data quality issues were encountered in the existing GIS-based network model provided by the DSO, including incorrect load connection points, inaccurate feeder material specifications, and substantial effort needed to transform the GIS data into a simulation-ready format (pandapower). Resolving these issues and producing a reliable single-phase topology consumed several months of development effort that had originally been allocated to the three-phase extension. Once the corrected single-phase model was in place, it proved sufficient for the pilot's core objective: reliable congestion forecasting and TLS-based grid assessment within sGRID. Given that the single-phase model met the operational requirements of the pilot and that the prerequisite data quality work left insufficient time and resources for three-phase development, this use case was descoped.
- **UC SI.04 "Grid state estimation in distribution network":** State estimation was originally envisioned to process available measurements in near-real-time to fill gaps and correct faulty data, particularly in the LV network where monitoring coverage was limited. A prerequisite for this was the availability of close-to-real-time measurement data from a part of smart meters, which the DSO planned to enable by reconfiguring selected meters for higher-frequency data delivery. However, this reconfiguration was not carried out, and smart meter data remained available only at D-1 granularity. With D-1 data, real-time state estimation serves no practical purpose. At the same time, the D-1 smart meter measurements provided sufficient coverage of the LV network (with data available for all metering points) removing the original motivation of compensating for sparse monitoring. The sGRID implementation ultimately relied on forecast-based congestion assessment (day-ahead and short-term), which proved sufficient for the pilot's congestion management objectives without requiring a state estimation step in the processing pipeline.

3.1.5 Key innovations of the Slovenian pilot site

Thanks to these demonstrations, the Slovenian pilot site has been able to go beyond the state of the art on demand-side flexibility utilization in ancillary services and smarter grid planning as follows:

- **Demand-side mFRR services provision:** While demand-side participation in mFRR ancillary services exists in Slovenia, it predominantly relies on assets with straightforward controllability such as batteries or generators. This test case demonstrates the use of industrial process loads (specifically large cold storage rooms and milling equipment) for mFRR provision through aggregation. These asset types are rarely utilised for ancillary services, both in Slovenia and more broadly across Europe, despite their significant flexibility potential. Cold storage rooms, for example, can temporarily reduce or increase their electrical load while thermal inertia maintains acceptable temperature levels within the storage facility. However, unlocking this potential requires asset-specific modelling to determine the available flexibility volume, duration constraints, and operational limits that must be respected to avoid disrupting the industrial process. The assets in this test case are individually too small to meet the 1 MW minimum bid size for mFRR in Slovenia and therefore participate through

aggregation via sFLEX, demonstrating that heterogeneous industrial loads can be combined into a viable portfolio for system-level ancillary services.

- **Related test cases:** SI-UC.06.01

- **Smarter DSO network planning:** Conventional DSO grid planning tools assess network adequacy and determine reinforcement needs (e.g., replacement of transformers or feeders with higher-capacity equipment) without considering flexibility as an alternative. sPLAN extends this approach by incorporating flexibility measures into the planning process, allowing the DSO to compare the cost of traditional grid reinforcement against the cost of procuring flexibility to address the same network constraint. This enables a technology-neutral planning methodology where flexibility (modelled as load shifting of distributed resources such as PV, BESS, heat pumps, and EVs) is evaluated alongside infrastructure investment as a viable solution.
  - **Related test cases:** SI-UC.01.01
- **Integrated flexibility ecosystem for distribution grid management:** Local flexibility markets for distribution-level congestion management do not currently exist in Slovenia, and operational implementations remain rare across Europe, where flexibility procurement typically relies on fragmented platforms and manual coordination between the grid operator, market operator, and flexibility providers. This test case demonstrates a complete, integrated ecosystem in which a congestion management workflow is executed end-to-end across multiple coordinated STREAM tools with tool-to-tool interfaces:
  - sGRID generates the congestion signal via the Traffic Light System (TLS), which automatically defines the auction parameters (stage, location, required volume and direction, time) in sMART.
  - sMART operates the auction and clears the market.
  - the Device Registry enforces locational and prequalification requirements before a bid enters the order book, ensuring that only technically eligible assets connected to the relevant grid element can participate.
  - sFLEX dispatches the activation to the flexibility assets.

  This coupling means a forecasted grid constraint translates directly into a locational flexibility procurement, making flexibility from small-scale, LV-connected distributed resources usable for resolving specific, localised distribution grid constraints rather than only system-wide balancing needs. The complete chain, from grid signal through auction clearing to verified physical activation, was validated end-to-end with real asset activations (EV charging and PV curtailment) and measurable impact at both the asset and grid level

  - **Related test cases:** SI-UC.02.01
- **Bottom-up grid state forecasting with topology validation:** Conventional distribution grid forecasting typically operates at aggregate levels (feeder or substation) and does not validate the underlying network topology model. sGRID instead applies a bottom-up approach: it forecasts each individual load and generation profile, runs a power flow calculation to derive the full grid state (voltages, line and transformer loading), and compares the result against grid limits to detect congestions at the MV/LV level where they occur. A key innovation demonstrated during the evaluation is that this approach also functions as a topology

validation instrument. Because each load must be correctly assigned to its topological location, systematic divergence between the simulated and measured grid state reveals errors in the grid model. During the evaluation period, a misassigned LV feeder was detected through this divergence and corrected, after which the simulated and measured profiles realigned. This dual capability, congestion forecasting and topology validation from the same workflow, is not provided by conventional DSO forecasting tools.

- **Related test cases:** SI-UC.05.01

3.1.6 Demonstration challenges and limitations

The following challenges and limitations have been faced during the demonstration activities related to each tool of the pilot site:

sPLAN:

- During the simulation of grid planning scenarios co-defined with EPR, several MV feeder segments exhibited abnormally high loading values (300–1000%) in the power flow results. The issue was investigated jointly with EPR by verifying the feeder segment material properties (cable cross-section, which determines thermal capacity) and segment lengths in the grid model. The root cause was identified as incorrect cable cross-section data in the network model, which led to underestimated thermal ratings for the affected segments. Once the correct cross-sections were entered, the loading values returned to realistic levels.

sGRID:

- A significant challenge was the accuracy of the network topology model. In the initial weeks of operation, the grid state forecasts at the MV/LV transformer level showed large systematic deviations from the control measurements. Investigation revealed that a LV feeder was incorrectly connected in the topology, causing simulated transformer loads to diverge substantially from the measured values. Once the connection was corrected, the forecast accuracy improved dramatically. This experience, described in more detail in the sGRID evaluation (Annex B, SI-UC.05.01), demonstrated that for the bottom-up forecasting approach taken in sGRID, the accuracy of the LV topology is critical. Incorrect load connections, missing loads, or loads assigned to the wrong part of the network directly translate into errors at the transformer and feeder level.
- A second challenge concerned the data retrieval pipeline from the DSO's systems via sDATA. The initial implementation retrieved AMI and SCADA data once daily, which resulted in a significant number of missing timestamps in the measurement data used for model training and evaluation. A second iteration adjusted the retrieval timing, which improved data completeness but did not fully resolve the issue, particularly for MV/LV transformer control measurements. Through close collaboration with EPR, the optimal timing for an additional daily retrieval was identified and implemented, which resolved the remaining data gaps. This iterative process highlighted that reliable data availability (not only data access) is a prerequisite for operational forecasting tools, and that close coordination between the tool developer and the DSO is essential to align data retrieval with the DSO's internal data processing cycles.

sFLEX:

- The demonstration activities were dependent on activation requests issued by the TSO, which are determined by the real-time conditions in the transmission network. In situations where network issues occur, the TSO activates bids according to the merit order, prioritising lower-priced offers. As a result, only a limited number of activations could be performed during the demonstration period, with one successful TSO activation involving the Mlinotest mill in January.
- At the same time, the participating asset owners were entering the mFRR market for the first time and initially showed a conservative approach towards offering their assets for flexibility services. Since the assets involved represent critical components of their operational processes, financial incentives alone were not sufficient to ensure full participation from the beginning. In this context, the limited number of activations provided a gradual and manageable introduction to market participation for all stakeholders involved.
- As LFMs currently do not provide direct financial incentives, an operational agreement was established with the participating asset owners to notify them at least seven days in advance of the planned market participation time slot for their devices.
- Consequently, the main challenge was the successful execution of the complete value chain within the predefined timeframe, including bid submission, bid acceptance and final activation. Any issue occurring during one of these phases required the scheduling of a new participation window, resulting in an additional waiting period of seven days before the next demonstration attempt could be carried out.

sMART:

- The range of flexibility sources available for the demonstrations was limited to EV charging stations and PV installations. This constrained what could be demonstrated from a congestion management perspective, both in terms of the timing of activations (dependent on asset availability and generation conditions) and the direction of flexibility (primarily upward for EV and downward for PV). Some planned assets were unavailable during the demonstration period: Tosla's PV installations were turned off due to negative wholesale electricity market prices at the time, and Tosla's BESS could not be activated because it is managed by an external aggregator outside the STREAM ecosystem.
- Because actual grid congestion could not be guaranteed during the pre-arranged demonstration windows, the flexibility requests from sGRID were generated manually rather than through the automated pipeline. The demonstrations required coordination with asset owners at least one week in advance to ensure asset availability at the scheduled time, which is fundamentally different from the operational setting where flexibility would need to be activatable at short notice (day-ahead or shorter) in response to automated congestion forecasts. While the manual approach was sufficient to validate the end-to-end market workflow, it means that the fully automated congestion detection → market activation chain was not tested under real operational conditions.
- The demonstrations involved a single aggregator (Kolektor sETup) as the sole market participant. While this was sufficient for validating the technical workflow and the clearing algorithm, it means that competitive price discovery between multiple aggregators was not tested. A multi-aggregator setting would be needed to assess the market's ability to drive efficient pricing through competition.

- When verifying the physical effect of flexibility activations, both at the smart meter level and at the grid level (MV/LV transformer and MV feeder SCADA measurements), the observed activation effect was in some cases less pronounced than expected. This is because the grid-level measurements reflect the aggregate behaviour of all loads and generators connected to the respective element, meaning that concurrent independent changes in other consumers' or producers' profiles can partially mask or amplify the activation signal within the 15-minute measurement interval. This is an inherent challenge of DSO-side activation verification using standard metering infrastructure.

3.2 SPANISH PILOT SITE

3.2.1 Demonstration plan

Prior to the execution of the demonstration activities, and once the deployment of the Spanish pilot site was at an advanced stage, the partners defined the experiments (hereafter referred to as test cases) to be executed in order to demonstrate the use cases and collect the expected KPIs defined in D2.2: Use cases and requirements definition [1]. Afterwards, a demonstration plan was prepared to execute the test cases in a structured and procedural manner.

To ensure that the most innovative solutions of the pilot site could be demonstrated while minimizing the risk of delays and lack of time during the demonstration phase, the pilot partners identified the dependencies between the different test cases and established execution priorities based on their innovation level and relevance to the pilot site. It is noteworthy that the test cases were executed progressively, as soon as the relevant functionalities were deployed at the pilot site. As a result, the following demonstration plan was prepared before proceeding with the execution of the test cases.

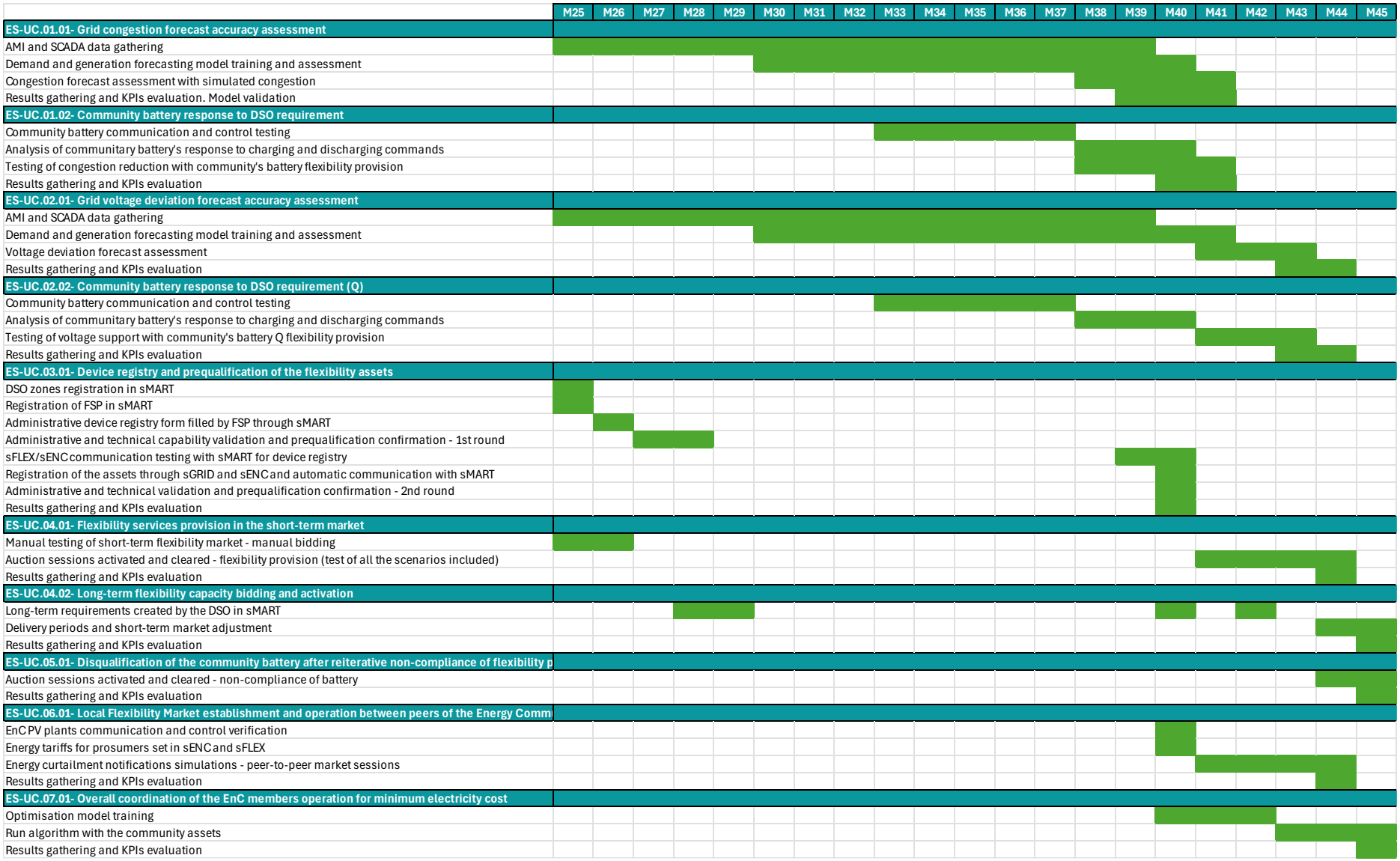


Figure 43: Spanish pilot site demonstration plan

Some deviations were faced as a consequence of the delays suffered in the deployments. Additionally, the community battery suffered a fault that put it out of service for a month. This delayed the execution of the first test cases, as indicated in Table 15:

Table 15: Spanish pilot site demonstration deviations

Test case ID	Expected execution date	Final execution date	Reason
ES-UC.01.01 Grid congestion forecast accuracy and automatic requirement assessment	M41	M44	The delay on the finalization of the grid modelling in sGRID delayed the finalisation of this demonstration.
ES-UC.01.02 Community battery response to DSO requirement	M41	M45	Similar to the previous item. Furthermore, the issues with the community battery (furtherly explained in section 3.2.6) delayed the execution of this demonstration until the problem was solved.
ES-UC.02.02 Community battery response to DSO requirement for voltage deviation	M44	M45	Similar to ES-UC.01.02
ES-UC.03.01 Device registry and prequalification of the flexibility assets	M40	M44	Although most of the assets were registered and prequalified by M40, an update on OMIE's systems made it necessary to wait until May to finalize the registration of the assets.
ES-UC.04.02 Long-term flexibility capacity bidding and activation	M45	Not executed	This test case has been finally merged with ES-UC.04.01 to demonstrate the full local flexibility market workflow (from long-term capacity bidding to short-term market and activation).
ES-UC.05.01 Disqualification of the community battery after reiterative non-compliance	M45	Not executed	This test case was not executed due to the deviations encountered during the pilot implementation. Given its lower priority within the pilot scope and its limited impact on the overall demonstration objectives, it was decided to focus the available resources on the execution of the remaining test cases.
ES-UC.06.01 Local Flexibility Market establishment and operation between peers of the Energy Community	M44	M45	Delayed as a consequence to the previous delays.

3.2.2 Stakeholder engagement activities for demonstration participation and validation

To ensure active participation of the end users during the demonstration activities, Enercoop as energy community manager has conducted workshops and other activities with the members of the energy community.

Table 16: Stakeholder engagement activities of the Spanish pilot site

Date	Focus	Consortium stakeholders	External stakeholders
Dec-23 (M15)	Presentation of the STREAM project to external stakeholders	Enercoop, OMIE, ETRA	Energy value chain stakeholders
Feb-24 (M17)	Presentation of the flexibility services provision through small-scale flexibility energy sources to the EnC members	Enercoop	EnC members
Sep-24 (M24)	Management of energy communities and engagement in the energy transition	Enercoop	EnC members
Nov-24 (M26)	Promote the use of renewable energies among energy community members to reduce electricity bills and contribute to a more sustainable and democratic energy model.	Enercoop	EnC members
Jul-25 (M34)	Promoting local development with a focus on sustainability and citizen participation.	Enercoop	Municipalities, Energy Agencies, Energy Communities, ESCOs
Apr-26 (M41)	Updates on the STREAM project and the flexibility services they can provide. Presentation of the tools and questionnaires.	Enercoop	EnC members

3.2.3 Updated KPIs for demonstration

An initial set of KPIs was provided for D2.2 for the pilot site, linked to the use cases defined in that deliverable. However, during the definition and execution of the demonstration experiments, it was noticed that some of the KPIs were not ideal to reflect the impact of the demonstrations and some readjustments were needed. Table 17 provides a summary of the modifications of the Spanish KPIs.

Table 17: Updated list of KPIs in the Spanish pilot site

KPI ID	Original KPI name	Updated KPI name	Type of change	Reason for update
KPI ES.01	Reduction of congestions frequency		Deleted	Deleted because no real congestion is currently happening in the grid. The congestions are going to be simulated creating scenarios.
KPI ES.02	Congestion forecast accuracy	Congestion forecast accuracy	No changes	
KPI ES.03	Congestion correctly identified	Congestion correctly identified	No changes	
KPI ES.04	Congestion resolution ratio	Congestion resolution ratio	No changes	
KPI ES.05	Correct automatic bids ratio	Correct automatic bids ratio	Definition and formula changed	sGRID does not generate automatically the requirements, since the DSO must assess how much flexibility will be required by analysing the scenario. sENC and sFLEX are generating automatically the bids upon detecting short-term open sessions.
KPI ES.06	Local self-consumption ratio	Local self-consumption ratio	No changes	
KPI ES.07	Variability of the voltage	Reduction of voltage deviations	Modification of the KPI	KPI more adapted to the demonstration of the reduction of voltage deviations.
KPI ES.08	Assets qualification ratio	Number of prequalified assets	Modification of the KPI	All the assets are expected to pass the prequalification, so it was more meaningful to quantify the number of assets instead of its ratio
KPI ES.09	Average activation time	Flexibility provision compliance ratio	Modification of the KPI	The activation time is not critical, since the short-term market operates in a 1-hour window from closing the session to the service. It was more critical to identify if the assets were compliant with the service.

KPI ES.10	Trustful bids percentage		Deleted	Overlapped with KPI ES.05.
KPI ES.11	Flexibility requests coverage	Flexibility requests coverage	No changes	
KPI ES.12	Flexibility delivery precision		Deleted	Overlapped with the updated KPI ES.09
KPI ES.13	Increase of economic welfare	Increase of economic welfare	No changes	
KPI ES.14	Percentage of flexibility availability	Percentage of flexibility availability	No changes	

3.2.4 Test cases results

The following test cases were executed to validate the functionalities and the seven use cases defined for the Spanish pilot site, enabling the assessment of the STREAM tools under operational conditions.

Table 18: Spanish pilot site demonstration execution summary

Test case ID	Title	Status	Main results
ES-UC.01.01	Grid congestion forecast accuracy assessment	Executed	Validation of congestion forecasting capabilities in more than 150 LV grids Calculated line utilisation rates Assessed model accuracy for congestion forecasting
ES-UC.01.02	Community battery response to DSO requirement to reduce overloading	Executed	Validated automatically generated flexibility requirements triggered by congestion detection in sGRID Successful activation of the community battery following DSO request Congestion mitigated in the affected line
ES-UC.02.01	Grid voltage deviation forecast accuracy assessment	Executed	Validation of voltage deviation forecasting capabilities in more than 150 LV grids Calculated voltage deviations at busbars Assessed model accuracy for voltage deviation forecasting
ES-UC.02.02	Community battery response to DSO requirement to reduce voltage deviation	Executed	Validated flexibility requirements triggered by voltage deviation detection Successful activation of the community battery Voltage deviations reduced
ES-UC.03.01	Device registry and prequalification of the flexibility assets	Executed	Successful registration and prequalification of flexibility assets in sMART

			Identification of flexibility service providers in sGRID enabling scenario simulations
ES-UC.04.01	Provision of flexibility services to the local flexibility market	Executed	Validation of the end-to-end workflow of the local flexibility market, from long-term to short-term flexibility market sessions Validation of market clearing workflows and flexibility activation
ES-UC.05.01	Disqualification of the community battery after reiterative non-compliance of flexibility provision	Not executed	
ES-UC.06.01	Local Flexibility Market establishment and operation between peers of the Energy Community	Executed	Calculated collective self-consumption surplus and deficit Demonstrated peer-to-peer flexibility exchanges within the Energy Community Validation of P2P market clearing workflows
ES-UC.07.01	Overall coordination of the EnC members operation to minimize electricity cost	Executed	Coordinated operation of Energy Community assets demonstrated to improve economic welfare Algorithm ensuring compliance with local flexibility market constraints validated

While initially seven use cases were defined in D2.2 [1] for the pilot site, two use cases were finally descoped, as explained below:

- **UC ES.05 "Detection, warning and block of untruthful bids (intentional and unintentional)":** As explained in Section 3.2.1, no test cases have been executed for this use case since it had the lowest priority as it was a proof of concept and, due to the challenges faced in the pilot site, it has been finally descoped.

The detailed documentation of the execution of the test cases and their results can be found in Annex B under Section 8.2.

3.2.5 Key innovations of the Spanish pilot site

Beyond the execution of the individual test cases, the demonstrations enabled the validation of several innovative concepts related to LFMs, LV grid operation and energy community participation in grid services. From these demonstrations, the pilot site has validated several cutting-edge innovations related to LFMs and the integration of energy communities into distribution grid operation:

- **Detailed modelling and forecasting of large-scale LV grids.** The pilot successfully modelled and calculated forecasts for more than 150 low-voltage grids, covering Enercoop's entire network, including more than 14,000 loads and generators, and 150 transformers. This detailed modelling is essential to enable the operation of LFMs in LV grids, where energy communities are mainly composed of small-scale consumers and distributed generators connected to the low-voltage network. The developed models enabled the detection and forecasting of congestions in LV grids, as well as the assessment of how flexibility asset activation can contribute to congestion mitigation.
    - **Related test cases**: ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02 and ES-UC.04.01.
- **Identification and mitigation of voltage deviations through flexibility assets.** The pilot demonstrated the identification of voltage deviations in LV grids, extending LFM services beyond congestion management. The demonstrations included the actuation of the community battery to support voltage regulation and grid stability. Voltage deviations are becoming a major challenge in LV grids with high penetration of renewable energy sources due to intermittency and sudden generation variations, as currently experienced in Enercoop's network. The demonstrations highlighted the role of BESS as key flexibility assets to support stable grid operation under high-RES penetration scenarios.
    - **Related test cases**: ES-UC.02.01 and ES-UC.02.02.
- **End-to-end local flexibility market operation enabled by an energy community.** The pilot demonstrated an end-to-end workflow for LFMs coordinated through an energy community, combining flexibility from large community assets, such as the community battery and collective self-consumption installations, with aggregated flexibility from small-scale prosumers. This demonstration validated the interaction between forecasting, flexibility management and market mechanisms required to enable local flexibility services in real operational environments.
    - **Related test cases**: ES-UC.04.01 and ES-UC.06.01.

Overall, the Spanish pilot site successfully demonstrated the feasibility of integrating energy communities, flexibility assets, forecasting mechanisms and LFM workflows into a coordinated ecosystem capable of supporting distribution grid operation under high-RES penetration scenarios.

3.2.6 Demonstration challenges and limitations

- **Low number of flexibility assets available in the grid:** From the initial list of actionable assets in the pilot, which was already small, some of them had to be discontinued due to integration issues, while the main asset (the community battery) faced some technical problems during the demonstration period. These issues had to be covered by simulation scenarios in some of the tools and additional calculations.
- **Inexistence of congestions in the grid:** Due to the technical capacity of the grid versus the actual energy flows, real congestions in the grid were infrequent, which jeopardized the validation of some of the functionalities to be demonstrated. Again, input values had to be manually modified to assess the validity of the algorithms.
- **Local congestions in LV grids, limiting the effect of flexibility assets:** The low number of flexibility assets and their dispersion in different LV feeders made the application of solutions by these means somehow challenging. The range of actuation of the assets was limited compared to the size of the grid and the chances of the congestion happening in a point in the grid not reachable by the flexibility elements were high.
- **Complexity on defining meaningful market zones:** The definition of market zones in sMART was linked to a Postal Code, which was limiting for the functionalities of the tools. Congestions are identified per LV feeder in sGRID, which are usually all located in the same PC or across several of them. This mismatch led to a generalisation of a single market zone for the pilot, with the identification of elements guided by alternate criteria.
- **Community battery failure:** During the period of demonstration, the community battery installation suffered two main issues. First, by the end of March, the computer hosting the system that provided measurements to the STREAM tools broke down, which resulted in a gap of data of several weeks. Then, by the end of April, the battery itself broke down, which strongly affected the schedule of the demonstrations. After considering several solutions, it was possible to recover one string of the battery by the beginning of June, which allowed for some limited demonstration times, although with half the capacity of the asset and some erratic behaviour. The tests that could not be performed with the actual battery were performed with alternate calculations.
- **Scarce RT data from smart meters, having to use forecasts:** The biggest amount of data coming from Enercoop's system were from the AMI, which included metering information from 15,000 usage points. However, this information is compiled with a 24-to-48-hour delay, as its main purpose is billing. As a result, STREAM tools had to rely on "forecasted in the past" data in order to have measurements for the current ("real") time. This resulted in calculations not as accurate as initially expected, but was considered a good solution to validate the algorithms and the functionalities of the tools.

3.3 ITALIAN PILOT SITE

3.3.1 Demonstration plan

The demonstration plan for the Italian pilot site is shown in Figure 44.

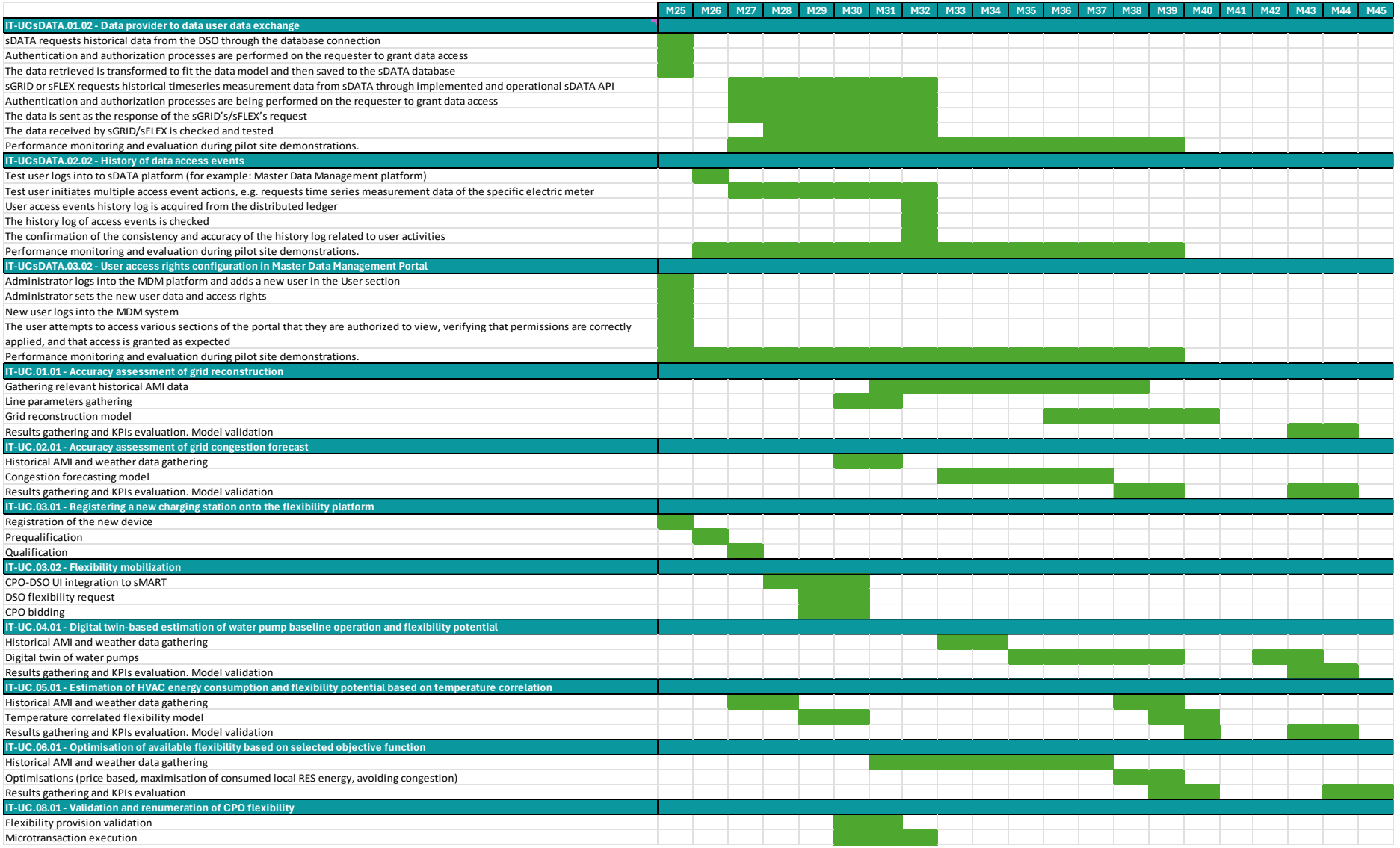


Figure 44: Italian pilot site demonstration plan

The Italian pilot site adhered to the demonstration plan without significant deviations.

3.3.2 Stakeholder engagement activities for demonstration participation and validation

Within the STREAM project, ASM Terni and EMOTION implemented a structured stakeholder engagement programme involving both internal and external stakeholders to support the development and validation of cross-sector energy flexibility solutions. Internal and external stakeholders, including operational and technical teams from the water utility, worked alongside actors such as DSOs, energy retailers, building managers, EV users, and representatives of energy communities. Through workshops, focus groups, and dedicated pilot events, these stakeholders jointly explored opportunities for flexibility across the energy and water sectors, with a specific focus on smart water pumping operations. The engagement activities enabled co-design, feasibility assessment, and real-world validation of optimized pumping strategies under operational constraints, strengthening collaboration between sectors and supporting the integration of water infrastructure into a more flexible and sustainable energy system.

Table 19: Stakeholder engagement activities of the Italian pilot site

Date	Focus	Consortium stakeholders	External stakeholders
Dec-23 (M15)	Workshop on cross-sector energy–water flexibility with diverse stakeholders to improve collaboration and optimize resource use.	ASM	building managers, and energy retailers
Jun-24 (M21)	Focus group on EV users and energy community end-users to assess needs, engagement with smart charging, and role in local energy markets.	ASM, EMOT	EV Users and the End-users of EnC
Jan-26 (M40)	Introduction of STREAM project and water pump flexibility use case, exploring cross-sector flexibility to support electricity grid operation.	ASM: water system distribution	water system distribution
Apr-26 (M43)	Stakeholder event by ASM Terni presenting STREAM project progress and the Italian pilot on energy flexibility and water-sector solutions for a more efficient and sustainable energy system.	ASM: energy and water sector	Energy communities users, citizens of Municipality of Terni
May-26 (M44)	Involvement of water sector operators in testing and validating optimized water	ASM: energy and water sector	water system distribution

	pumping flexibility solutions within the Italian pilot.		

3.3.3 Updated KPIs for demonstration

Table 20 provides a summary of the modifications of the Italian KPIs:

Table 20: Updated list of KPIs in the Italian pilot site

KPI ID	Original KPI name	Updated KPI name	Type of change	Reason for update
KPI IT.01	Reduction of congestions	-	Removed	There were no real congestion in the grid
KPI IT.03	Contribution of flexibility assets to total energy demand	Share of users with detectable HVAC flexibility	Formula updated	The share of flexible energy is time and temperature dependent and therefore hard to fairly evaluate
KPI IT.04	Self-consumption efficiency	Increase in local renewable energy self-consumption	Formula updated	New KPI monitors the improvement due to flexibility activation
KPI IT.07	Accuracy of grid reconstruction	-	New KPI	

3.3.4 Test cases results

Table 21 provides a summary of the results of the Italian test cases.

Table 21: Italian pilot site demonstration execution summary

Test case ID	Title	Status	Main results
IT-UC.01.01	Accuracy assessment of grid reconstruction	Partially passed	Implemented MV grid reconstruction service using simulation-supported data. Reconstructed an equivalent feeder impedance matrix and compared it with the reference matrix. Validation was limited by missing tap changer information and uncertain locations of some MV-connected loads.
IT-UC.02.01	Accuracy assessment of transformer loading forecast	Executed	Evaluated transformer-level loading forecast accuracy. Since no actual congestion events were observed in the historical data, the evaluation focused on forecast accuracy rather than congestion-event detection.
IT-UC.03.01	Registering a new charging station onto the flexibility platform	Executed	Successfully demonstrated registration and integration of EV charging stations into the flexibility platform. Charging station data were submitted by the CPO, verified by the DSO, and registered as asset profiles in the platform. Registered assets became visible in the platform dashboard and available for flexibility market interactions.
IT-UC.03.02	EV charging flexibility response to DSO flexibility request	Executed	Demonstrated mobilisation of EV charging flexibility through the sMART marketplace. Flexibility requests issued by the DSO were received by the CPO, bids were submitted, and charging schedules were adapted to provide flexibility during the requested time window. The test case validated the operational link between congestion identification, flexibility request, bid submission and activation.

IT-UC.04.01	Digital twin-based estimation of water pump baseline operation and flexibility potential	Executed	Developed and applied a digital twin of the water pumping station in sFLEX. The model calculated the baseline pump operation, reservoir level evolution and baseline electricity consumption profile at 15-minute resolution. It also estimated threshold-based interruption potential and shiftable energy under different reservoir level and consumption assumptions.
IT-UC.05.01	Estimation of HVAC energy consumption and flexibility potential based on temperature correlation	Executed	Analysed anonymised apartment-level smart meter data and outdoor temperature data to estimate HVAC-related consumption and flexibility potential. Aggregated temperature-dependent flexibility curves were generated as input for sENC.
IT-UC.06.01	Optimisation of available flexibility based on selected objective function	Executed	Demonstrated sENC as an aggregator-level optimisation tool using flexibility information from sFLEX and grid/PV forecasts from sGRID. Optimisation scenarios included electricity cost minimisation, local PV self-consumption maximisation and congestion-aware scheduling. In addition, a supervised real-life load-shifting activation of the water pumping station was carried out on 11 June 2026, demonstrating that pump electricity consumption can be curtailed and partially recovered later while respecting water system operation.
IT-UC.08.01	Validation and remuneration of CPO flexibility	Executed	Demonstrated the validation and remuneration workflow for EV charging flexibility. The platform associated operational charging data with flexibility activation events, generated validation reports, confirmed delivered flexibility and calculated remuneration based on the accepted bid and verified flexibility provision.
sDATA-UC.01.02	Data provider to data user data exchange in the Italian pilot site	Executed	Validation of end-to-end data exchange workflow between data provider (ASM), the sDATA platform (IND), and data users (sGRID, sFLEX), confirming correct ingestion, transformation, and provision of data through standardized APIs.

			Demonstration of high system reliability and robustness, achieving a 99.3% API success rate and stable performance under high-frequency requests, with correct handling of authentication, timeout, and data quality exceptions. Confirmation of strong interoperability and data integrity across heterogeneous systems, establishing sDATA as a reliable central data hub supporting downstream applications such as sGRID forecasting and sFLEX operations.
sDATA-UC.02.02	History of data access events in the Italian pilot site	Executed	Validation of distributed ledger-based logging mechanism for capturing and storing all user actions on the sDATA platform in a secure and immutable manner. Confirmation of full traceability and data integrity of user activity logs, with a 100% match between executed actions and recorded events, including correct timestamps and action types. Demonstration of system robustness and non-intrusiveness of the logging architecture, ensuring near real-time event recording and efficient log retrieval without impacting platform performance.
sDATA-UC.03.02	User access rights configuration in Master Data Management Portal in the Italian pilot site	Executed	Validation of end-to-end user management workflow in the MDM portal, including user creation, role assignment, and access rights configuration by the administrator (ASM). Confirmation of correct enforcement of access control policies, with accurate distinction between Viewer and Editor permissions and immediate restriction of unauthorized actions. Demonstration of system robustness and security compliance, including prevention of duplicate users, blocked unauthorized access attempts, and enforcement of session-based permission updates.

While initially eleven use cases were defined in D2.2 [1] for the pilot site, one use case was finally descoped, as explained below:

- **UC IT.07 "Energy community management and flexibility service provisioning coordination":** UC IT.07 was descoped as a standalone use case because the pilot evolved from a P2P community marketplace concept towards a DSO-driven LFM for congestion management, with the relevant market interaction covered by UC IT.03 and the flexibility coordination/optimisation functions covered by UC IT.06.

3.3.5 Key innovations of the Italian pilot site

Beyond the execution of individual test cases, the Italian pilot enabled the validation of several innovative concepts related to cross-sector flexibility, digital twin-based scheduling and marketplace-based coordination of flexibility providers. From these demonstrations, the pilot site validated several important innovations within the STREAM ecosystem:

- **Cross-sector flexibility from water infrastructure**

The Italian pilot demonstrated that a water pumping station can serve as a relevant flexibility asset for the electricity grid. Although the pumping station is not a flexible asset in the conventional electricity market sense, its electricity consumption can be shifted in time by using the water reservoir as operational storage. The sFLEX digital twin calculated the baseline pump operation and quantified the technical interruption potential, while sENC used this baseline to generate feasible day-ahead schedules. This validated the use of water infrastructure as a cross-sector flexibility resource, linking electricity system operation with water system constraints.

  - **Related test cases**: IT-UC.04.01 and IT-UC.06.01.

- **Day-ahead optimisation of controllable flexibility assets under physical constraints**

The pilot demonstrated that the operation of water pumps can be optimised according to different objective functions while respecting reservoir limits, water demand and discrete pump operation. The same flexible asset was used to support different operational objectives: minimising electricity cost, increasing local renewable self-consumption and mitigating forecasted congestion. This confirms the relevance of sENC as an aggregator-level optimisation tool capable of converting flexibility potential into feasible operational schedules.

  - **Related test case**: IT-UC.06.01.

- **Aggregation of less deterministic residential flexibility**

Residential HVAC flexibility was estimated from anonymised smart meter data and outdoor temperature correlation. The pilot showed that HVAC-related flexibility cannot be treated as a uniform portfolio because apartments exhibit different temperature-sensitive behaviour. The analysis identified heating-related, cooling-related and combined profiles and aggregated the resulting flexibility into temperature-dependent curves. These outputs provide sENC with an operational flexibility envelope, while recognising that actual activation depends on end-user behaviour and comfort constraints.

  - **Related test case**: IT-UC.05.01.

- **Marketplace-based coordination of EV charging flexibility**

The Italian pilot demonstrated the registration of EV charging stations in the flexibility platform, the submission and activation of flexibility bids, and the validation and remuneration of delivered flexibility. This validated the role of sMART as the coordination layer between the DSO and external flexibility providers such as the CPO. The demonstrated workflow covered the full process

from asset registration to flexibility activation, operational monitoring, validation and remuneration.

- **Related test cases**: IT-UC.03.01, IT-UC.03.02 and IT-UC.08.01.

Overall, the Italian pilot site demonstrated the feasibility of coordinating grid monitoring, flexibility estimation, optimisation and marketplace-based activation within a cross-sector environment. The most relevant contribution of the pilot is the demonstration of how water infrastructure, residential HVAC flexibility and EV charging infrastructure can be represented, assessed and coordinated through the STREAM ecosystem to support distribution grid operation and future flexibility market participation.

3.3.6 Demonstration challenges and limitations

- **Absence of real congestion events in the pilot grid**
  No actual congestion events were observed in the historical or demonstration-period data used for the Italian pilot. Consequently, validation of the congestion forecasting workflow focused primarily on transformer loading forecast accuracy rather than on detecting real congestion events. For the congestion-aware optimisation scenario, input conditions had to be adapted or simulated to demonstrate the behaviour of the algorithm.
- **Limited renewable generation and need for simulated future scenarios**
  The current level of local renewable generation in the pilot area was insufficient to cause reverse power flows or voltage-related operational issues. Consequently, scenarios related to local PV self-consumption maximisation required assumptions of higher renewable penetration or modified grid conditions. While these scenarios were useful for demonstrating the technical capabilities of sENC and the wider STREAM ecosystem, they should be interpreted as forward-looking validation cases rather than direct evidence of recurring operational conditions in the current grid.
- **Grid model and measurement data limitations**
  The accuracy assessment of grid reconstruction was affected by limitations in the available grid and measurement data. In particular, missing tap changer information and uncertainty regarding the exact location of some MV-connected loads limited validation of the reconstructed equivalent feeder impedance matrix.

3.4 FINNISH PILOT SITE

3.4.1 Demonstration plan

Figure 45 shows the demonstration plan of the Finnish pilot.

	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36	M37	M38	M39	M40	M41	M42	M43	M44	M45
FI-UC.01.01 FCR-D: Using apartments' explicit flexibility for FCR-D ancillary services																					
FCR-D-up first demo																					
FCR-D-up: full simulated load																					
FCR-D-up: multiple flex groups for linear response (load normalization)																					
FCR-D-up: abnormal cases																					
FCR-D-up: interaction with spot price control																					
FCR-D-up: usage of real heating assets																					
FCR-D-down																					
Connection-to-Fingrid																					
Usage assets visibility to the customer																					
FI-UC.01.02 FCR-D-multiple-activations																					
FCR-D-up first demo																					
FCR-D-up: full simulated load																					
FCR-D-up: multiple flex groups for linear response (load normalization)																					
FCR-D-up: abnormal cases																					
FCR-D-up: interaction with spot price control																					
FCR-D-up: usage of real heating assets																					
FCR-D-down																					
Connection-to-Fingrid																					
Usage assets visibility to the customer																					
Fingrid acceptance test cases																					
FI-UC.01-06 Simulated frequency																					
FI-UC.01-07 Measured frequency																					
FI-UC.01-08 Sine response																					
FI-UC.01-09 Linearity																					
FI-UC.01-10 Fast ramp																					
FI-UC.01.05 FCR-multiple-simultaneous-bids																					
Multiple simultaneous bids																					
FI-UC.05.01 Cust-flex-profitability: Evaluating the profitability for the customer when using explicit flexibility																					
FCR-D																					
FCR-D up and FCR-D-down																					
FI-UC.02.01 Room-level-flexibility-basic: minimizing customer discomfort																					
FCR-D																					
FI-UC.02.02 Room-level-flexibility-time-range-disabled: minimizing customer discomfort																					
FCR-D																					
FI-UC.02.03 Room-level-flexibility-temp-limit-reached: minimizing customer discomfort																					
FCR-D																					
FI-UC.02.04 Occupancy-info (maximizing usage of flexibility)																					
FCR-D																					

Figure 45: Demonstration plan of the Finnish Pilot

Table 22 provides an overview of the main delays on the execution of the test cases when compared to the plan:

Table 22: Finnish demonstration plan deviations

Test case ID	Expected execution date	Final execution date	Reason
FI-UC.01.01 FCR-D Using apartments' explicit flexibility for FCR-D ancillary services (simulated manual frequency changes to test the functionality)	May 2026	June 2026	It was decided to finalize the testing of the functional cases with the corrected version of the SW which was created during the testing of FI-UC.01.02.
FI-UC.01.02 FCR-D-multiple-activations (freq. sampling at 10Hz)	May 2026	June 2026	Completing the testing required changes in the SW architecture and the creation of new debugging tools.
FI-UC.05.01 Cust-flex-profitability: Evaluating the profitability for the customer when using explicit flexibility	September 2025	May 2026	This test case needed completion of at least part of FI-UC.01.02
FI-UC.02.01/02/03/04 Room-level-flexibility-	May 2026	-	Related to the descoped use case UC FI.02
FI-UC.01-06/07/08/09/10 Fingrid acceptance test cases	October 2025	-	Descoped since part of the commercial version of the feature, as reported in the deployment plan deviations

3.4.2 Stakeholder engagement activities for demonstration participation and validation

Table 23 contains a summary of the engagement activities with different stakeholders. There have been regular **on-line meetings with the pilot customers** in order to keep them engaged, to update them about the status of the project and in order to receive their feedback. There have been ten such meetings altogether.

There has been a good **communication channel with the TSO** which has been kicked off in an online meeting in spring 2024. This channel has helped reviewing the implementation specification of sFLEX as well as the details about the off-line log reports to the TSO. The TSO has also provided very useful statistical data which has greatly helped in planning the features and to make early calculations about profitability and about the potential environmental impact.

Also, the FlexFinland task force has been joined, and this has helped to interact with other players which are active in the flexibility market outside the STREAM project. The main scope of the task force is to put together DSOs and other players interested in the flexibility market, such as aggregators, in order to **push opening the flexibility market in Finland** since currently this market is heavily dominated by the TSO.

Table 23: Stakeholder engagement activities of the Finnish pilot site

Date	Focus	Consortium stakeholders	External stakeholders
05/03/2024	**First meeting with the residential pilot customer**: introducing them to the demand-response functionality	OptiWatti, VTT	Pilot customers
22/03/2024	**Kick off of the technical cooperation with Fingrid, the Finnish TSO**. Technical discussion to agree about the asset types, accuracy of the flexible power estimation, details about Fingrid specifications	OptiWatti, VTT	Fingrid (Finnish TSO)
07/05/2024	Update the pilot customers about the project status and receive feedback: **interactive feedback** by using Miro board	OptiWatti, VTT	Pilot customers
20/08/2024	Getting customer permission to use their data, agreeing on detailed cottages to use, discussing about HW installation scheduled. **Customer feedback**: concern about the additional noise of the relays	OptiWatti, VTT	Aurora Village pilot customer
02/09/2024	Update the pilot customers about the project status and keep them engaged. Explain the principles of flexibility and piloting. **Customer feedback:** need of a method to inform that flexibility is active	OptiWatti, VTT	Pilot customers
09/12/2024	Update the pilot customers about the project status and keep them engaged. Customer	OptiWatti, VTT	Pilot customers

	feedback: **new customer request** about asset usage info in UI		
10/03/2025	Update the **pilot customers** about the project status and keep them engaged	OptiWatti, VTT	Pilot customers
05/06/2025	Update the **pilot customers** about the project status and **keep them engaged.** The main detailed use case with message sequence chart and datasets shown, **sFLEX video** shown	OptiWatti, VTT	Pilot customers
13/08/2025	Demand-response seminar by FlexFinland, a Think Tank whose scope is to **promote demand-response in Finland** by putting together difference stakeholders in order to help to **open the market**. Interesting feedback was received from participants of the BungEES EU project.	OptiWatti, VTT	Voltalis, Lähienergialiitto, Ouman Oy
30/10/2025	**Update the pilot customers** about the project status and keep them engaged. **sDATA video** demo shown	OptiWatti, VTT	Pilot customers
05/03/2026	Prepare testing with pilot customers assets. Demonstrate UI features enabled by the new SW version.	OptiWatti, VTT	Pilot customers
29/04/2026	**Getting feedback about usage of real heating assets for demand-response.**	OptiWatti, VTT	Pilot customers

3.4.3 Updated KPIs for demonstration

Table 24 provides a table with a summary of the modifications of the Finnish KPIs.

Table 24: Updated list of KPIs in the Finnish pilot site

KPI ID	Original KPI name	Updated KPI name	Type of change	Reason for update
KPI FI.01	Activation success rate	FCR activation speed	Scope updated	Making a simple ratio between successful and total number of FCR activation requests does not provide any useful information related to the efficiency of the demand-response functionality since the system is designed with a certain redundancy which allows to use other load when part of the load is not responding. On the other hand, the FCR activation speed is one of the most challenging requirements for the aggregator.

KPI FI.02	Flexibility estimation reliability	Flexibility estimation accuracy	Definition refined	The KPI name has been corrected.
KPI FI.03	Additional flexibility gained	Customized flexibility variations	Definition refined > Removed	The user settings do not add flexibility but rather decrease the available flexible load. Later descoped since the related use case (UC_FI.02) has been descoped.
KPI FI.04	Answer rate percentage	Customer answer rate	Definition refined	The KPI name has been modified.
KPI FI.05	-	Bid acceptance rate	New KPI	This is a very important KPI since it has a direct impact onto the profit of the aggregator.
KPI FI.06	-	Customer satisfaction	New KPI	It is a critical KPI, to be able to conclude how well the functionality is accepted by the customers.

3.4.4 Test cases results

Table 25 summarizes the test cases that were executed to validate the STREAM ecosystem in the Finnish pilot site and their key results.

Table 25: Finnish pilot site demonstration execution summary

Test case ID	Title	Status	Main results
FI-UC.01.01	FCR-D: Using apartments' explicit flexibility for FCR-D ancillary services	Executed	Validation of end-to-end FCR-D-up and FCR-D-down flexibility workflows, including flexibility estimation, bid creation, simulated TSO interaction, and market acceptance via Flex Manager, Flex Server, and TSO Connector. Demonstration of frequency-based activation and deactivation of flexibility resources, confirming correct system response to simulated grid frequency deviations for both upward and downward regulation services. Validation of scalability and control performance using both large-scale simulated loads (up to ~1 MW, FCR-D-up) and limited real-load pilot assets, including measurable linear response and activation granularity constraints. Confirmation of correct handling of full flexibility lifecycle, including bid generation, reserve allocation, real-time activation, logging (FCR logs), and exception path execution under multiple failure scenarios.
FI-UC.01.02	FCR-D-multiple-activations	Executed	Validation of end-to-end FCR-D-up and FCR-D-down flexibility workflows, including flexibility estimation, bid creation, simulated TSO interaction, and bid acceptance through Flex Simulator, Flex Manager, Flex Server, and TSO Connector, using both simulated and real-load pilot configurations. Demonstration of correct frequency-based activation and deactivation of flexibility resources for both upward and downward regulation, confirming that the system responds proportionally and within seconds to simulated grid frequency deviations, including full and partial activation states. Frequency data from Fingrid database sampled at 10Hz has been used. This has allowed to test how the system responds in a real environment to continuous changing frequency. Validation of technical performance and KPI compliance under both large-scale simulated conditions (up to ~1 MW aggregated flexibility) and limited real-load pilot deployments,

			including correct activation timing behaviour, observable linear control response, and practical constraints due to actuator granularity in small-scale heating assets.
FI-UC.05.01	Cust-flex-profitability: Evaluating the profitability for the customer when using explicit flexibility	Executed	Preliminary estimation of the economic impact of using residential heating assets for FCR-D services based on long-term TSO statistical frequency deviation data (2019–2024), including analysis of frequency excursions and derivation of annual activation time in both upward and downward directions. Calculation of customer-level profit/loss impacts using both statistical models and measured pilot data, combining appliance configurations, real consumption profiles, electricity tariffs, and 10-minute resolution flexibility activation data to estimate annual financial effects per household. Cross-validation of results between statistical-based and measurement-based approaches, confirming consistent order-of-magnitude results (5–12 € annual impact per apartment), with minor deviations explained by differences in installed capacity, test sample size, and variability in frequency deviation occurrence during the pilot period.

While initially four use cases were defined in D2.2 [1] for the pilot site, two use cases were finally descoped, as explained below:

- **UC FI.02 "Maximizing flexibility":** After feedback from pilot customers and after research done based on statistical data from Fingrid, this use case evolved into room-level customer settings based on time ranges. The use case could not be demonstrated due to unavailability from the sub-contractor to do the necessary changes to the customer UI in time. The subcontractor is not a big company and the person who was taking care of OW UI has changed job. Also, in the last couple of years OW has focused on core STREAM functionality and has not made regular orders to the subcontractor. This has weakened OW contractual position with the subcontractor.
- **UC FI.03 "Defining the building potential":** Priorization has been needed due to the time it has taken to have a working version of sFLEX SW which reacts properly and quickly enough to frequent grid frequency changes. Therefore, this lower priority use case has been descoped.
- **UC FI.04 "User experience when using flexibility":** The use case has not been implemented as originally defined since the functionality to trigger periodically a request for feedback through the customer interface has been considered not relevant for the prototype but more useful for the commercial version of the feature. Nevertheless, user feedback has been gathered through other channels such as periodical calls with pilot customers and written questionnaires. This has enabled the calculation of KPIs FI.04 and FI.06.

3.4.5 Key innovations of the Finnish pilot site

Thanks to these demonstrations, the Finnish pilot site has been able to go beyond the state of the art on demand-side flexibility utilization in FCR-D as follows:

- **Normalized load for FCR-D linear response:** ENTSOE and Fingrid standards require that the reserved flexible capacity is activated proportionally to the actual frequency deviation. The frequency range of each of the two the FCR-D services is 0.4 Hz. If the grid frequency deviates, let's say, 0.2 Hz from the standard frequency range, then only half of the reserved flexible capacity shall be activated. Frequency changes continuously and the activated flexible power shall change linearly with the actual frequency deviation. However, standards do not mention how this shall be done in practice. An aggregator has to manage a certain number of heating assets having each a nominal power and a defined response time at activation. Pilot partners are planning to fill a patent: "Normalized load for FCR-D linear response" which describes the selected solution. This is about grouping the available flexible load into chunks which behave in the same way from power and response time point of view. No further details can be provided in this document.
    - **Related test cases:** FI-UC.01.02
- **Evaluating the profitability for the customer when using explicit flexibility:** One of the hottest topics related to the usage of customers' heating assets for flexibility is the so-called customer compensation. The assumption is that, since heating assets in customers' apartments are used to stabilize the transmission grid frequency, the customer shall be compensated in a monetary form. The rationale of this compensation is possible customer annoyances due to temperature deviations in the rooms or extra costs in customers' bills due to the additional time those heating assets are connected. Also, it is well known that the

aggregators receive a certain monetary compensation from the TSO for providing FCR-D_ services. In here the possibility of not providing any monetary customer compensation is explored. The idea comes after obtaining results from both calculations based on statistical data provided by the TSO and on measurements done during the tests with real load. Such results have shown negligible differences in temperature deviations and extremely small extra costs for the customers due to the usage of the assets for flexibility. Hence the idea of compensating the customers through non-monetary means, such as for example, more accurate data in the customer interface. The fact that this solution rises always animated discussion in different forums indicates that it is probably not that obvious.

- **Related test cases:** FI-UC.05.01

3.4.6 Demonstration challenges and limitations

Challenges

- One of the risks identified in the early phases of the project was the difficulty to comply with the tights FCR activation requirements in terms of activation time. sFLEX needs the capability to react to quick grid frequency changes in all possible cases of frequency deviations. This has required partial redesign of the original SW which has caused the need to prioritize the content of the prototype to be demonstrated.

Limitations

- The scope of the pilot is limited to a **prototype**. The interface with the TSO is not yet fully tested. The high availability requirements set by the TSO are not yet fully met. The bid process is not yet automatized. Monitoring features like additional alarms are not yet implemented.
- Tests with real load are limited to the pilot customers which offer **a limited amount of real flexible load**. This amount of load is not enough to test certain pieces of functionality like, for example, the linear response of the amount of activated flexible power with the grid frequency deviation. Such functionality has been tested by using simulated load and an amount of power that is at least equal to the minimum flexible power required by the TSO for a single bid (1MW).

4 DATA GATHERING FROM STREAM PILOT SITES

4.1 SLOVENIAN PILOT SITE

Table 26 presents an overview of the datasets (DS) collected in the Slovenian pilot site. The detailed documentation of the data gathered in the pilot site can be found in Annex C (Section 9.1).

Table 26: Slovenian pilot site datasets summary

Dataset ID	Dataset name	Data provider	Type of dataset	Collection status	Related UCs	Public/confidential
DS SI.01	Historical timeseries measurement data (P & Q)	EPR	Operational	Integrated	SI.01, SI.05	Confidential
DS SI.02	Grid topology data (CIM or GIS)	EPR	Operational	Integrated	SI.01, SI.05	Confidential
DS SI.03	Timeseries measurement data (AMI)	EPR	Operational	Integrated	SI.05	Confidential
DS SI.04	Timeseries measurement data (SCADA)	EPR	Operational	Integrated	SI.05	Confidential
DS SI.05	Weather data (solar irradiation, temperature, etc.)	External source	Operational	Integrated	SI.01, SI.05	Public
DS SI.06	Grid limits	EPR+UL	Demonstration	Calculated	SI.05	Confidential
DS SI.07	Congestion forecast results (TLS status)	UL through sGRID	Demonstration	Calculated	SI.05	Confidential
DS SI.08	Flexibility sources measurements	EVs, industries	Operational	Integrated	SI.02, SI.06	Confidential

DS SI.09	EV charging station (CS) measurements	AVA CSs	Operational	Integrated	SI.02, SI.06	Confidential
DS SI.10	Device registration information	FDO/Aggregators	Operational	Integrated	SI.07	Confidential
DS SI.11	Device measurement data for prequalification	Flexibility sources	Operational	Integrated	SI.08	Confidential
DS SI.sDATA.01	Distributed ledger history data	All pilot partners	Operational	Integrated	SI_sDATA-UC.02	Confidential
DS SI.sDATA.02	Master data	All pilot partners	Operational	Integrated	SI_sDATA-UC.03	Confidential

4.2 SPANISH PILOT SITE

Table 27 presents an overview of the datasets collected in the Spanish pilot site. Operational data required to run the pilot tools is provided by ENER, acting as DSO and energy community manager. Data generated from the demonstration activities is provided by ETRA, covering grid, aggregation and prosumer analytics, and by OMIE, which provides the results of the market sessions. The detailed documentation of the data gathered in the pilot site can be found in Annex C (Section 9.2).

Table 27: Spanish pilot site datasets summary

Dataset ID	Dataset name	Data provider	Type of dataset	Collection status	Related UCs	Public/confidential
DS ES.01	LV and MV grid topology	ENER	Operational	Integrated	ES.01, ES.02, ES.04	Confidential
DS ES.02	Active and reactive power value at grid lines	ENER	Operational	Integrated	ES.01, ES.04	Confidential
DS ES.03	Voltage and angle of busbars	ENER	Operational	Integrated	ES.02	Confidential
DS ES.04	Active and reactive power of PV +	ENER	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04,	Public

	community battery installation				ES_UC.06, ES_UC.07	
DS ES.05	Community battery SOC	ENER	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.06, ES_UC.07	Public
DS ES.06	Prosumer's consumption and generation	ENER	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.06, ES_UC.07	Confidential
DS ES.07	Generation from EnC collective self-consumption installations	ENER	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.06, ES_UC.07	Confidential
DS ES.08	Domestic batteries SOC	ENER	Operational	Integrated	ES_UC.04, ES_UC.06, ES_UC.07	Confidential
DS ES.09	Active energy of EV chargers	ENER	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.06, ES_UC.07	Confidential
DS ES.10	Weather data	External source	Operational	Integrated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.06, ES_UC.07	Public
DS ES.11	Prosumer's energy tariffs	ENER	Operational	Integrated	ES_UC.04, ES_UC.06, ES_UC.07	Public
DS ES.12	Demand and production forecasts at grid level	ETRA	Demonstration	Calculated	ES_UC.01, ES_UC.02, ES_UC.04	Confidential
DS ES.13	Power flows forecasts	ETRA	Demonstration	Calculated	ES_UC.01, ES_UC.02, ES_UC.04	Confidential

DS ES.14	Congestion forecast	ETRA	Demonstration	Calculated	ES_UC.01, ES_UC.04	Confidential
DS ES.15	Voltage deviations forecast	ETRA	Demonstration	Calculated	ES_UC.02	Confidential
DS ES.16	Flexibility bids, asks and requests	ETRA	Demonstration	Calculated	ES_UC.04, ES_UC.05, ES_UC.06	Confidential
DS ES.17	Flexibility market results	OMIE	Demonstration	Calculated	ES_UC.04, ES_UC.05, ES_UC.06	Confidential
DS ES.18	Community battery setpoint	ETRA	Demonstration	Calculated	ES_UC.01, ES_UC.02, ES_UC.04, ES_UC.07	Public
DS ES.19	Consumption, generation and flexibility forecasts	ETRA	Demonstration	Calculated	ES_UC.04, ES_UC.05, ES_UC.06, ES_UC.07	Restricted (only for the hybrid PV+BESS installation)
DS ES.20	Flexibility delivery compliance	ETRA	Demonstration	Calculated	ES_UC.04, ES_UC.05, ES_UC.06	Confidential
DS ES.21	Self-consumption allocation coefficients	ENER	Operational	Integrated	ES_UC.06	Confidential

4.3 ITALIAN PILOT SITE

Table 28 presents an overview of the datasets collected in the Italian pilot site. Operational data is primarily provided by ASM and includes grid topology information, transformer measurements, water pumping system data, smart meter consumption profiles, and PV production data. Additional weather information is obtained from public sources. Demonstration datasets generated within the project include the grid impedance matrix, congestion forecast results, HVAC flexibility estimations, and optimized water pump schedules. EV charging station and vehicle-related data is provided by EMOT to support the EV flexibility use cases. These datasets have been integrated into the corresponding STREAM tools and used during the execution and validation of the Italian pilot demonstrations.

Table 28: Italian pilot site datasets summary

Dataset ID	Dataset name	Data provider	Type of dataset	Collection status	Related UCs	Public/confidential
DS IT.01	MV GIS grid model	ASM	Operational	Integrated	IT.01	Confidential
DS IT.02	Grid impedance matrix	COMS	Demonstration	Calculated	IT.01	Confidential
DS IT.03	Power and voltage values at MV/LV transformers	ASM	Operational	Integrated	IT.01, IT.02	Confidential
DS IT.04	Weather data (solar irradiation, temperature, etc.)	External source (open meteo)	Operational	Integrated	UC.IT.02	Public
DS IT.05	Loading forecast results	COMS	Demonstration	Integrated	UC.IT.03, UC.IT.06	Confidential
DS IT.06	Water pumps data	ASM	Operational	Integrated	UC.IT.04, UC.IT.06	Confidential
DS IT.07	Schedule for water pump operation	COMS	Demonstration	Calculated	UC.IT.06	Public
DS IT.08	Power values of end-user	ASM	Operational	Integrated	UC.IT.05	Confidential
DS IT.09	HVAC flexibility	COMS	Operational	Calculated	UC.IT.05	Confidential
DS IT.10	Production of PV power plants on LV	ASM	Operational	Integrated	UC.IT.02, UC.IT.06	Confidential
DS IT.11	Voltages, power and charging	EMOT	Operational	Integrated	UC. IT.03, UC.IT.08	Confidential

	station plug status					
DS IT.12	SOC, odometer	EMOT	Operational	Integrated	UC. IT.03, UC.IT.08	Confidential
DS IT.sDATA.01	Distributed ledger history data	All pilot partners	Operational	Integrated	SI_sDATA-UC.02	Confidential
DS IT.sDATA.02	Master data	All pilot partners	Operational	Integrated	SI_sDATA-UC.03	Confidential

4.4 FINNISH PILOT SITE

The data-sets structure that has been defined originally has been simplified since, when the project has got into a more mature state, it was realized that some of the data sets were contained in other data sets that were already defined.

Also, a couple of data sets are no longer relevant since they are related to functionality that has been dropped from the content of the Finnish pilot.

The original data set labelling has used the syntax FIxx_yy where xx refers to the related use case and yy is sequential number within a single use case.

The main datasets used in the Finnish pilot are contained in the following table:

Table 29: Finnish pilot site datasets summary

Dataset ID	Dataset name	Data provider	Type of dataset	Collection status	Related UCs	Public/confidential
DS FI.01	Configuration data	OPT	Operational	Integrated	UC_FI.01	Confidential
DS FI.02	Periodic measurements	OPT	Operational	Integrated	UC_FI.01	Confidential
DS FI.03	Energy spot prices	Nordpool	Operational	Integrated	UC_FI.01	Confidential
DS FI.04	Power consumption	OPT	Operational	Integrated	UC_FI.01	Confidential
DS FI.06	Baseline flex power forecast output	OPT	Demonstration	Calculated	UC_FI.01	Confidential
DS FI.09	FCR group bid (1 hour granularity)	OPT	Demonstration	Calculated	UC_FI.01	Restricted

DS FI.11	FCR log	OPT	Demonstration	Calculated	UC_FI.01	Restricted
DS FI.12	FCR bid acceptance rate (KPI)	OPT	KPI	Calculated	UC_FI.05	Restricted
DS FI.13	Flexibility estimation accuracy (KPI)	OPT	KPI	To be calculated	UC_FI.01	Restricted
DS FI.14	FCR activation speed (KPI)	OPT	KPI	To be calculated	UC_FI.01	Restricted
DS FI.16	Customer profitability output	OPT	Demonstration	Calculated	UC_FI.05	Restricted
DS FI.20	Temperature variations' calculations results	OPT or VTT	Demonstration	Calculated	UC_FI.01	Confidential
DS FI.21	Customer feedback	OPT	Demonstration, KPI	To be calculated	UC_FI.04	Restricted
DS FI.22	Customer answer rate percentage (KPI)	OPT	KPI	To be calculated	UC_FI.04	Restricted

Figure 46 shows the datasets and their role in FCR-D. Configuration data, periodic measurements including power consumption measurements and energy spot prices are used as input data to calculate the baseline flexible power. The result is the baseline flexible power output. The results of such simulations are used as input for the calculation of the available flexible power by using a certain scaling factor. The result, together with the price for each hour for each service, is the input for the bid creation.

Once the bids are accepted from the TSO, the FCR group bid and the FCR Bid acceptance rate are available. Once frequency monitoring starts, FCR Logs are produced and periodic measurements are updated with the used flexible power aggregate information. Finally, the technical KPIs are calculated. Social end economical KPIs are not included in the figure.

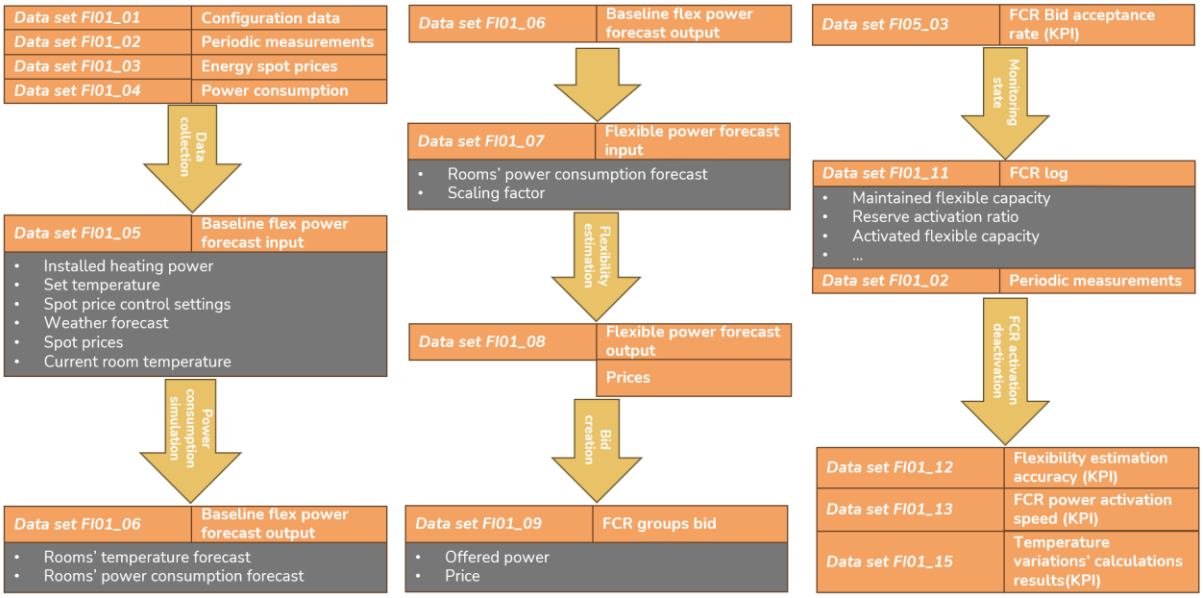


Figure 46: Datasets and their role in the Finnish Pilot

5 CONCLUSIONS

The STREAM ecosystem has been successfully deployed and demonstrated across the four pilot sites. Although each pilot site follows a different approach, they have been complementary in demonstrating different scopes on how flexibility assets connected to the LV grid can support the energy system at different levels, ranging from LFMs providing congestion management services to DSOs to the provision of ancillary services to TSOs.

The four pilot sites have deployed their respective toolsets to demonstrate the use cases defined in WP2. A large number of test cases have been executed, ranging from the validation of individual functionalities and model accuracy to end-to-end demonstrations involving the different components of the STREAM ecosystem operating together in realistic conditions. These demonstrations have shown how the effective orchestration of DSO planning and operation tools, FSP solutions and LFM platforms can leverage flexibility services in operational contexts. The challenges encountered during the demonstrations, together with the large volume of datasets collected, have also highlighted the importance of data quality and availability for ensuring accurate modelling and reliable operation. In addition, given the active role of end users in flexibility markets, significant efforts were made to maintain user engagement throughout the project, enabling demonstrations under real operating conditions and the execution of real flexibility activations whenever possible.

The impact evaluation, scalability, and replicability aspects will be further detailed in D6.1, D6.2 and D6.3, while exploitation and market uptake considerations will be consolidated in D7.4. Overall, the results presented in this deliverable provide a solid validation of the STREAM approach and establish a strong foundation for future large-scale and operational deployments of flexibility services.

6 REFERENCES AND ACRONYMS

6.1 REFERENCES

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6.2 ACRONYMS

Acronyms list	
A	Ampere
AC	Alternating Current
aFRR	Automatic Frequency Restoration Reserve
AMI	Advanced Monitoring Infrastructure
API	Application Programming Interface
BESS	Battery Energy Storage System
BEMS	Building Energy Management System
CHP	Combined Heat and Power
CMOL	Common Merit Order List
CPO	Charging Point Operator
D	Deliverable
DA	Day-Ahead
DER	Distributed Energy Resource

DLT	Distributed Ledger Technology
DR	Device Registry
DS	Dataset
DSO	Distribution System Operator
EMS	Energy Management System
EnC	Energy Community
EnCM	Energy Community Manager
EV	Electric Vehicle
FCR-D	Frequency Containment Reserve for Disturbances
FSP	Flexibility Service Provider
GHI	Global Horizontal Irradiance
GIS	Geographical Information Sytem
GUI	Graphical User Interface
HP	Heat Pump
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
IP	Internet Protocol
ISP	Imbalance Settlement Period
KV	Kilovolt
KPI	Key Performance Indicator
LFM	Local Flexibility Market
LOI	Letter Of Intent
LV	Low Voltage
MDM	Master Data Management
M	Month

mFRR	Manual Frequency Restoration Reserve
MO	Market Operator
MV	Medium Voltage
MW	Megawatt
NaN	Not a Number
P2P	Peer-to-Peer
PLC	Power Line Communication
PV	Photovoltaic
RES	Renewable Energy Source
RT	Real-Time
SCADA	Supervisory Control And Data Acquisition
SOA	State Of the Art
ST	Short-Term
TC	Test Case
TCP	Transmission Control Protocol
TLS	Traffic Light System
TSO	Transmission System Operator
UC	Use Case
V	Voltage
WP	Work Package

7 ANNEX A — UPDATED SET OF STREAM KPIS

7.1 SLOVENIAN PILOT SITE

KPI ID	KPI SI.01
KPI name	Data collection reliability
Description	This KPI calculates the percentage of reliable data received from measurement devices across the four data sources used in the Slovenian pilot: (a) smart meter data, (b) control measurements from transformer stations, (c) SCADA measurements, and (d) flexibility asset measurements collected via sFLEX. The KPI is calculated separately for each data source as an aggregate value. For smart meter data, the range of per-meter reliability is additionally reported to capture variability across individual channels.
Unit of measurement	%
Related Use Cases	SI.02, SI.04, SI.05, SI.06, SI.08
Related STREAM Tools	sFLEX, sGRID, sMART
Formula	$$D_{ata}R_{eliability} = \frac{N_{successful}}{N_{total}} \times 100$$ Or in case of multiple devices (example smart meters), $$D_{ata}R_{eliability} = \frac{N_{successful}}{N_{total} \times n} \times 100$$
Variable explanation	$N_{successful}$ is the total count of data transmissions successfully received without errors or loss within the defined time period (e.g., a day). N_{total} is the anticipated total number of data transmissions during the same specified time period. n is the number of measured assets or units.
Comments	Reported as four sub-KPIs (SI.01a: smart meters, SI.01b: transformer station control measurements, SI.01c: SCADA, SI.01d: flexibility asset measurements via sFLEX).

KPI ID	KPI SI.02
KPI name	STREAM tools communication reliability
Description	This KPI assesses the reliability of data exchange between the STREAM tools deployed in the Slovenian pilot. Given that the pilot operates in demonstration mode rather than continuous automated operation, this KPI is evaluated based on the integration tests and demonstration runs conducted during the pilot period. For each tool-to-tool connection, the KPI reports

	whether the communication was successfully established and whether all test exchanges completed without errors. The assessed connections include: sDATA ↔ sGRID (measurement data provisioning), sDATA ↔ sFLEX (asset and EV charging data), sDATA ↔ sMART/Device Registry (asset metadata), sGRID → sMART (congestion messages), and sFLEX → sMART (flexibility bids).
Unit of measurement	% (per connection, based on test runs)
Related Use Cases	SI.02, SI.05, SI.06, SI.08
Related STREAM Tools	sFLEX, sGRID, sMART, sDATA
Formula	$$C_{ommunication}R_{eliability} = \frac{N_{successful}}{N_{total}} \times 100$$
Variable explanation	$N_{successful}$ is the total count of exchanges successfully completed without errors or loss within the defined time period (e.g., a day). N_{total} is the anticipated total number of data exchanges during the same specified time period.
Comments	Evaluated per tool-to-tool connection across the demonstration sessions conducted during the pilot. The number of test runs per connection is reported alongside the result.

KPI ID	**KPI SI.03**
KPI name	Grid investment savings ratio (GISR) due to the flexibility utilization
Description	This KPI calculates the cost savings achieved by the Distribution System Operator (DSO) through the utilization of demand side flexibility instead of conventional grid reinforcements. It represents the ratio of savings realized through demand side flexibility to the total investment required for grid reinforcements, expressed as a percentage.
Unit of measurement	%
Related Use Cases	SI.01
Related STREAM Tools	sPLAN
Formula	$$GISR = \frac{C_{reinf} - C_{flex}}{C_{reinf}} \times 100$$
Variable explanation	C_{reinf} are the total costs for the demand side flexibility in a defined time interval (example 1 year).

	C_{flex} are the total costs needed for a grid reinforcement in a defined time interval (example 1 year).
Comments	

KPI ID	**KPI SI.04**
KPI name	Load and generation forecast accuracy
Description	This KPI calculates the accuracy of the load and generation (active power) forecasts produced by the sGRID tool. It covers forecasts for individual loads (consumption, generation, and prosumer profiles) as well as directly forecasted aggregated loads at the transformer station level. Accuracy is evaluated separately for (a) individual asset-level forecasts and (b) aggregated transformer-level forecasts, with results reported for both the day-ahead (DA) and short-term (ST) forecast cycles.
Unit of measurement	% (for WMAPE); kW (for MAE, RMSE)
Related Use Cases	SI.05, SI.06
Related STREAM Tools	sGRID
Formula	$$WMAPE = \left(\frac{\sum_{t\in T}\left\lvert P_{t,Actual} - P_{t,Forecast}\right\rvert}{\sum_{t\in T}\left\lvert P_{t,Actual}\right\rvert}\right) \times 100$$ $$MAE = \sum_{i=t}\left\lvert P_{t,Actual} - P_{t,Forecast}\right\rvert$$ $$RMSE = \sqrt{\sum_{i=1}\left(P_{t,Actual} - P_{t,Forecast}\right)^2}$$
Variable explanation	$P_{t,Actual}$ is the actual metered power during the metering period *t*. $P_{t,Forecast}$ is the forecasted power during the metering period *t*. *T* is the total period of observation.
Comments	Results are reported separately for individual asset-level forecasts (with distribution statistics: median, min, max across assets) and for directly forecasted aggregated loads at transformer station level. Both DA and ST forecast horizons are evaluated.

KPI ID	**KPI SI.05**
KPI name	Grid state forecast accuracy
Description	This KPI measures the end-to-end accuracy of the grid state forecast pipeline in sGRID, specifically the forecasted loading of transformer substations

	(MV/LV and HV/MV) and MV feeders. Unlike KPI SI.04, which evaluates the accuracy of individual load/generation forecasts, this KPI assesses the combined accuracy of the full pipeline: individual forecasts fed into the power flow calculation, producing forecasted loading values for grid elements. The forecasted loading is compared against actual measured loading for the same elements and periods.
Unit of measurement	% (for WMAPE); kW (for MAE, RMSE)
Related Use Cases	SI.05, SI.06
Related STREAM Tools	sGRID
Formula	$$WMAPE = \left(\frac{\sum_{t\in T}\lvert L_{t,Actual} - L_{t,Forecast}\rvert}{\sum_{t\in T}\lvert L_{t,Actual}\rvert}\right) \times 100$$ $$MAE = \sum_{i=t}\lvert L_{t,Actual} - L_{t,Forecast}\rvert$$ $$RMSE = \sqrt{\sum_{i=1}\left(L_{t,Actual} - L_{t,Forecast}\right)^2}$$
Variable explanation	$L_{t,Actual}$ is the actual metered power of the grid element during the metering period *t*. $L_{t,Forecast}$ is the forecasted power of the grid element (output of power flow calculation on forecasted values) during the metering period *t*. *T* is the total period of observation.
Comments	Reported for transformer substations and MV feeders. This KPI captures the cumulative effect of forecast errors and power flow model accuracy, representing the quality of the congestion prediction that drives the TLS and sMART market triggering.

KPI ID	**KPI SI.06**
KPI name	Bid success rate
Description	This KPI measures the percentage of flexibility bids accepted in the sMART local flexibility market auctions. Given that the pilot operated in demonstration mode, the KPI is evaluated based on the auction sessions conducted during the demonstration period. In these sessions, bids were ranked by price using a pay-as-cleared merit order and accepted until the DSO's flexibility demand was satisfied, with remaining bids not selected due to their higher price. The KPI reflects the functioning of the market clearing mechanism rather than continuous market performance.
Unit of measurement	Percentage in %

Related Use Cases	SI.02, SI.06
Related STREAM Tools	sFLEX, sMART
Formula	$$BSR = \frac{N_{Bids_ok}}{N_{total}} \times 100\%$$
Variable explanation	BSR [%]: Bid satisfaction rate N_{Bids_ok}: The number of accepted market bids from the system operator. N_{total}: The total number of market bids placed.
Comments	Reported per demonstration auction session, with context on the number of bids submitted, the DSO's flexibility demand, and the reason for bid rejection.

KPI ID	**KPI SI.07**
KPI name	Number of Devices Registered
Description	This KPI evaluates the Total number of flexible devices that are registered in the Device Registry.
Unit of measurement	n/a (it is a number)
Related Use Cases	SI.07
Related STREAM Tools	sFLEX, Device Registry
Formula	$$DeviceReg_{total} = \sum DevicesRegistered_n$$
Variable explanation	$DevicesRegistered_n$ denotes the number of registered devices.
Comments	

KPI ID	**KPI SI.08**
KPI name	Total Nominal Capacity of Registered Devices
Description	This KPI evaluates the sum of all nominal capacities (measured in MW) of flexible devices that are registered in the Device Registry, since its deployment
Unit of measurement	MW

Related Use Cases	SI.07
Related STREAM Tools	sFLEX, Device Registry
Formula	$$RegDevCapacity_{sum} = \sum_{n=1}^{n} RegDevCapacity_n$$
Variable explanation	$RegDevCapacity_n$ denotes the nominal capacity of device n in DR
Comments	

KPI ID	**KPI SI.09**
KPI name	Percentage of Devices with failed Communication
Description	This KPI evaluates the percentage of registered devices that initiated communication but did not acknowledge the test signal from Device Registry
Unit of measurement	None (it is a %)
Related Use Cases	SI.08
Related STREAM Tools	sFLEX, Device Registry
Formula	$$CommFailDev_{\%} = \frac{N_{fail}}{N_{reg}} \times 100$$
Variable explanation	N_{fail}… Number of Devices with no Acknowledgement of communication N_{reg}…number of devices registered in DR
Comments	If desired, we can have separate KPI for different products (thus having different prequalification criteria, most probably)

KPI ID	**KPI SI.10**
KPI name	Percentage of Prequalified Devices
Description	This KPI evaluates the percentage of devices that are prequalified for at least one flexibility product.
Unit of measurement	None (it is a %)

Related Use Cases	SI.08
Related STREAM Tools	sFLEX, Device Registry
Formula	$$Prequalified_{\%} = \frac{N_{preq}}{N_{reg}} \times 100$$
Variable explanation	N_{preq} …number of prequalified devices in DR N_{reg}…number of devices registered in DR
Comments	If desired, we can have separate KPI for different products

KPI ID	**KPI SI.11**
KPI name	Number of Devices Prequalified
Description	This KPI evaluates the total number of flexible devices that are prequalified in the Device Registry
Unit of measurement	None (it is a number)
Related Use Cases	SI.08
Related STREAM Tools	sFLEX, Device Registry
Formula	$$DevicePreq_{total} = n_{devices_preq}$$
Variable explanation	$n_{devices_preq}$… number of prequalified devices in DR
Comments	

KPI ID	**KPI SI.12**
KPI name	Total Capacity of Prequalified Devices
Description	This KPI evaluates the total sum of all nominal and flexible capacities (measured in MW) of flexible devices that are Prequalified in the Device Registry, since its deployment
Unit of measurement	MW

Related Use Cases	SI.08
Related STREAM Tools	sFLEX, Device Registry
Formula	$PreqDevCapacity_{sum} = \sum_{d=1}^{n} PreqDevCapacity_d$
Variable explanation	$PreqDevCapacity_d$ …nominal or flexible capacity/power of the prequalified device d
Comments	

7.2 SPANISH PILOT SITE

KPI ID	**KPI ES.02**
KPI name	Congestion forecast accuracy
Description	This KPI evaluates the percentage of times that the congestion forecast is correct.
Unit of measurement	%
Related UCs	UC ES.01
Related STREAM Tools	sGRID
Formula	Congestion forecast accuracy = $\frac{\sum_{t \to T} C_{t,correctly\ forecasted}}{\sum_{t \to T} C_{t,forecasted}}$
Variable explanation	$C_{t,\ correctly\ forecasted}$ is the number of congestions forecasted by sGRID and corroborated by the DSO. $C_{t,\ forecasted}$ is the number of congestions forecasted by sGRID.
Comments	The DSO has to check if the congestion has indeed taken place. The KPI will not take into account those forecasted congestions that have triggered preventive actions to mitigate them.

KPI ID	**KPI ES.03**
KPI name	Congestion correctly identified
Description	This KPI evaluates the percentage of times that sGRID detects a congestion in the real-time monitoring correctly.

Unit of measurement	%
Related UCs	UC ES.01
Related STREAM Tools	sGRID
Formula	Congestion correctly detected = $\frac{\sum_{t \to T} C_{t,correctly\ detected}}{\sum_{t \to T} C_{t,detected}}$
Variable explanation	$C_{t,\ correctly\ detected}$ is the number of congestions detected by sGRID and corroborated by the DSO. $C_{t,\ detected}$ is the number of congestions detected by sGRID.
Comments	The DSO has to check if the congestion has indeed taken place.

KPI ID	**KPI ES.04**
KPI name	Congestion resolution ratio
Description	This KPI evaluates the percentage of times that the activation of flexibility services solves the congestion.
Unit of measurement	%
Related UCs	UC ES.01
Related STREAM Tools	sGRID, sMART, sFLEX, sENC
Formula	Congestion resolution ratio = $\left(1 - \frac{C_{RT}}{C_{Forecast}}\right) \times 100$
Variable explanation	C_{RT} are the congestions that are detected in the Real-Time. $C_{Forecast}$ are the congestions forecasted by sGRID.
Comments	To take into account that the reliability of this KPI relies on the accuracy of KPI ES.02 and KPI ES.03. Only forecasted congestions (and their associated event time stamps) that have triggered flexibility services will be taken into account.

KPI ID	**KPI ES.05**
KPI name	Correct automatic bids ratio
Description	This KPI evaluates the percentage of times that sENC and sFLEX automatically identifies an open DSO requirements auction and send at least

	one bid correctly (with the correct bid direction (sell of buy), correct zone, correct unit offer, etc.).
Unit of measurement	%
Related UCs	UC ES.04
Related STREAM Tools	sENC, sFLEX and sMART
Formula	Correct automatic bids ratio = $\frac{\text{Auctions with bids validated in sMART}}{\textit{Sessions with bids validated in sMART}} \times 100$
Variable explanation	Auctions with bids validated in sMART are the number of auctions with at least one bid validated in sMART, correctly generated and submitted by sENC and sFLEX. Open auctions are the number of auctions total auctions that have been opened in sMART.
Comments	

KPI ID	**KPI ES.06**
KPI name	Local self-consumption ratio
Description	This KPI evaluates the percentage of energy produced in the local grid relative to the total consumption in the grid
Unit of measurement	%
Related UCs	UC ES.06, UC ES.07
Related STREAM Tools	sGRID, sMART, sFLEX, sENC
Formula	Local self-consumption ratio = $\frac{\sum_t GE_t}{\sum_t CE_t}$
Variable explanation	$GE_{t\ is}$ the energy generated in the local grid. CE_t is the energy consumed in the local grid
Comments	The energy that has been generated locally and stored in the batteries has to be taken into account once, be careful not to count it twice.

KPI ID	**KPI ES.07**
KPI name	Reduction of voltage deviations

Description	This KPI calculates the reduction in the number of voltage deviations, comparing scenarios with the battery providing voltage conservation services with scenarios without the battery action.
Unit of measurement	%
Related UCs	UC ES.02
Related STREAM Tools	sGRID
Formula	$\%Volt_dev.red = \frac{N_{volt_devs_w/o\ the\ battery} - N_{volt_devs_w\ the\ battery}}{N_{volt_devs_w/o\ the\ battery}} \times 100$
Variable explanation	$N_{volt_devs_w/o\ the\ battery}$ are the number of voltage deviations during the studied period in the scenario without the battery $N_{volt_devs_w\ the\ battery}$ are the number of voltage deviations during the studied period in the scenario with the battery
Comments	

KPI ID	**KPI ES.08**
KPI name	Number of prequalified assets
Description	This KPI shows the number of assets that have been qualified in the local flexibility market
Unit of measurement	/
Related UCs	UC ES.03
Related STREAM Tools	sMART
Formula	$N_{qualified\ assets\ in\ sMART}$
Variable explanation	$N_{qualified\ assets\ in\ sMART}$ is the number of qualifed assets in sMART
Comments	

KPI ID	**KPI ES.09**
KPI name	Flexibility provision compliance ratio
Description	This KPI measures the extent to which the flexibility assets fulfil their flexibility commitments resulting from the market clearing process. It is

	calculated as the ratio between the flexibility actually delivered and the flexibility committed in the market.
Unit of measurement	%
Related UCs	UC ES.01, UC ES.02, UC ES.04
Related STREAM Tools	sFLEX, sENC, sMART, sGRID
Formula	$$Flexibility\ compliance = \frac{F_{provided}}{F_{committed}}$$
Variable explanation	$F_{provided}$ the flexibility actually provided by the asset (forecasted consumption/generation minus the actual consumption/generation) $F_{committed}$ flexibility that the assets are committed to provide as a result of the market auctions.
Comments	

KPI ID	**KPI ES.11**
KPI name	Flexibility requests coverage
Description	This KPI measures the flexibility energy requested by the DSO covered by the FSPs.
Unit of measurement	%
Related UCs	UC ES.04
Related STREAM Tools	sGRID, sFLEX, sENC, sMART
Formula	Flexibility requests coverage = $\frac{\sum_t E_{t,provided}}{\sum_t E_{t,requested}} \times 100$
Variable explanation	$E_{t,\ provided}$ is the energy activated during the period t. $E_{t,\ provided}$ is the energy requested by the DSO during the period t.
Comments	The energy provided considers just the energy that has been effectively provided by the FSPs, not the energy matched in the local flexibility market.

KPI ID	**KPI ES.13**
KPI name	Increase of economic welfare

Description	This KPI measures, in a peer-to-peer energy operation, the increase of economic welfare comparing the costs/gains of this operation to buying/selling this energy to their retailer.
Unit of measurement	€
Related UCs	UC ES.06
Related STREAM Tools	sFLEX, sENC, sMART
Formula	Increase of economic welfare = $\sum_t E_{t,peers\ operation} \times \left[\left(P_{retailer} - P_{peers\ operation}\right) + \left(P_{peers\ operation} - P_{wholesale\ market}\right)\right]$
Variable explanation	$E_{t,\ peers\ operation}$ is the energy exchanged between energy community peers through the local market. $P_{retailer}$ is the price the consumer would have to pay to its retailer. $P_{peers\ operation}$ is the price of the operation between peers. $P_{wholesale\ market}$ is the selling price in the wholesale market.
Comments	The price of the operation between peers is set between the price of the wholesale market and the retailer. This difference of price is due to ancillary services, retailer margin and, if the regulation allows it, the transport and distribution tolls. In the case of avoiding an energy curtailment of the producer by using this method, the price of the wholesale market is 0.

KPI ID	**KPI ES.14**
KPI name	Percentage of flexibility availability
Description	This KPI evaluates the flexibility capacity relative to the total installed power capacity in the grid.
Unit of measurement	%
Related UCs	UC ES.04
Related STREAM Tools	sGRID, sFLEX, sENC
Formula	Percentage of flexibility availability = $\frac{\sum_i^n P_{i,flex}}{\sum_{i=1}^n P_i} \times 100$
Variable explanation	n is the number of installations of the grid. $P_{i,\ flex}$ is the amount of flexibility capacity available at a given moment of the installation i.

	P_i is the total capacity of the asset i.
Comments	$P_{i,\ flex}$ has to be greater or equal to one, and lower or equal than the installed capacity. The KPI measures, at a given moment, the percentage of flexibility capacity relative to the total power capacity of the system.

7.3 ITALIAN PILOT SITE

KPI ID	**KPI IT.02**
KPI name	Response to flexibility request
Description	This KPI measures two variables. Firstly, it tracks the percentage of actual flexibility activations in relation to all requests for flexibility provision; secondly, it measures how much of the energy requested by flexibility request was actually covered by the flexibility providers.
Unit of measurement	%
Related Use Cases	UC IT.03, UC IT.08
Related STREAM Tools	sMART
Formula	$activ = \frac{N^{prov}}{N^{req}} * 100\%, \qquad FEC = \frac{\sum_t W_t^{prov}}{\sum_t W_t^{req}} * 100\%$
Variable explanation	$activ$ – percentage of actual flexibility activations N^{prov} – number of provided flexibility activations N^{req} – number of all requests for flexibility activations FEC – Flexibility energy coverage W_t^{prov} – provided flexibility energy in time period t W_t^{req} – required flexibility energy in time period t
Comments	

KPI ID	**KPI IT.03**
KPI name	Share of users with detectable HVAC flexibility
Description	This KPI measures the proportion of valid residential users/smart meters for which detectable HVAC-related behaviour was identified based on the correlation between electricity consumption and outdoor temperature. It indicates the share of users that can be considered relevant candidates for HVAC flexibility aggregation.

Unit of measurement	%
Related Use Cases	UC IT.05
Related STREAM Tools	sFLEX
Formula	$$\alpha_{HVAC} = \frac{N_{HVAC}}{N_{valid}}$$
Variable explanation	α_{HVAC} – share of users with detectable HVAC flexibility [%] N_{HVAC} – number of users with detected HVAC-related behaviour N_{valid} – total number of valid users/meters considered in the HVAC flexibility assessment
Comments	

KPI ID	**KPI IT.04**
KPI name	Increase in local renewable energy self-consumption
Description	This KPI measures the relative increase in locally generated renewable energy used by pump operation in the optimised schedule compared with the baseline schedule. It quantifies the added value of the self-consumption optimisation.
Unit of measurement	%
Related Use Cases	UC IT.04, UC IT.06
Related STREAM Tools	sENC
Formula	$$\Delta SC = \frac{W_{PV}^{OPT} - W_{PV}^{BASE}}{W_{PV}^{BASE}}$$
Variable explanation	ΔSC – relative increase in PV energy used for pumping [%] W_{PV}^{OPT} – PV energy used by pump operation in the optimised schedule [kWh] W_{PV}^{BASE} – PV energy used by pump operation in the baseline schedule [kWh]
Comments	

KPI ID	**KPI IT.05**
KPI name	Accuracy of transformer loading forecast

Description	This KPI evaluates the accuracy of the forecasted transformer loading by comparing the forecasted loading profile with the actual measured loading profile.
Unit of measurement	%
Related Use Cases	UC IT.02
Related STREAM Tools	sGRID
Formula	$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\frac{P_t^{act} - P_t^{for}}{P_t^{act}}100\%$$ $$WMAPE = \frac{\sum_{t=1}^{n} P_t^{act} - P_t^{for}}{\sum_{t=1}^{n} P_t^{act}}100\%$$
Variable explanation	$MAPE$ – Mean absolute percentage error $WMAPE$ – Weighted mean absolute percentage error n – Number of analysed time intervals P_t^{act} – actual measured transformer loading in interval t P_t^{for} – forecasted transformer loading in interval t
Comments	The KPI is evaluated at transformer level. Forecasts are generated for the analysed transformer lines and then aggregated into one forecasted loading profile per transformer. The same aggregation is applied to the measured loading profile, so that forecasted and actual transformer loading can be compared consistently.

KPI ID	**KPI IT.06**
KPI name	Number of registered flexibility providers
Description	This KPI simply tracks how many flexibility providers are registered on the STREAM flexibility marketplace.
Unit of measurement	/
Related Use Cases	UC IT.03
Related STREAM Tools	sMART
Formula	N^{flex}

Variable explanation	N^{flex} – number of flexibility providers registered on the marketplace
Comments	

KPI ID	**KPI IT.07**
KPI name	Accuracy of grid reconstruction
Description	This KPI measures the percentage error (PE) between the line parameters supplied by the DSO and those calculated by the sGRID component.
Unit of measurement	[%]
Related Use Cases	UC IT.01
Related STREAM Tools	sGRID
Formula	$$PE = \frac{Z^{calc} - Z^{meas}}{Z^{meas}} * 100\%$$
Variable explanation	PE – percentage error Z^{calc} – calculated line impedance Z^{meas} – measured line impedance provided by DSO
Comments	

7.4 FINNISH PILOT SITE

KPI ID	**KPI FI.01**
KPI name	FCR activation speed
Description	▪ The FCR activation speed is a measure on how well the system complies with the tight requirements related to linearity and response time when activating a reserve containment reserve. Its calculation requires a complex algorithm. ▪ After 5 seconds, 50% of the necessary reserved power shall be activated. ▪ After 7,5 seconds, 86% of the necessary reserved power shall be activated. ▪ After 30 seconds, 100% of the necessary reserved power shall be activated. ▪ Therefore, there are 3 aggregate results for each of the services (FCR-D-up and FCR-D-down). ▪ This is a very important KPI to verify how well the solution meets the technical requirements of the TSO.

Unit of measurement	Triplet of integer for each service
Related Use Cases	FI.01
Related STREAM Tools	sFLEX, sDATA
Formula	• The calculation requires few hundred lines of python scripts. • For each activation event, a triplet of KPIs is calculated. • Then, the average of the events KPIs is summarized into a triplet which provides the KPI for the whole log file, which typically spans through a day. • Then, the average of the day KPI triplets is calculated for the wished time rage (week, etc ..) • The result is a triplet of integers for each service with possible values from 0 to 1. • The logic is summarized here. See also the variable explanation section. ○ *Monitor the reserve activation ratio (ContOutSig), which tells if FCR-D is activated, how much and in which direction* ○ *When ContOutSig != 0, count time & monitor the activated flexible power (Act_x) till ContOutSig deviates in the opposite direction* ○ *If after 5 seconds, Act_x >= 50%*Cap_x*ContOutSig, then 50%actKPI = 1 (the values are compared by using absolute values))* ○ *If after 7 seconds, Act_x >= 86%*Cap_x*ContOutSig, then 86%actKPI = 1* ○ *If after 30 seconds, Act_x >= 100%*Cap_x*ContOutSig, then 100%actKPI 1 = 1* ○ *Calculate the average of the events KPIs within one Log file (one day)* ○ *Calculate the average of the Log file KPIs for the selected group of logs (spanning, for example, through a week)*
Variable explanation	The reserve activation ratio *(ContOutSig)* is a measure of how much flexible capacity has been activated. It tells how much the frequency has deviated within the FCR frequency range because the amount of reserved power to use shall be proportional to the frequency deviation. When it is different than zero, there is some activated flexible capacity (1 means that the full maintained flexible capacity has been activated). The maintained flexible capacity (*Cap_X*, where X is FcrdUp or FcrdDo) is the capacity that the system is maintaining for a certain flex group. The product of *ContOutSig* Cap_X* tells how much reserved capacity shall be activated based on the actual frequency deviation. The activated flexible power (*Act_X*, where X is FcrdUp or FcrdDo) indicates how much flexible power has been activated at a certain time.

Comments	• The **source of the data** to calculate this KPI is the FCR Log (data set FI01_11 FCR Log). • The source information is available with a **sampling interval** of 1 second.

KPI ID	**KPI FI.02**
KPI name	Flexibility estimation accuracy
Description	▪ Flexibility estimation accuracy measures how accurate the calculation of the flexible power has been. It is the percentage of the ratio between the actual maintained flexibility (MW) and the reserved flexibility (MW). ▪ There are separate values for FCR-D-up and FCR-D-down. ▪ This KPI has also a potential impact on aggregator revenues since not being able to maintain the offered flexible capacity might lead to fines.
Unit of measurement	%
Related Use Cases	FI.01
Related STREAM Tools	sFLEX, sDATA
Formula	$flexibility_estimation_accuracy(\%) = \sum_{s=1}^{3600} \frac{maintainedflexpower_s}{reservedflexpower_s} \div 3600 \times 100$
Variable explanation	• $maintainedflexpower_s$ is the field Cap_X of the FCR Log (data set FI01_11), where X is FcrdUp or FcrdDo • $reservedflexpower_s$ is the field capacity_mw of the table flexdb_flex_bid_period The sum is done for each second of a certain hour. Then, average values per day, week, … can be calculated.
Comments	• The **source of the data** to calculate this KPI is the bid data (data set FI01_09 FCR group bid) and the FCR Log (data set FI01_11 FCR Log). • The source information is available with a **sampling interval** of 1 hour in bid data and of 1 second in the FCR Log. Hour based data is calculated.

KPI ID	KPI FI.04

KPI name	Customer answer rate
Description	▪ The answer rate percentage measures the customer answer rate (as a percentage) to the user experience questionnaires provided during the pilot phase. ▪ It is a critical KPI to be able to understand the limits in understanding customers' feelings (social KPI).
Unit of measurement	%
Related Use Cases	FI.04
Related STREAM Tools	sDATA
Formula	$customer_answer_rate(\%) = \frac{\#_of_answered_questionnaires}{\#_of_sent_questionnaires} \times 100$
Variable explanation	• *#_of_asnwered_questionnaires*: number of full questionnaires sent to the pilot customers • #_of_sent_questionnaires: number of full questionnaires that have been answered
Comments	• This KPI consists of one single value.

KPI ID	KPI FI.05
KPI name	Bid acceptance rate
Description	▪ This KPI is a measure of how many aggregator's bids are accepted by the TSO in a defined time interval. The reserved power might be smaller than the offered power since the TSO might not accept all the bids. This KPI is the percentage of the ratio between the reserved power (MW) and the offered power (MW). ▪ There are separate values for FCR-D-up and FCR-D-down. ▪ This is a very important KPI since it impacts directly the profit of the aggregator.
Unit of measurement	%
Related Use Cases	FI.01, FI.05
Related STREAM Tools	sFLEX, sDATA

Formula	$$bid_acceptance_rate(\%) = \frac{reserved_power}{offerend_power} \times 100$$
Variable explanation	This KPI uses the data set FI01_09 FCR group bid. • The variable *offered_power* is calculated by using the variable capacity_mw of the table flexdb_flex_bid_period for each hour of each service. • The variable *reserved_power* is calculated by using the same variable and by multiplying it for zero if the rejection reason is not NULL.
Comments	▪ The **source of the data** to calculate the KPI is the bid data. ▪ The **sampling interval** is 1 hour. Average values can be calculated per day / week / etc … ▪ During the time of the STREAM project, this KPI can be calculated only with estimations since the real connection to the TSO is not part of the prioritized content. The price of flexibility services is driven by assets such as energy storage assets (batteries). So, an aggregator which controls just electric radiators as flexible assets might offer bids for a very low price. Still, Fingrid rules says that, if the bid is accepted (and at very low price the probability that this happens is clearly higher), the aggregator is compensated with the price of the most expensive accepted bid for that hour. Hence, the **target value** is set at 90%.

KPI ID	KPI FI.06
KPI name	Customer satisfaction
Description	▪ This KPI is a measure of the overall satisfaction of the pilot customers and it is calculated as an average of the overall satisfaction scores provided by each single customer. The overall satisfaction score is a number that can have one of the 5 values from 1 to 5. ▪ It is a critical KPI to be able to conclude how well the functionality is accepted by the customers (social KPI).
Unit of measurement	integer
Related Use Cases	FI.04
Related STREAM Tools	sDATA
Formula	$$average\ satisfaction\ score = \frac{SUM(cust_satisf_score)}{\#_of_respondents}$$

Variable explanation	• *cust_satisf_score*: overall satisfaction score of each single pilot customer (values from 1 to 5, where 5 is most satisfied and 1 is less satisfied) • *#_of_respondents*: number of pilot customers answering this survey
Comments	• This KPI consists of one single value.

8 ANNEX B — TEST CASES RESULTS REPORTING

8.1 SLOVENIAN PILOT SITE

Experiment number	**SI-UC.01.01**
Name	Grid network planning simulations
Timeframe	May-June 2026 (M44-M45)
Targets	Scenario-based assessment of distribution network development options with comparison of grid reinforcement and flexibility utilisation from technologies such as PVs, EVs, HPs, BESS in LV grid.
Actors	• UL as the tool provider • EPR as the data provider and the main user of the tool.
STREAM products	sPLAN
Assets & systems	Smart meters, SCADA, MV and LV distribution grid data for network modelling
Description of the experiment	Based on scenarios defined in collaboration with EPR (including the expected number of various new devices in the network and the anticipated load increase), simulations are initiated in sPLAN. The tool calculates the load flow and estimates the network status (voltage, load, and losses) for two operating modes: 1. Devices operating in a non-controlled manner 2. Devices following defined flexibility measures **Pre-condition/triggering event:** 1. User of the tool inputs the required information (planned number of various devices such as PVs, HPs, EVs and BESS, as well as the percentage of yearly load increase) 2. Historical data needed to create load profiles is available (smart meter measurement data and transformer control measurements) **Steps:** 1. sPLAN generates load profiles for the users with new technologies (PVs, HPs, EVs and BESS) using the typical seasonal profiles and adding the operational profiles of new technologies. 2. Load flow simulation, which uses the load profiles as inputs and results in the grid state (calculates U per node, I per line and power losses) 3. Load flow results are compared to limits defined for lines and transformers, which determines violations (voltage or congestion) and identifies weak sections of the grid

	4. sPLAN determines the type and location of optimal reinforcement measure, calculates the associated costs and estimated time needed to install the reinforcement. 5. (In case of flexibility measures utilization): sPLAN generates load profiles that consider flexible operation of newly installed devices and calculates the load flow again 6. (In case of flexibility measures utilization): sPLAN evaluates the results and compares them to original results (without flexibility measures) to determine if the previously detected violations have been addressed. 7. sPLAN calculates the potential monetary savings (when using flexibility measures compared to reinforcements) and by how many years the investment can be deferred. **Post condition:** • Simulation results, cost savings and deferral time are available The results of the experiment will be validated with expert opinions from EPR.
Exception paths and scenarios of the experiment	**Steps:** 1. sPLAN generates load profiles for the users with new technologies (PVs, HPs, EVs and BESS) 2. Load flow simulation, which uses the load profiles as inputs and results in the grid state (calculates U per node, I per line and power losses) does not converge 3. The tool identifies the issue (insufficient inputs, low number of iterations etc.) 4. The simulation is run again with the updated parameters
Datasets required for the experiment	• Network topology and electrical parameters of grid elements • Consumption profiles and Generation profiles, where available (P and Q measurements) • DER implementation scenarios (PV, BESS, EV, HP) • Grid reinforcement cost assumptions
Field data to be gathered	/
Related KPIs	KPI SI.03
Results of the Experiment	
The sPLAN tool was tested through a comprehensive test case evaluation covering input data preparation, scenario definition, network simulation and techno-economic assessment of different mitigation strategies. The tool allows users to specify input parameters either through the graphical user interface (GUI) or by running simulations directly from the program code. In this case, the latter option was used, with the input parameters specified directly in the program code. However, Figure 47 illustrates how the input parameters can be configured using the GUI.	

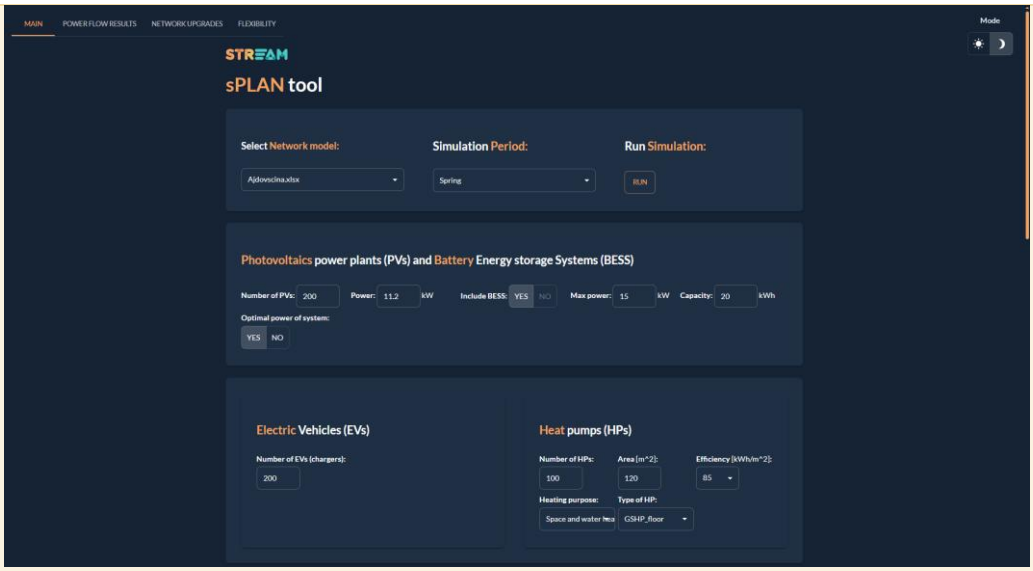


Figure 47: sPLAN input parameters GUI

Four representative seasonal simulations (Spring, Summer, Autumn and Winter) were executed and analysed. The objective of using multiple seasonal simulations was to consider variations in demand profiles, RES generation, DER integration and the availability of flexibility resources under different operating conditions. Due to computational complexity and the size of the analysed network model, representative seasonal periods were selected instead of performing full-year simulations.

For each season, several future network development scenarios were prepared and evaluated. The analysed scenarios included:

1. **Baseline scenario** – representing the reference network operation and providing the initial assessment of existing network conditions,
2. **PV scenario (SC1)** – analysing the impact of additional photovoltaic generation connected to the distribution network,
3. **PV + BESS scenario (SC2)** – evaluating the combined impact of photovoltaic generation and BESS,
4. **EV + HP scenario (SC3)** – analysing the impact of increased electricity consumption caused by electric vehicle charging and heat pump integration,
5. **EV + HP + PV scenario (SC4)** – evaluating the combined impact of increased electricity consumption due to EVs and HPs and additional PV generation,
6. **Combined scenario (SC5)** – representing the simultaneous integration of multiple technologies, including PV, BESS, EVs and HPs.

A visual representation of the various scenarios and the technologies included in each scenario is available in the table below:

Table 30: sPlan scenarios

Scenario	PV	EV	HP	BESS
SC1	✓	–	–	–
SC2	✓	–	–	✓

SC3	–	✓	✓	–
SC4	✓	✓	✓	–
SC5	✓	✓	✓	✓

Within each scenario, different penetration levels of technologies were analysed by varying the number of connected units thus resulting in 3 subsections to every scenario (Low Stress, Reference and High Stress). This approach enabled assessment of gradual changes in network conditions caused by increasing integration of DERs and other (flexibility) assets.

Table 31: sPlan constants

Parameter	Low Stress	Reference	High Stress
Installed PV power [kW]	0,8*P+	0,8*P+	0,8*P+
BESS power per unit [kW]	0,8*P+	0,8*P+	0,8*P+
BESS energy capacity per unit [kWh]	1,6*P+	1,6*P+	1,6*P+
Heat pump area [m2]	120	140	160
Heat pump specific demand for area [kWh/m2]	90	100	110
Change of uncontrollable loads [%]	0	2,5	5
Number of PVs [#]	200	400	600
Number of EVs [#]	200	600	1200
Number of HPs [#]	100	300	600

The scenario variations provided input for the comparison of required grid reinforcement measures and the potential utilisation of flexibility resources. This allowed evaluation of how different levels of integration influence investment needs and the possibility of using flexibility as an alternative or complementary planning measure.

Based on the simulation results, technical constraints in the distribution network were first identified. The analysis included detection of overloaded network elements, voltage-related limitations and other operational constraints. These identified limitations were then used as input for the evaluation and comparison of possible mitigation measures.

The main focus of the test case was the comparison between conventional grid reinforcement and the utilisation of flexibility resources.

The first mitigation approach considered conventional reinforcement of the distribution network, including replacement or upgrade of overloaded network elements such as lines and transformers. For each identified reinforcement measure, the required investment costs were calculated, enabling evaluation of the expected infrastructure upgrade requirements.

In addition to conventional network reinforcement, the test case evaluated the possibility of using flexibility resources to address and mitigate identified network constraints. Instead of considering grid upgrades as the only possible solution, the sPLAN tool analysed whether available flexible assets could contribute to reducing operational limitations. An example of the results is presented in Figure 48.

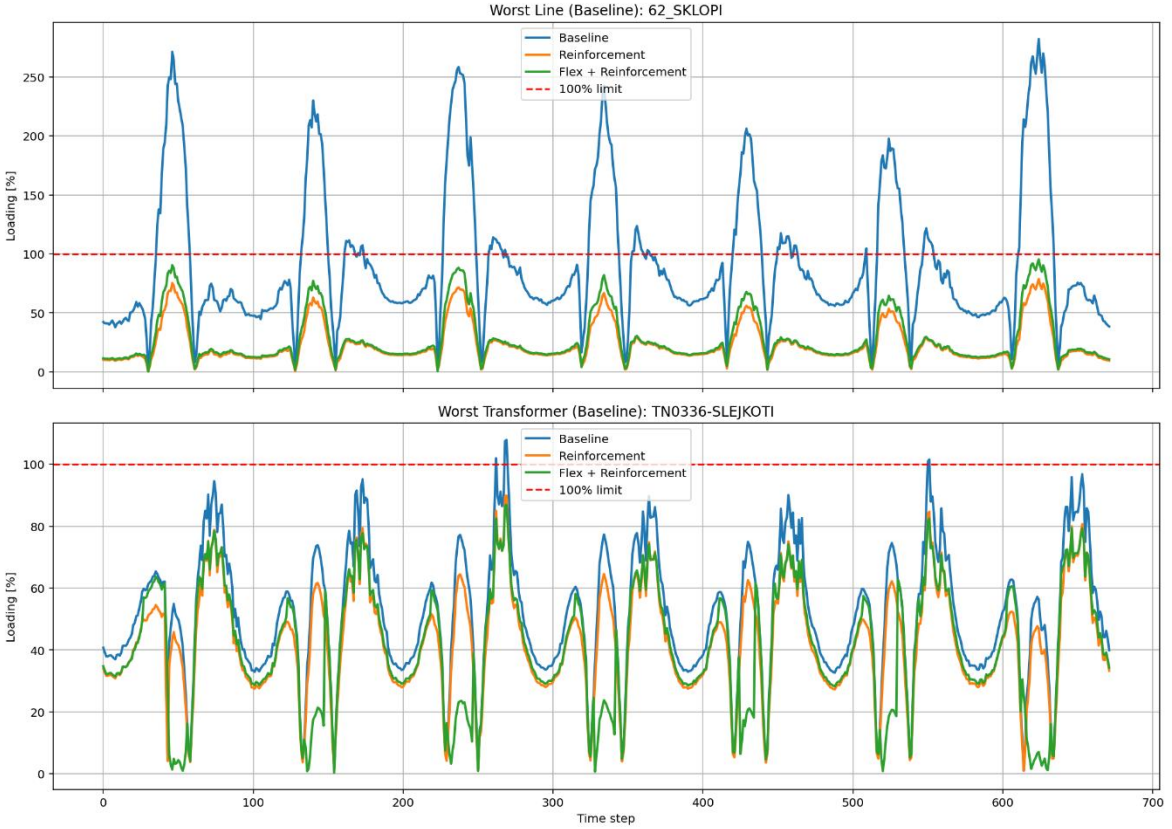


Figure 48: sPLAN worst element loading comparison

For the analysed scenarios, the cost of flexibility activation was evaluated and compared with the required reinforcement investments. This comparison provides information on whether flexibility can represent a technically and economically feasible alternative or complementary measure to conventional network upgrades.

As evident from the example above (Figure 48) with the use of flexibility assets we reduced the loading of this particular element to the point where reinforcement is not needed. In this same scenario we reduced the number of elements in need of reinforcement from 34 to 18.

For the analysed scenarios, the cost of flexibility activation was evaluated and compared with the required reinforcement investments. This comparison (shown in Figure 49 for winter and in Figure 50 for Spring) provides information on whether flexibility can represent a technically and economically feasible alternative or complementary measure to conventional network upgrades.

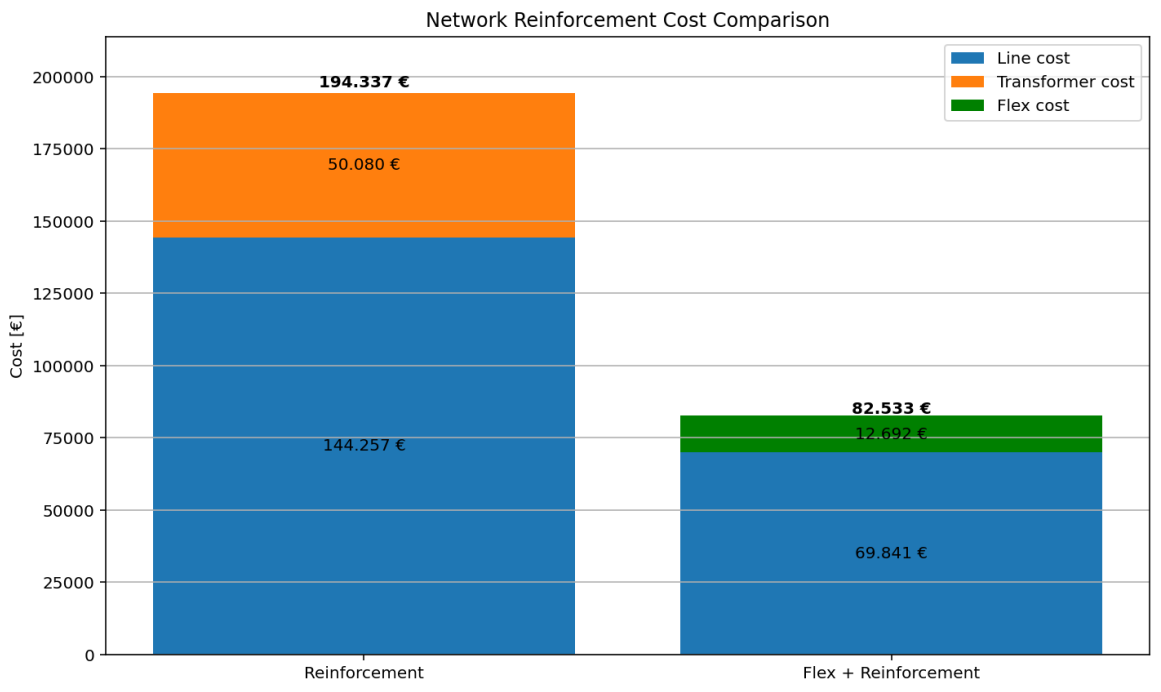


Figure 49: Network reinforcement cost comparison - Winter

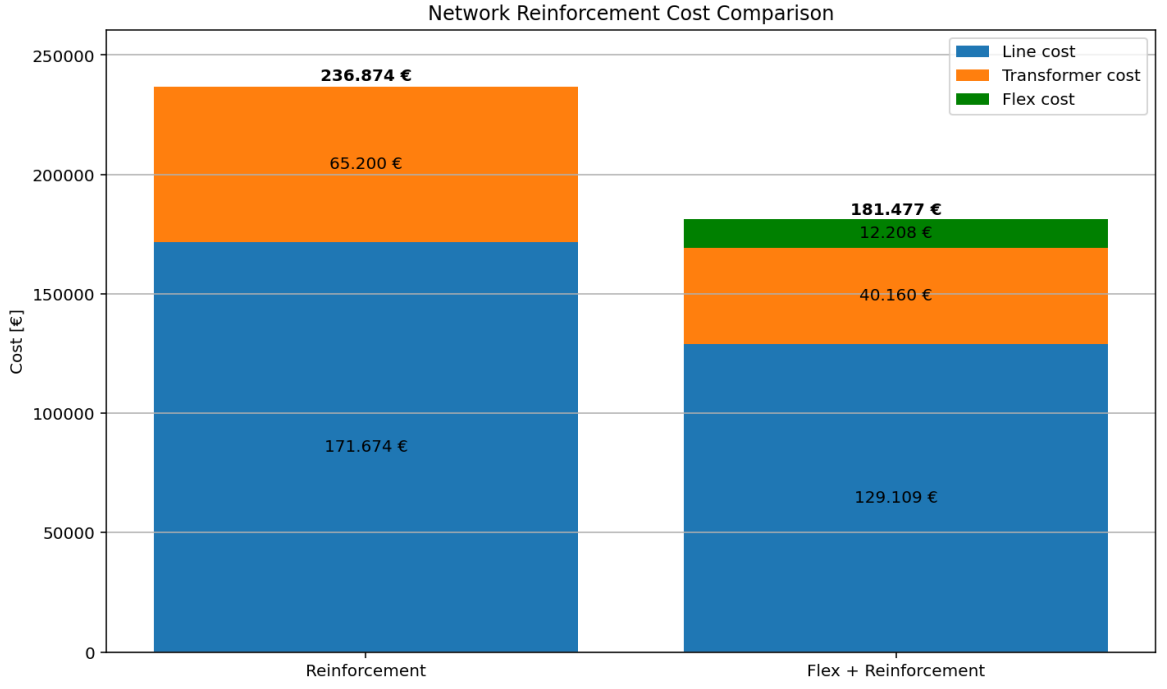


Figure 50: Network reinforcement cost comparison - Spring

The following figure presents indicative results demonstrating the tool's functionality and capabilities. For improved visibility and clarity, the actual results obtained from the test case are presented separately in the previous graphs.



Figure 51: sPLAN results

The results demonstrate that flexibility can be considered as an additional planning option in distribution network development. Depending on the analysed scenario and network conditions, flexibility resources can contribute to reducing network stress, improving utilisation of existing infrastructure and potentially postponing reinforcement investments. However, in cases where flexibility is not sufficient to resolve network limitations, conventional infrastructure upgrades remain necessary.

The main output of the sPLAN tool is therefore not only the identification of technical violations, but a structured technical and economic comparison of different mitigation strategies. The tool supports the transition from a reinforcement-only planning approach towards a planning process where grid investments and flexibility solutions are evaluated together.

Qualitative analysis of the results

The test case confirmed the relevance of including flexibility assessment as an integral part of distribution network planning processes. Traditional planning approaches are mainly based on the identification of future network constraints and their mitigation through reinforcement of grid infrastructure. However, increasing integration of renewable generation, electrification of transport and heating, and changing consumption patterns require additional planning approaches that also consider the potential utilisation of flexibility resources.

The methodology implemented within the sPLAN tool extends the conventional planning process by introducing flexibility as an additional planning option. This enables DSOs to evaluate and compare different network development strategies before making final investment decisions.

One of the main advantages of the developed and tested approach is the possibility to analyse multiple future scenarios with different numbers and combinations of new units, such as PV systems, BESS, EVs and HPs. This allows DSOs to evaluate how gradual changes in the network influence future reinforcement needs and flexibility requirements.

The GUI-based implementation of the tool enables practical use by DSO network planning departments, including users without advanced programming skills. Users can prepare scenarios, configure input parameters and analyse simulation results directly through the graphical interface. At the same time, background data handling enables integration with existing DSO systems and supports automated larger-scale studies, as demonstrated in the presented test case.

Based on the results of the test case, the following conclusions can be derived:

- grid reinforcement provides a long-term increase of network capacity and remains necessary in cases where technical constraints cannot be solved efficiently by other measures,
- flexibility utilisation can improve the use of existing grid assets and support network operation,
- flexibility can potentially reduce or postpone selected investments by addressing temporary or location-specific constraints,
- a combined approach, including both grid upgrades and flexibility solutions, can provide technically and economically efficient network development strategies.

The seasonal analysis showed that planning decisions strongly depend on both current operating conditions and expected future scenarios. Therefore, future network planning cannot rely only on a single predefined worst-case scenario, but should consider different combinations of demand, generation, DER penetration and flexibility availability.

An important observation from the test case was that the winter season, which is traditionally expected to represent one of the most critical operating conditions due to higher demand and peak loading conditions, did not necessarily result in the highest network constraints. Other seasonal conditions, influenced by different combinations of RES generation, DER penetration levels and consumption patterns, resulted in comparable or even more challenging situations.

This confirms the importance of analysing multiple scenarios instead of relying only on conventional assumptions regarding critical network conditions. The scenario-based approach implemented in sPLAN enables identification of actual limiting cases and provides a more realistic basis for comparing grid reinforcement needs with the potential utilisation of flexibility resources.

Overall, the test case demonstrated that sPLAN can be used as a planning support tool enabling DSOs to evaluate future network development options through a structured comparison of traditional reinforcement measures and flexibility-based solutions from both technical and economic perspectives.

Experiment number	**SI-UC.02.01**
Name	sMART congestion management market operation
Timeframe	March – May 2026 (M43-M44)
Targets	The goal is to successfully initiate a market auction, gather bids that meet locational requirements, clear the market, and send activation signals to selected assets (either directly or through the asset's FPS/aggregator, which in the case of STREAM, is the sFLEX tool).
Actors	UL, EPR, IND, KOL, CYG, AVA
STREAM products	sMART, sGRID, sFLEX, DR
Assets & systems	Connection to sGRID, sFLEX and Device Registry (DR), flexibility assets in the pilot site
Description of the experiment	**Pre-condition/triggering event:** 1. sGRID and sMART are connected. 2. sMART and sFLEX are connected. 3. sMART and DR are connected

	4. sMART receives a yellow/orange TLS status for a grid element from sGRID (stage, location, required flex and time). **Steps:** 1. sMART receives TLS information (location, time, required flexibility – magnitude and direction) from sGRID and opens an auction based on this information. 2. sMART collects bids and verifies them with the Device Registry to ensure locational and product requirements are satisfied. 3. At Gate Closure Time (GCT), sMART stops collecting bids and performs market clearing, selecting the most economically optimal bids for activation. 4. sMART sends activation signal to sFLEX which in turn sends the signal to activate to the flexibility assets The experiment will be tested in parts: • Firstly, testing the sGRID - sMART connection, making sure that sMART receives the necessary information in an appropriate format. • Test if sMART uses the received sGRID information to open an auction with the correct requirements (location, required flexibility and time). • Test that the bid information is correctly received from sFLEX. • Test the connection with the Device Registry – when a bid is submitted it should include an ID of the asset, which is then communicated to DR. The DR should send back the locational information of the device, as well as the information if the device is prequalified. If the asset is prequalified and meets the locational requirements of the auction, it should be accepted and put into the order book. • Test the clearing algorithm of sMART (initially with simulated data and later with real requests from sGRID and bids from sFLEX) • Test the connection from sMART to sFLEX – if they receive the activation signal. • Demonstrate the complete operation of the flexibility ecosystem in the SI pilot, including all of the mentioned tools **Post condition:** • Market is cleared with determined price and volume of flexibility • Activation signal is sent to sFLEX, which activates the assets
Exception paths and scenarios of the experiment	**Steps:** 2b. The asset included in the bid does not satisfy the auction requirements through the DR check (issue with prequalification status or location)
Datasets required for the experiment	• Congestion forecast results (TLS status) • Flexibility bids from the flexibility assets • Asset information (technical and prequalification information)
Field data to be gathered	/
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.06
Results of the Experiment	

The demonstration of SI-UC.02.01 was carried out in multiple stages between March and May 2026, progressing from integration and validation testing to end-to-end demonstrations with real asset activations. The test case covers the short-term flexibility product (energy market) operated through sMART at 15-minute resolution. All demonstrations used simulated congestion scenarios with conservatively set planning limits. The sGRID congestion signals used to open the auctions were prepared manually for each demonstration session, as the demonstrations required coordination with asset owners approximately one week in advance.

Integration and validation tests

Prior to the live demonstrations, a series of integration tests were performed to validate the sGRID–sMART connection, the sFLEX–sMART connection, and the sMART–Device Registry (DR) interaction.

The sGRID–sMART JSON interface was tested by transmitting congestion messages in the defined format. sMART correctly received the messages, parsed the congestion details, and opened auctions with the corresponding requirements. The sFLEX–sMART bid interface was tested by submitting flexibility bids from sFLEX. sMART correctly received and placed valid bids into the auction order book.

Five DR validation scenarios were tested to verify that sMART correctly rejects bids that do not satisfy the eligibility requirements:

1. A bid with flexibility volume exceeding the asset's prequalified power was rejected (Figure 52).

```
Authentication successful!
Status code: 200
Raw response: {"Errors":[{"Identifier":"FlexibilityOffered","Message":"FlexibilityOffered \u0027250000\u0027 exceeds qualified
quantity for AssetID \u0027980ecec4-0995-4e02-97c2-655d0a668219\u0027.","IsWarning":false,"Arguments":[],"IsTranslated":false}]}
Error from server: [{'Identifier': 'FlexibilityOffered', 'Message': "FlexibilityOffered '250000' exceeds qualified quantity for
AssetID '980ecec4-0995-4e02-97c2-655d0a668219'.", 'IsWarning': False, 'Arguments': [], 'IsTranslated': False}]
Response: None
```

Figure 52: DR validation — bid exceeding prequalified power

2. A bid for an asset not assigned to the submitting aggregator was rejected (Figure 53).

```
Authentication successful!
Status code: 200
Raw response: {"Errors":[{"Identifier":"AggregatorID","Message":"MarketParticipant with AggregatorID \u002728X000000000056P\u0027
is not provider for asset \u0027be7874af-8864-4138-aa8e-e437ee9c1ad5\u0027.","IsWarning":false,"Arguments":
[],"IsTranslated":false}]}
Error from server: [{'Identifier': 'AggregatorID', 'Message': "MarketParticipant with AggregatorID '28X000000000056P' is not
provider for asset 'be7874af-8864-4138-aa8e-e437ee9c1ad5'.", 'IsWarning': False, 'Arguments': [], 'IsTranslated': False}]
Response: None
```

Figure 53: DR validation (Figure: DR validation — incorrect aggregator assignment

3. A bid for an asset whose location does not match the auction's congested grid element was rejected (Figure 54).

```
Authentication successful!
Status code: 200
Raw response: {"Errors":[{"Identifier":"AssetID","Message":"Asset with AssetID be7874af-8864-4138-aa8e-e437ee9c1ad5 cannot bid on
auction with AuctionID 7741901_2026-06-03_52.","IsWarning":false,"Arguments":[],"IsTranslated":false}]}
Error from server: [{'Identifier': 'AssetID', 'Message': 'Asset with AssetID be7874af-8864-4138-aa8e-e437ee9c1ad5 cannot bid on
auction with AuctionID 7741901_2026-06-03_52.', 'IsWarning': False, 'Arguments': [], 'IsTranslated': False}]
Response: None
```

Figure 54: DR validation — incorrect asset location

4. A bid for an asset without prequalification status was rejected (Figure 55).

```
Authentication successful!
Status code: 200
Raw response: {"Errors":[{"Identifier":"AssetID","Message":"Asset with AssetID \u0027be7874af-8864-4138-aa8e-e437ee9c1ad5\u0027
is not qualified for bid.","IsWarning":false,"Arguments":[],"IsTranslated":false}]}
Error from server: [{'Identifier': 'AssetID', 'Message': "Asset with AssetID 'be7874af-8864-4138-aa8e-e437ee9c1ad5' is not
qualified for bid.", 'IsWarning': False, 'Arguments': [], 'IsTranslated': False}]
Response: None
```

Figure 55: DR validation — unqualified asset

5. A bid with a flexibility direction not matching the auction direction was rejected (Figure 56).

```
Authentication successful!
Status code: 200
Raw response: {"Errors":[{"Identifier":"FlexibilityDirection","Message":"Bid direction \u0027Upward\u0027 does not match the
direction of auction \u002777741901_2026-06-03_52\u0027. Valid products: ENG ST DOWN 15 MIN.","IsWarning":false,"Arguments":
[],"IsTranslated":false}]}
Error from server: [{'Identifier': 'FlexibilityDirection', 'Message': "Bid direction 'Upward' does not match the direction of
auction '7741901_2026-06-03_52'. Valid products: ENG ST DOWN 15 MIN.", 'IsWarning': False, 'Arguments': [], 'IsTranslated':
False}]
Response: None
```

Figure 56: DR validation — incorrect flexibility direction

Demonstration 1: EV charging station activation (8 May 2026)

An upward auction was opened for MV/LV transformer station Knauf (congested element ID: 7000808), requesting 11 kW of flexibility for ISP 51 (12:30–12:45), Yellow TLS (Figure 57).

```
ISP number: 51  |  Order amount: 11000 W
{
  "CongestionDetails": {
    "CongestedElementID": "7000808",
    "OrderAmount": 11000,
    "OrderDirection": "Upward",
    "ISPNumber": 51,
    "AuctionDate": "2026-05-08",
    "AuctionID": "7000808_2026-05-08_51"
  },
  "TLS": {
    "Stage": "Yellow"
  }
}
Authentication successful!
Response: []
```

Figure 57: sGRID JSON message — Demonstration 1

AVA submitted a sell bid of 11 kW at 25 €/kWh for the AVACar EV station Knauf 2 (Figure 58).

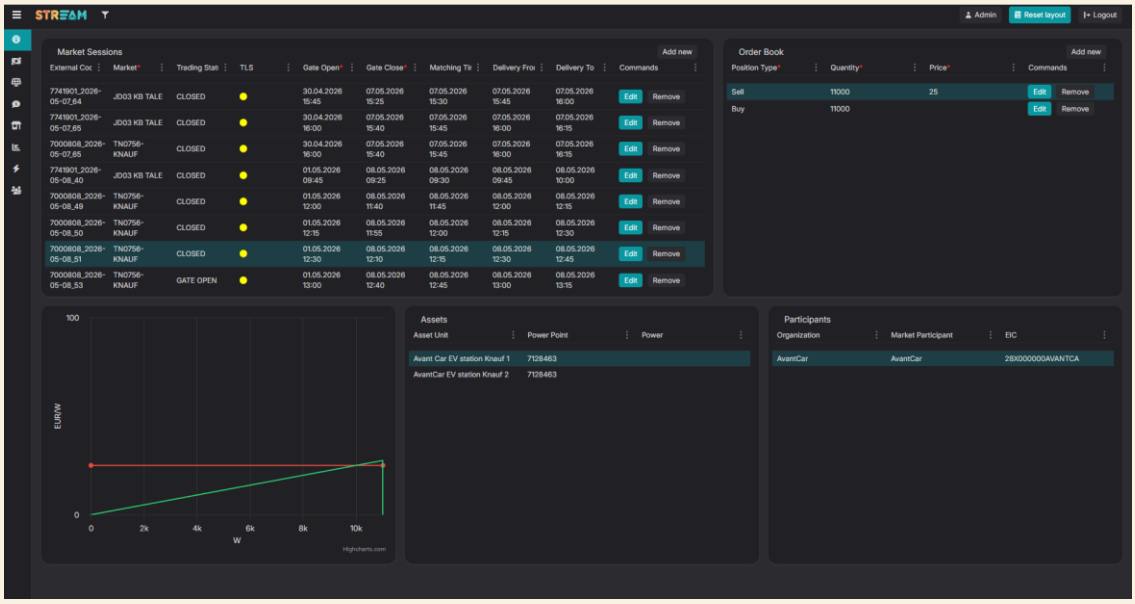


Figure 58: sMART auction view — Demonstration 1

The market was cleared with the bid fully accepted at 25 €/kWh (Figure 59).

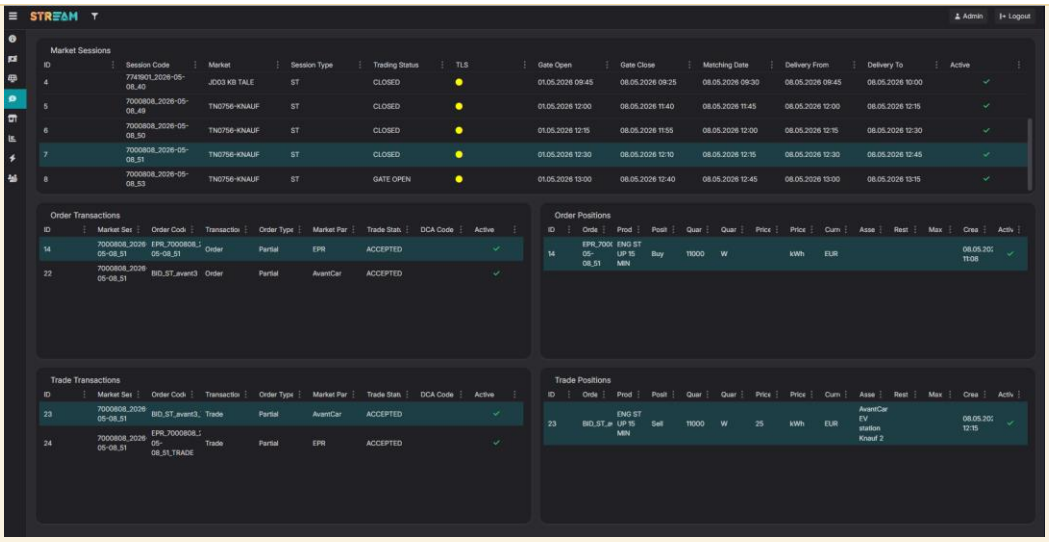


Figure 59: sMART market clearing — Demonstration 1

sFLEX sent the activation signal to the EV charging station. The sFLEX activation profile shows the charging power dropping from approximately 11.26 kW to near zero at the start of the activation window and resuming after 12:45 (Figure 60).

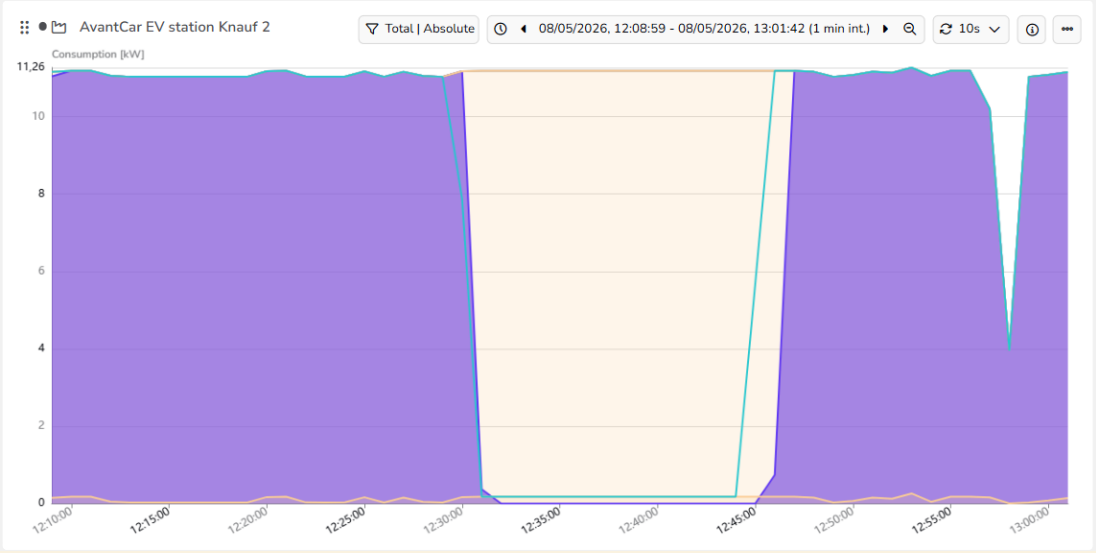


Figure 60: activation profile — AvantCar EV station Knauf 2, Demonstration 1

Demonstration 2: PV curtailment activation (21 May 2026)

The second demonstration involved PV curtailment using assets from Petrič (2 inverters, power point 7134865) and Metal Design (4 inverters, power point 8022737), managed by aggregator Kolektor sETup (KOL) via sFLEX. Three consecutive downward auction scenarios were executed with increasing flexibility requirements.

Scenario 1: Secondary substation Obrtna cona Ajdovščina 2, 100 kW downward (12:00–12:15)

A downward congestion signal of 100 kW was sent for element 7061191, ISP 49, Yellow TLS (Figure 61).

```
{
  "CongestionDetails": {
    "CongestedElementID": "7061191",
    "OrderAmount": 100000,
    "OrderDirection": "Downward",
    "ISPNumber": 49,
    "AuctionDate": "2026-05-21",
    "AuctionID": "7061191_2026-05-21_49"
  },
  "TLS": {
    "Stage": "Yellow"
  }
}
Authentication successful!
Response: []
```


Figure 61: sGRID JSON message — Scenario 1

KOL submitted two bids: 50 kW and 45 kW, both at 50 €/kWh (Figure 62).


```
{
  "Aggregator": {
    "AggregatorID": "28X000000000056P"
  },
  "BidDetails": {
    "AuctionID": "7061191_2026-05-21_49",
    "BidID": "BID_DEMO_petric1_49",
    "FlexibilityOffered": 50000,
    "FlexibilityDirection": "Downward",
    "PricePerkWh": 50,
    "BidStatus": "Active"
  },
  "AssetDetails": {
    "AssetID": "7795bc47-6697-4edf-9599-f18f1aa62143"
  }
}
Authentication successful!
Status code: 200
Raw response: {"Errors":null}
Response: []
```


Figure 62: sFLEX bid JSON example — Scenario 1

The auction view and merit order curve are shown in Figure 63.

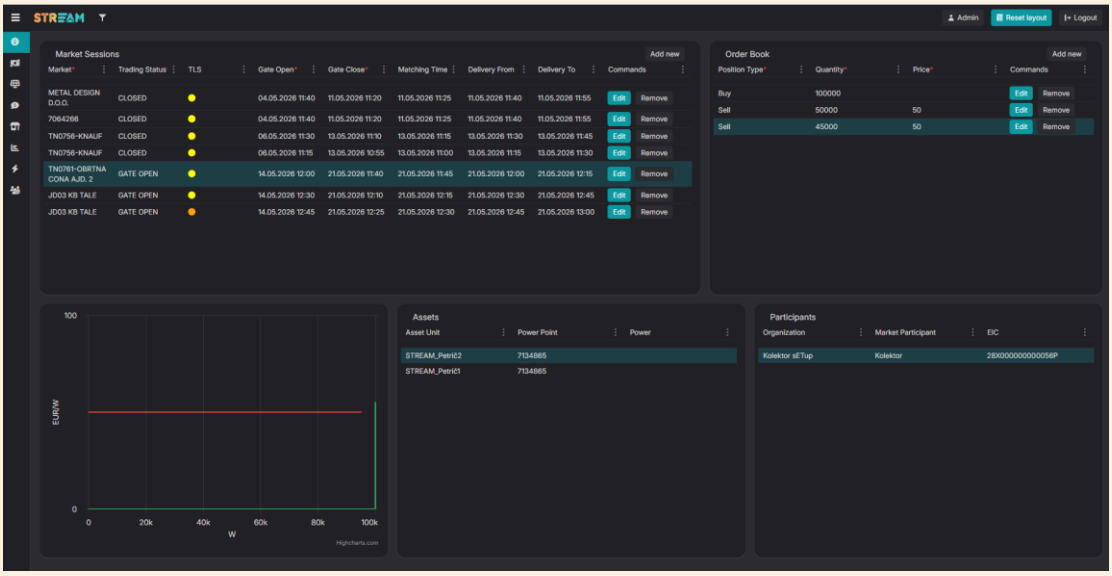


Figure 63: sMART auction view — Scenario 1

All bids were accepted in full at a clearing price of 50 €/kWh (Figure 65).

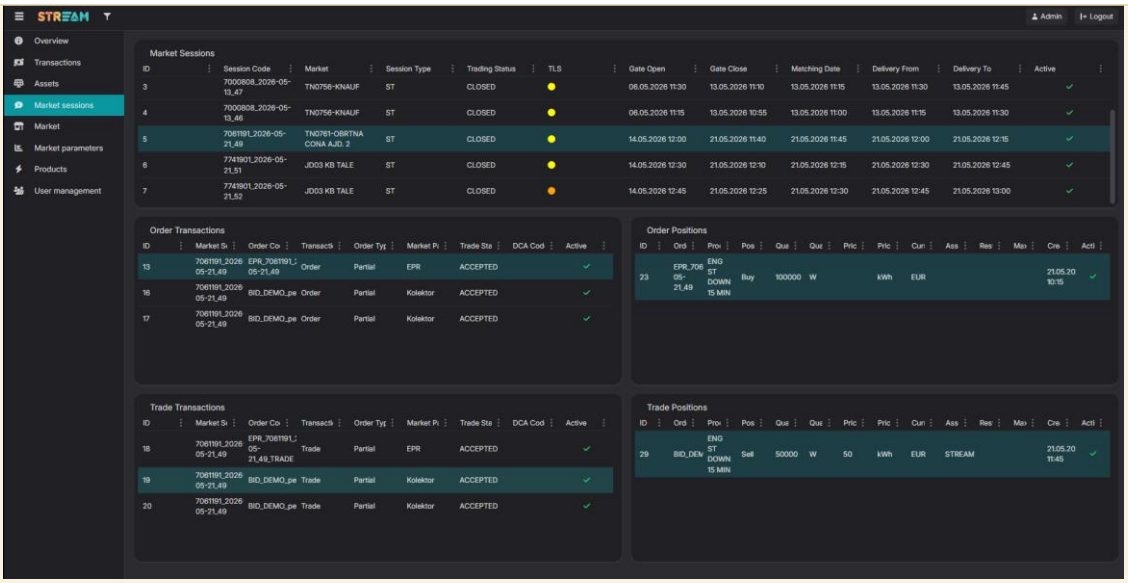


Figure 64: sMART market clearing — Scenario 1

sFLEX sent curtailment setpoints to the inverters (Figure 65) and the activation was confirmed through the sFLEX monitoring interface (Figure 66).

Topic: controllers/QYD3-3TBZ-WWNO-I6E1/devices/3/setpoint/set QoS: 1


```
{
  "values":
  [
      {
      "action": "SET",
      "type": "POWER_ACTIVE",
      "location": "DEFAULT",
      "target": "MIN",
      "phaseType": null,
      "value": -15000,
      "validForTime": 900000,
      "priority": 100
      }
  ]
  }
```


2026-05-21 12:02:49:319

Figure 65: sFLEX activation signal — Scenario 1



Figure 66: sFLEX activation view — Petrič inverters, Scenario 1

Activation verification via EPR measurements is shown in Figure 67.

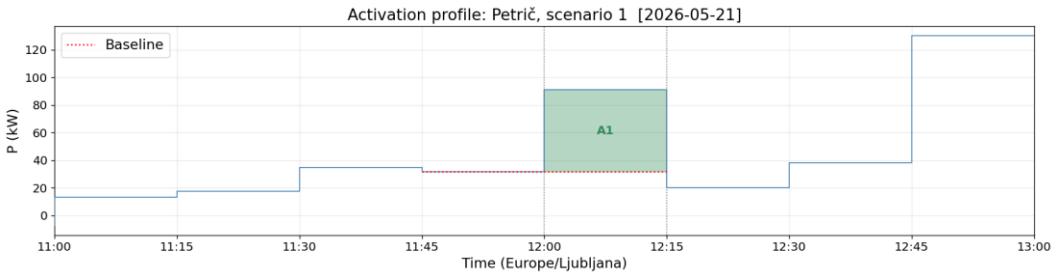


Figure 67: Activation profile — Petrič, Scenario 1

The activation results are shown in Table 32.

Table 32: Petrič activation results - scenario 1

Interval	Baseline (kW)	Actual (kW)	ΔP (kW)	Energy (kWh)
12:00-12:15	31.86	91.00	−59.14	−14.79

The effect of the activation was verified at the grid level using measurements from the MV/LV transformer station Obrtna cona Ajdovščina 2. They are shown in Figure 68 and Table 33.

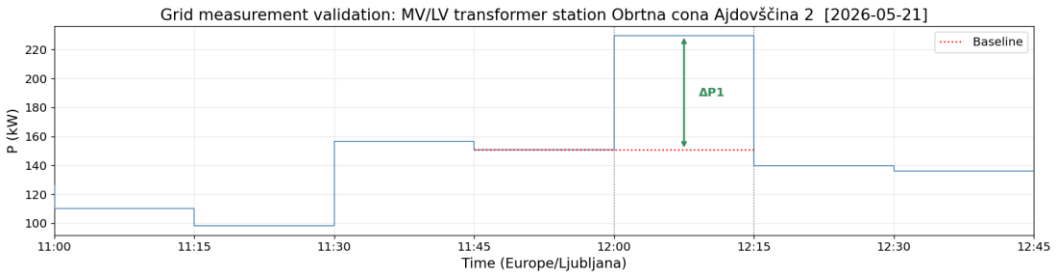


Figure 68: Grid measurement validation, MV/LV transformer, scenario 1

Table 33: Grid measurement validation, MV/LV transformer, scenario 1

Interval	Baseline (kW)	Actual (kW)	ΔP (kW)	Energy (kWh)
12:00-12:15	150.84	229.60	−78.76	−19.69

Scenario 2: MV feeder Tale, 150 kW downward (12:30–12:45) — partial acceptance

A downward congestion signal of 150 kW was sent for MV feeder Tale (element 7741901), ISP 51, Yellow TLS (Figure 69). Both Petrič and Metal Design assets are located on this feeder.


```
{
  "CongestionDetails": {
    "CongestedElementID": "7741901",
    "OrderAmount": 150000,
    "OrderDirection": "Downward",
    "ISPNumber": 51,
    "AuctionDate": "2026-05-21",
    "AuctionID": "7741901_2026-05-21_51"
  },
  "TLS": {
    "Stage": "Yellow"
  }
}
Authentication successful!
Response: []
```


Figure 69: sGRID JSON message — Scenario 2

Both Petrič and Metal Design assets are located on this feeder. KOL submitted six bids (Figure 70) totalling 180 kW (exceeding demand to test partial acceptance): two from Petrič at 50 €/kWh and four from Metal Design at 65 €/kWh (Figure 71).


```
{
  "Aggregator": {
    "AggregatorID": "28X000000000056P"
  },
  "BidDetails": {
    "AuctionID": "7741901_2026-05-21_51",
    "BidID": "BID_DEMO_md2_51",
    "FlexibilityOffered": 20000,
    "FlexibilityDirection": "Downward",
    "PricePerkWh": 65,
    "BidStatus": "Active"
  },
  "AssetDetails": {
    "AssetID": "0a895728-dab9-4a2b-82e3-947279bfa5db"
  }
}
Authentication successful!
Status code: 200
Raw response: {"Errors":null}
Response: []
```


Figure 70: sFLEX bid JSON example — Scenario 2

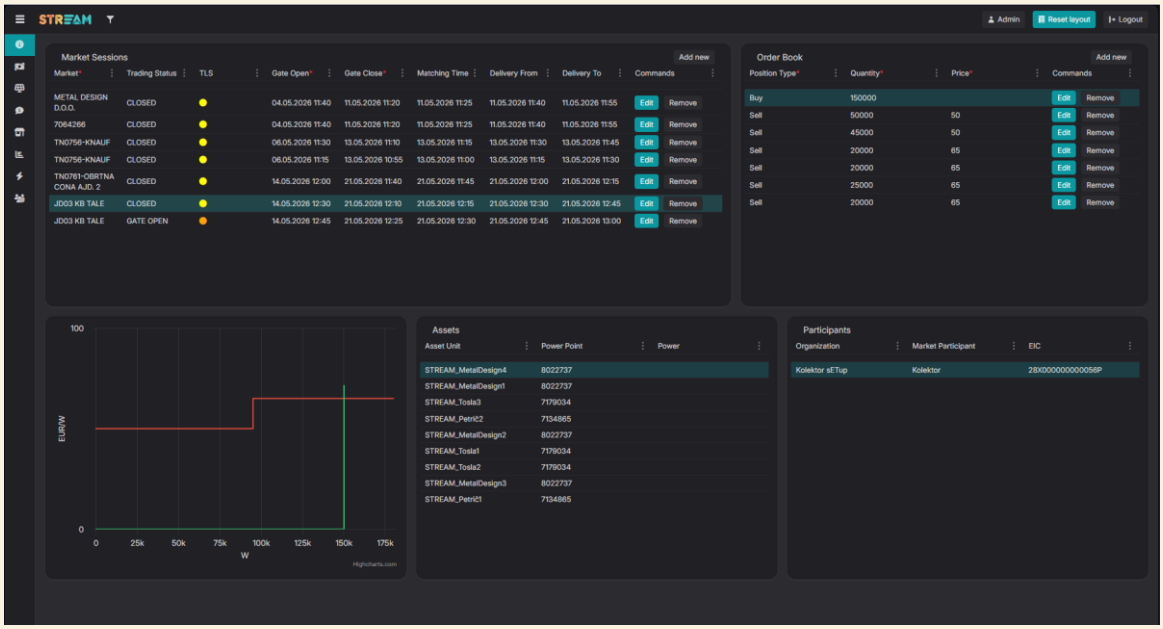


Figure 71: sMART auction view — Scenario 2

The clearing results are shown in Table 34 and Figure 72. The clearing price was 65 €/kWh

Table 34: sMART clearing results, scenario 2

BidID	Asset	Offered (kW)	Price (€/kWh)	Accepted (kW)
BID_DEMO_petric1_51	Petrič inverter 1	50	50	50
BID_DEMO_petric2_51	Petrič inverter 2	45	50	45
BID_DEMO_md1_51	Metal Design inv. 1	20	65	15
BID_DEMO_md2_51	Metal Design inv. 2	20	65	10
BID_DEMO_md3_51	Metal Design inv. 3	25	65	20
BID_DEMO_md4_51	Metal Design inv. 4	20	65	10

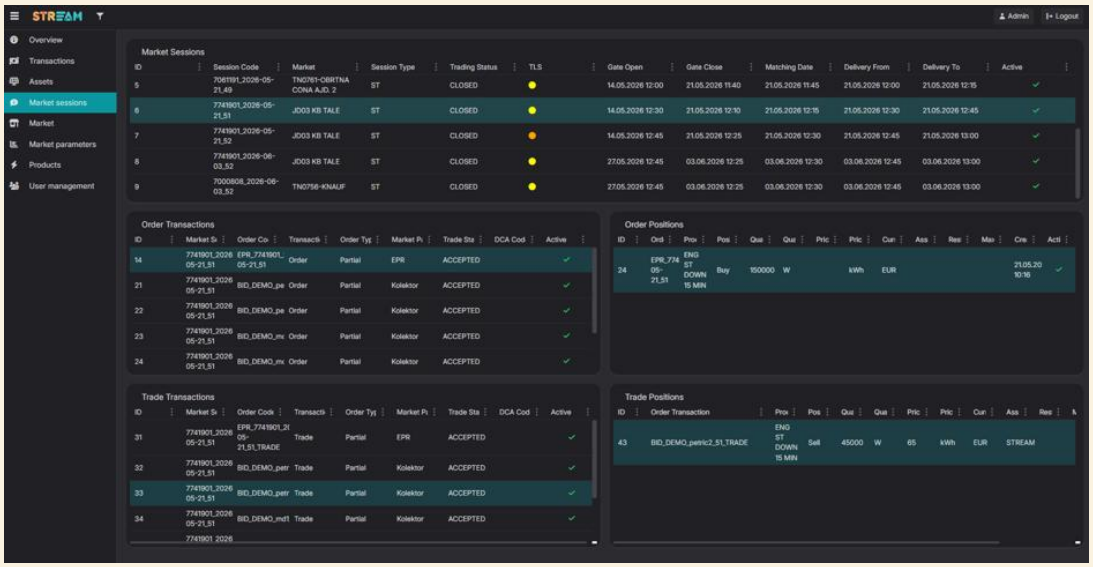


Figure 72: sMART market clearing — Scenario 2

Scenario 3: MV feeder Tale, 250 kW downward (12:45–13:00) — full acceptance

A downward congestion signal of 250 kW was sent for the same feeder, ISP 52, Orange TLS (Figure 73).

```
{
  "CongestionDetails": {
    "CongestedElementID": "7741901",
    "OrderAmount": 250000,
    "OrderDirection": "Downward",
    "ISPNumber": 52,
    "AuctionDate": "2026-05-21",
    "AuctionID": "7741901_2026-05-21_52"
  },
  "TLS": {
    "Stage": "Orange"
  }
}
Authentication successful!
Response: []
```


Figure 73: sGRID JSON message — Scenario 3

KOL submitted the same six bids as in Scenario 2 (example shown in Figure 74).


```
{
  "Aggregator": {
    "AggregatorID": "28X0000000000056P"
  },
  "BidDetails": {
    "AuctionID": "7741901_2026-05-21_52",
    "BidID": "BID_DEMO_md4_52",
    "FlexibilityOffered": 20000,
    "FlexibilityDirection": "Downward",
    "PricePerkWh": 65,
    "BidStatus": "Active"
  },
  "AssetDetails": {
    "AssetID": "639e3699-1920-4e85-84e5-a0d81ca5f6ea"
  }
}
Authentication successful!
Status code: 200
Raw response: {"Errors":null}
Response: []
```


Figure 74: sFLEX bid JSON example — Scenario 3

The sMART auction view confirmed all bids in the order book with the merit order curve (Figure 75).

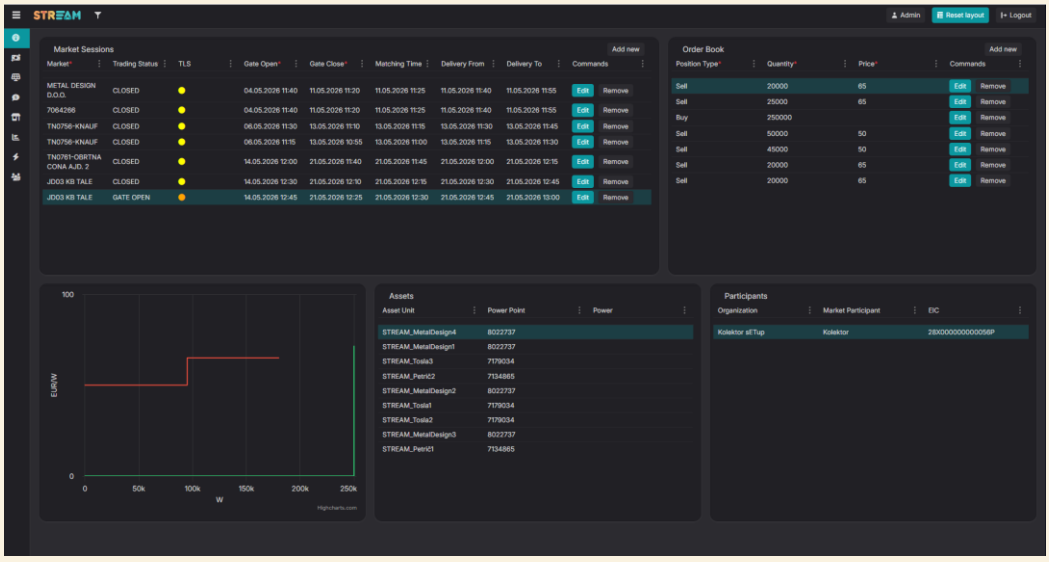


Figure 75: sMART auction view — Scenario 3

The market clearing accepted all bids in full (Table 35):

Table 35: sMART clearing results, scenario 3

BidID	Asset	Offered (kW)	Price (€/kWh)	Accepted (kW)
BID_DEMO_petric1_51	Petrič inverter 1	50	50	50
BID_DEMO_petric2_51	Petrič inverter 2	45	50	45
BID_DEMO_md1_51	Metal Design inv. 1	20	65	20
BID_DEMO_md2_51	Metal Design inv. 2	20	65	20
BID_DEMO_md3_51	Metal Design inv. 3	25	65	25
BID_DEMO_md4_51	Metal Design inv. 4	20	65	20

The total accepted flexibility was 180kW (all offered volume). The final clearing price was again 65 €/kWh (shown in Figure 76).

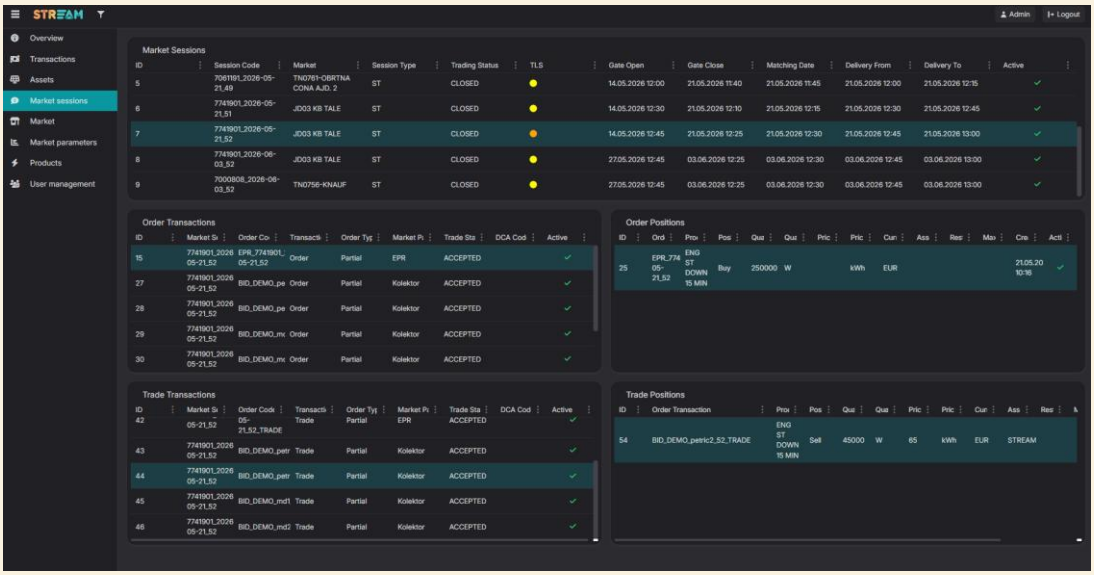


Figure 76: sMART market clearing — Scenario 3

The activation was monitored in real time through the sFLEX interface for both PV systems, showing the progressive curtailment across the two consecutive activation windows (shown in Figure 77 and Figure 78).

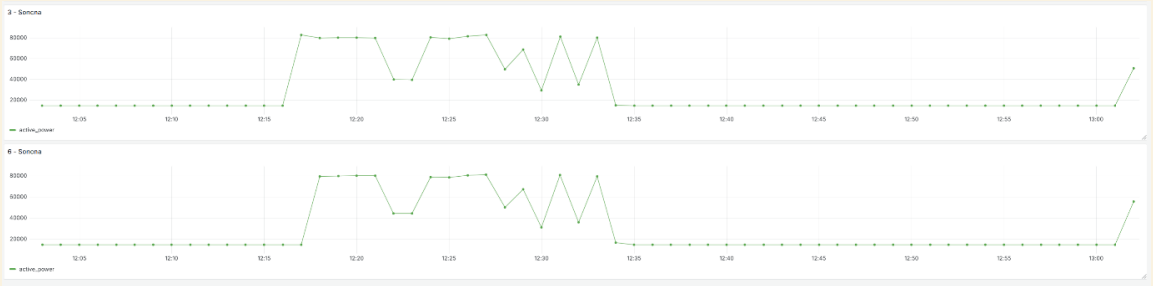


Figure 77: sFLEX activation view — Petrič inverters, Scenarios 2 and 3



Figure 78: sFLEX activation view — Metal Design inverters, Scenarios 2 and 3

Activation verification via EPR measurements for Petrič and Metaldesign is shown in Figure 79 and Figure 80. The verification is done via measurements from the main smart meter, which is the reason for differences between the activation profile shown in the figures above and the amount of provided flexibility seen from the activation profile figures below and values presented in the table.

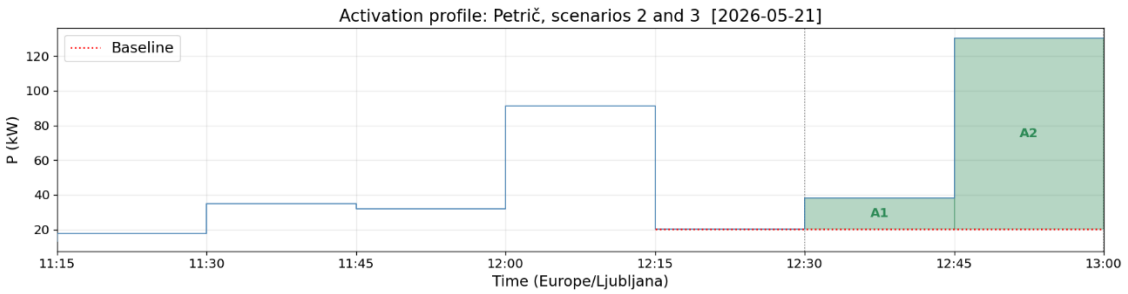


Figure 79: Activation profile — Petrič, Scenarios 2 and 3

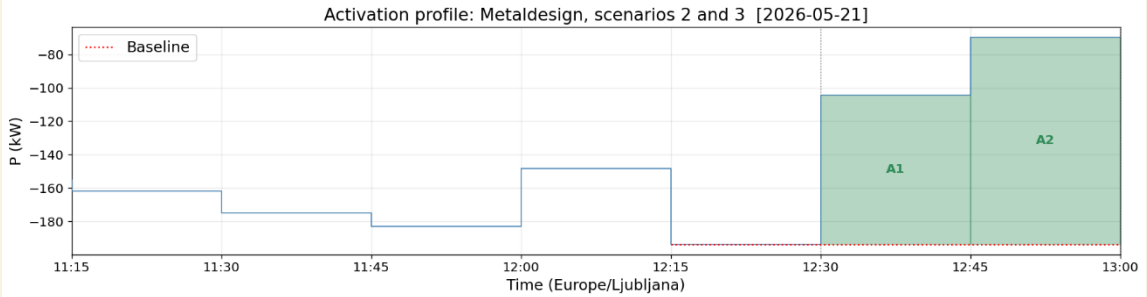


Figure 80: Activation profile — Metaldesign, Scenarios 2 and 3

The activation results are shown in Table 36.

Table 36: Activation results, scenarios 2 and 3

Interval	Asset	Baseline (kW)	Actual (kW)	ΔP (kW)	Energy (kWh)
12:30-12:45	Petrič	20.28	38.27	−18.00	−4.50
	Metaldesign	−193.63	−104.50	−89.13	−22.28
12:45-13:00	Petrič	20.28	130.29	−110.01	−27.50
	Metaldesign	−193.63	−69.78	−123.85	−30.96

The effect of the activation was verified at the grid level using SCADA measurements from the MV feeder Tale. They are shown in Figure 81 and Table 37.

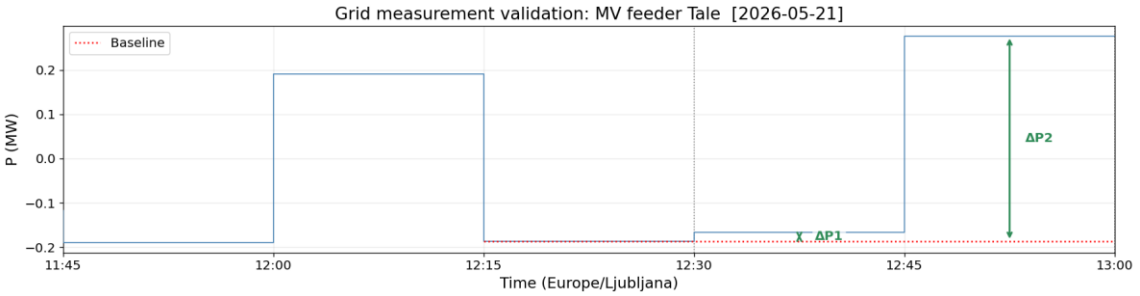


Figure 81: Grid measurement validation, MV feeder, scenarios 2 and 3

Table 37: Grid measurement validation, MV feeder, scenarios 2 and 3

Interval	Baseline (MW)	Actual (MW)	ΔP (MW)	Energy (MWh)
12:30-12:45	−0.19	−0.17	−0.02	-0.005
12:45-13:00	−0.19	0.28	-0.46	-0.116

Qualitative analysis of the results

The demonstration of SI-UC.02.01 successfully validated the end-to-end operation of the sMART-based congestion management workflow in the Slovenian pilot. The complete chain from the sGRID congestion signal, through auction opening in sMART, bid submission and Device Registry validation, market clearing, activation signal dispatch via sFLEX, real asset activation, and independent measurement verification was executed and confirmed to operate as designed.

The integration tests confirmed that the tool-to-tool interfaces (sGRID–sMART, sFLEX–sMART, sMART–Device Registry) function correctly and that the platform enforces all eligibility constraints before admitting a bid into the order book. The five DR validation scenarios demonstrated that sMART reliably rejects bids that fail any of the required checks: prequalified power, aggregator assignment, asset location, prequalification status, and flexibility direction. This is a key requirement for the credibility and security of the market mechanism, as it ensures that only technically eligible and correctly located assets can participate in a given auction.

The two live demonstrations covered two different asset types (EV charging and PV curtailment) and three market scenarios designed to test different clearing outcomes.

In Demonstration 1 (EV activation at Knauf), the full workflow was executed with a single asset and a single bid, validating the simplest auction case. The sFLEX activation profile confirmed that the EV

charging station responded promptly to the activation signal, with consumption dropping to near zero within the activation window.

In Demonstration 2 (PV curtailment), the three scenarios were structured to test how sMART handles different supply-demand conditions: roughly balanced supply and demand (Scenario 1, 95 kW offered and 100 kW required), supply exceeding demand with partial bid acceptance (Scenario 2, 180 kW offered and 150 kW required), and demand exceeding supply with all bids fully accepted but the flexibility need not fully met (Scenario 3, 180 kW offered and 250 kW required). In the latter case, the market selected and activated all available bids; in an operational setting, the DSO would complement the market outcome with additional measures such as long-term contracted flexibility or non-firm connection agreements, as foreseen by the TLS framework for Orange-stage congestions.

The pay-as-cleared merit order algorithm operated as specified across all scenarios. In Scenario 2, where bids were submitted at two price levels (50 and 65 €/kWh), the cheaper bids were accepted in full while the more expensive bids were partially accepted to meet the remaining demand, with all accepted bids remunerated at the marginal clearing price. This demonstrated the correct functioning of the welfare-maximising clearing logic with divisible bids.

The asset-level measurements from smart meters confirmed that the activations had a real physical effect. However, the comparison between accepted bid volumes and measured flexibility at the metering point revealed a general challenge inherent to this type of verification. Since smart meter measurements represent 15-minute averages of the total power at the metering point (combining both consumption and generation), the measured activation effect depends not only on the curtailed PV output but also on concurrent changes in on-site consumption that are independent of the activation. This averaging effect can both understate and overstate the delivered flexibility relative to the accepted bid volume within any single interval. For example, the relatively low ΔP observed for Petrič in Scenario 2 (−18 kW against an accepted volume of 95 kW) is partly attributable to lower PV generation at that moment and partly to the 15-minute averaging that can mask the activation within the measurement interval. Conversely, ΔP values at Metal Design in some intervals exceeded the corresponding accepted volumes, likely due to concurrent independent load changes at the site. More granular measurement data (like 5-minute or 1-minute resolution) and separate metering of the PV inverters and site consumption would improve activation verification accuracy.

At the grid level, SCADA measurements from the MV feeder and transformer control measurements confirmed that the activations had a measurable impact on the distribution network. The most notable observation was the reversal of power flow direction on MV feeder Tale during Scenario 3, where the feeder shifted from −0.19 MW (reverse power flow due to PV generation exceeding local consumption) to +0.28 MW (normal power flow direction). While the demonstrations used simulated congestion scenarios and were not designed to resolve actual grid constraints, this result illustrates that coordinated PV curtailment at the scale demonstrated can materially alter power flow conditions on an MV feeder. The smaller grid-level impact observed in Scenario 2 (ΔP of only −0.02 MW despite significant asset-level curtailment) is attributable to the fact that MV feeder SCADA measurements reflect the aggregate behaviour of all loads and generators connected to the feeder, meaning that concurrent changes in other consumers' profiles can mask or offset the effect of a single activation.

It should be noted that the demonstrations validated the technical workflow and the ability to produce real activations with measurable grid impact, rather than the resolution of actual congestion events. The congestion scenarios were simulated by setting conservative planning limits, and the sGRID signals were prepared manually to ensure asset availability at the scheduled time. In a fully operational deployment, the sGRID pipeline would generate congestion signals automatically based on its forecasting output, and activations would be triggered without prior coordination with asset owners.

A practical challenge encountered during the demonstrations was the unavailability of some planned assets. Tosla's PV assets were turned off during the demonstration period due to negative wholesale market prices, making them ineligible for activation. Tosla's BESS could not be activated because it is managed by an external aggregator outside the STREAM ecosystem. These situations reflect realistic operational constraints (asset availability for local flexibility markets will depend on wholesale market conditions and contractual arrangements) and highlight the importance of having a sufficiently diverse asset portfolio to ensure market liquidity.

The demonstrations involved a single aggregator (Kolektor sETup) as the sole market participant. While this was sufficient for validating the technical workflow, it means that competitive price discovery between multiple aggregators was not tested. Similarly, only the short-term flexibility product was demonstrated; the long-term product was deliberately excluded to focus the demonstration effort on the primary congestion management mechanism.

Experiment number	**SI-UC.05.01**
Name	sGRID congestion forecast module assessment
Timeframe	April – May 2026 (M43-M44)
Targets	Generate a day-ahead congestion forecast in order to detect any congestions ahead of time. Determine the congested area and needed flexibility (direction and amount) to address the congestion. Determine the TLS status for all parts of the grid. Assess the accuracy of the models.
Actors	• UL as the provider of the tool • EPR as the data provider and DSO • IND as the operator of sDATA
STREAM products	sGRID, sMART, sDATA
Assets & systems	Loads and production assets in the grid, smart meters, MV/LV assets (transformers, lines, switches), SCADA
Description of the experiment	The main function of sGRID is to perform a congestion forecast using the forecasted state of the network to identify congestions by comparing the forecasted values to the defined grid limits. Congestion occurs in case the forecasted value exceeds the grid limit (either planning or operational). The congestion forecast data will be stored in sGRID repository and will be evaluated by comparing it to the actual grid values gathered from measurements (if available), or by using the real smart meter measurements to calculate the estimated grid state. **Pre-condition/triggering event:** Done periodically (every 24h for the day ahead and every 15min for the next 2h). • Distribution grid topology modelled in sGRID • "Real-time" data available from sDATA (as real time data will not be available, we will use data from the previous day as "real-time") • TLS state boundaries defined (planning and operational limits for every grid element) **Steps:** 1. sGRID forecasts P and Q load profile for all loads and production units

	2. sGRID uses forecasted load profiles to perform load flow calculation resulting in state of the grid (U per node, I per line, loading factor for lines and transformers) 3. Using the defined grid limits, sGRID determines if there are any foreseen congestions (timestamp, location, magnitude) 4. Based on this congestion forecast, sGRID assigns TLS status to each grid element for all timesteps and calculates the needed flexibility (direction, amount) to address the congestion 5. The results are communicated to sMART, as well as saved in the sGRID database for DSO analyses **Post condition:** • Determined TLS stages for grid elements • Calculated needed flexibility • sMART receives grid state information (TLS state, congestion information) The experiment will be validated by: • Comparing the forecasted P and Q profiles with the actual measurements (to determine the accuracy of the load forecast) • Comparing the forecasted grid state to actual control measurements (where they are available) to check if the congestions were correctly predicted. • Testing that the results are correctly saved in the sGRID database • Testing the connection between sGRID and sMART
Exception paths and scenarios of the experiment	**Steps:** 1. sGRID forecasts P and Q load profile for all loads and production units 2. sGRID uses forecasted load profiles to perform load flow calculation resulting in state of the grid (U per node, I per line) 3. Load flow calculation does not converge 4. sGRID checks for potential issues (nan or very high values in the simulation inputs), then tries to run the power flow again with increased iterations
Datasets required for the experiment	• Historical timeseries measurements (P and Q) • Historical weather timeseries data • Weather forecast data • “Real-time” grid measurements (for updated forecasts) • Grid limits • Network topology
Field data to be gathered	• Timeseries measurement data from AMI and SCADA (Real-time data not possible with current metering equipment so data from D-1 will be used as real-time data)
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.04, KPI SI.05
Results of the Experiment	
sGRID was operated continuously over the evaluation period from 1 April to 21 May 2026 on a dedicated server infrastructure. The start of the evaluation period corresponds to the completion of the sDATA data retrieval stabilisation process described in Section 3.1.5, after which the data pipeline provided measurement data with sufficient quality and completeness for operational	

forecasting. The evaluation period concluded at the end of the third week of May to allow for results collection, KPI calculation, and preparation of the present deliverable within the reporting timeline.

The DA run executed daily at 12:00 local time, producing a 96-step forecast (00:00–23:45) at 15-minute resolution. The ST run executed every 15 minutes, producing a single-step one-hour-ahead update. Average execution time was 30–40 seconds for both run types. Operation was generally stable, but occasional ST runs encountered power flow convergence issues, in which case DA forecast values were used as fallback.

The results are structured in two parts: load forecasting accuracy (comparing individual load forecasts against smart meter and transformer measurements received via sDATA) and grid state accuracy (comparing simulated power flows against SCADA and control measurements at the MV feeder, MV/LV transformer, and primary substation levels). All KPIs reported below are preliminary, computed against data received from sDATA, which may contain missing values and data quality issues. The definitive KPI calculation will be performed as part of WP6.

Load forecasting results

sGRID forecasts 147 load points individually, classified into five categories based on the measurement source and load magnitude. Individual loads are metered via smart meters and are further subdivided by connected power into small (<30 kW, n=81), medium (30–300 kW, n=29) and large (≥300 kW, n=12). Aggregated loads are represented at the transformer level and are subdivided based on whether dedicated control measurements are available at the MV/LV transformer (control, n=16) or whether the load profile is constructed by aggregating individual smart meter profiles (aggregated profile, n=9). The distribution of connected power within each individual load category is shown in Figure 82.

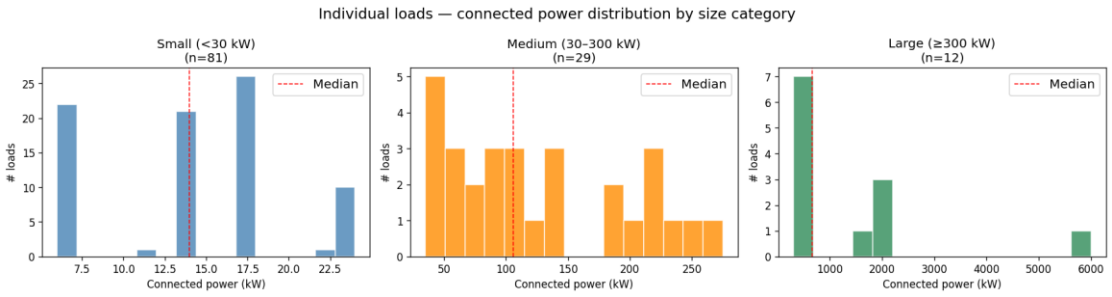


Figure 82: Individual loads — connected power distribution by size category

For each category, representative timeseries comparisons between the DA forecast, ST forecast, and actual measurements are presented for one week (4–11 May 2026), selected to illustrate the range of forecasting performance within the category across different load types and consumption patterns. Additionally, preliminary KPI distribution is shown for each category (more accurate KPI calculation will be performed in scope of WP6).

Individual loads — Small (<30 kW)

This category contains the largest number of loads (81) and exhibits the most varied consumption patterns. Loads range from meters with regular, predictable on/off cycles to meters with near-zero average consumption and sporadic peaks.

A good forecast example is shown for a load with a stable daily pattern, where both the DA and ST forecasts closely track the measured profile (Figure 83).

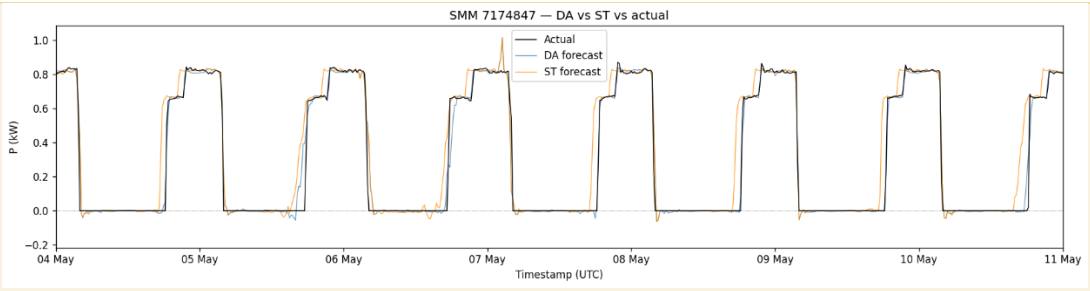


Figure 83: sGRID, Small load — good example

A bad example shows a load with near-zero average consumption and rare sporadic spikes, where the forecast cannot anticipate individual peaks (Figure 84).

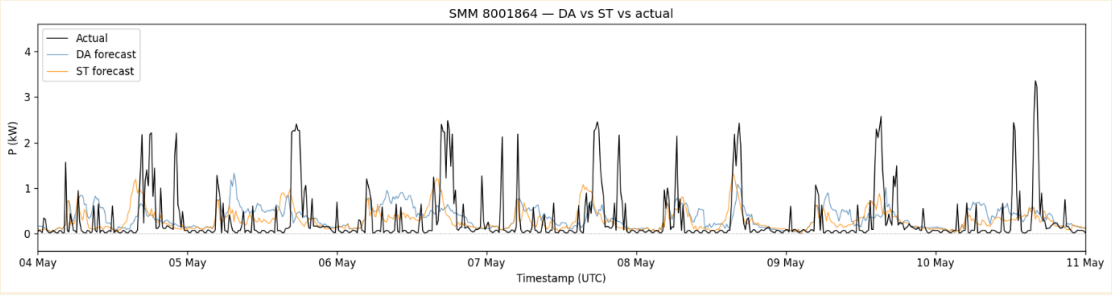


Figure 84: sGRID, Small load — bad example

The KPI distributions across all 81 loads are shown in Figure 85. Outliers (5) beyond the 95th percentile of the x-axis range were removed for readability.

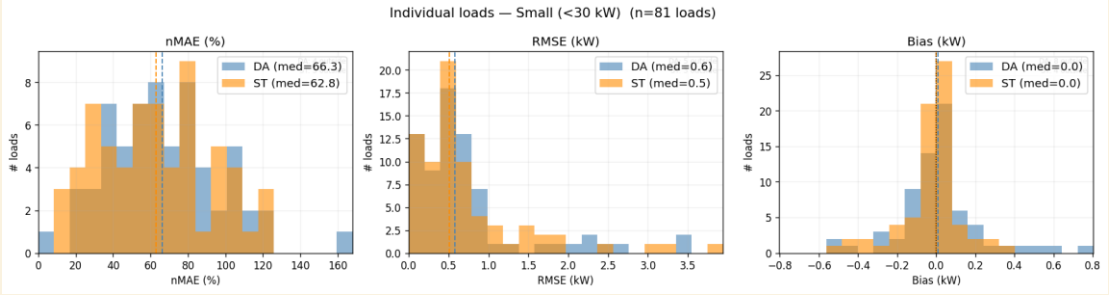


Figure 85: KPI distribution — individual loads, small

Individual loads — Medium (30–300 kW)

This category (29 loads) includes a range of industrial consumers with connected power from 35 to 275 kW. Good, intermediate, and bad examples are shown in Figure 86, Figure 87 and Figure 88 respectively.

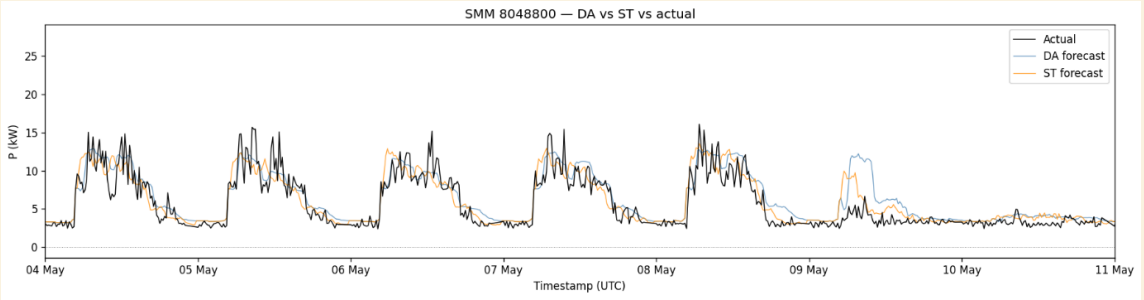


Figure 86: sGRID, medium load — good example

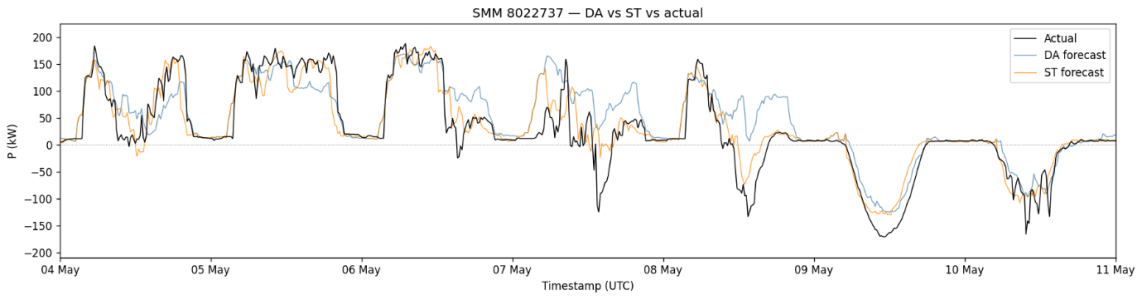


Figure 87: sGRID, medium load — intermediate example

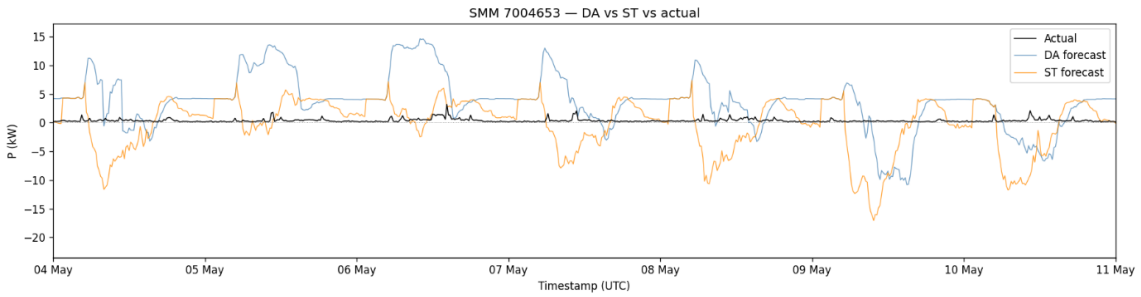


Figure 88: sGRID, medium load— bad example

The KPI distributions are shown in Figure 89. Outliers (2) beyond the 95th percentile of the x-axis range were removed for readability.

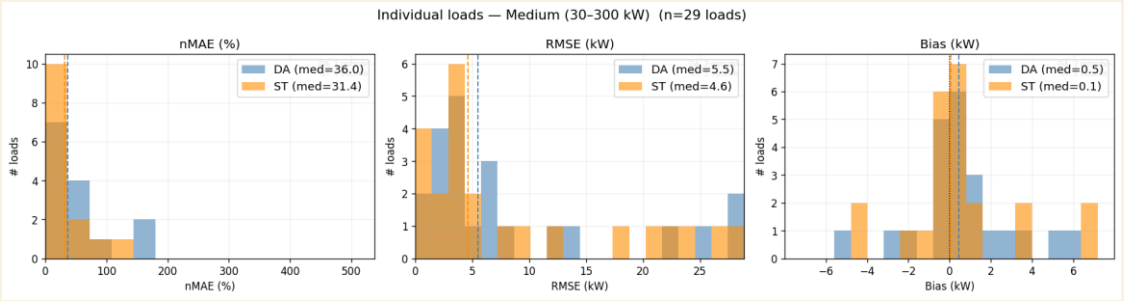


Figure 89: KPI distribution — individual loads, medium

Individual loads — Large (≥300 kW)

This category (12 loads) includes the largest industrial consumers with connected power from 300 kW to 6 MW. A good timeseries example is shown in figures for large load (Figure 90) and large production (Figure 91).

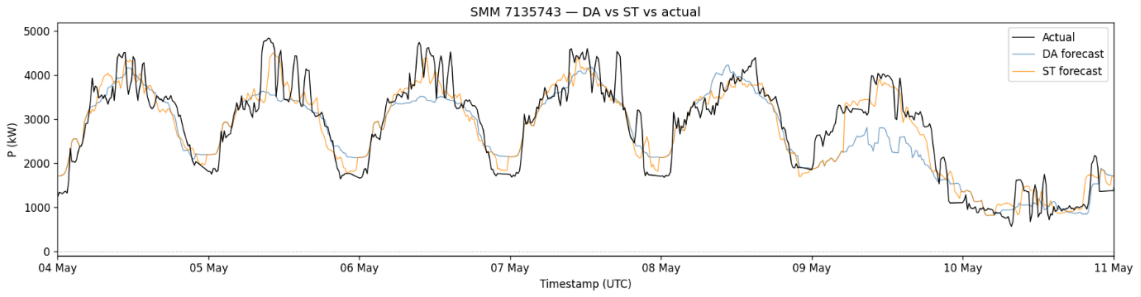


Figure 90: sGRID, large load – good example

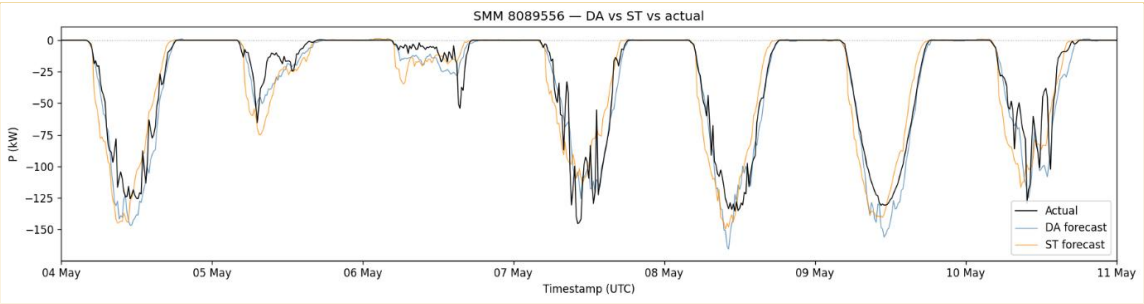


Figure 91: sGRID, large production – good example

The KPI distributions are shown in Figure 92. Outliers (5) beyond the 95th percentile of the x-axis range were removed for readability.

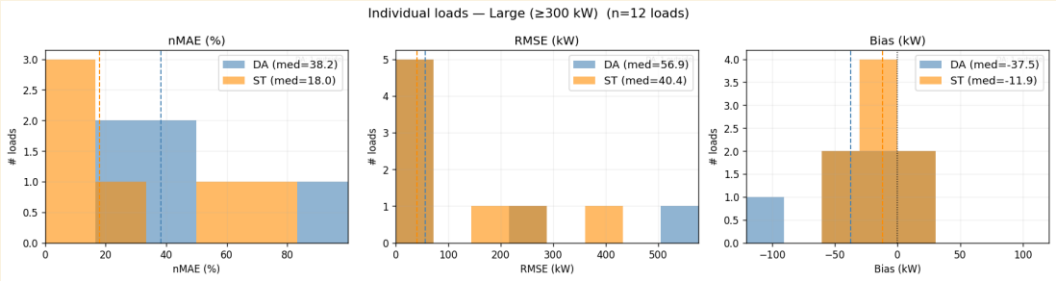


Figure 92: KPI distribution — individual loads, large

Aggregated loads — Control measurements

This category (16 loads) represents MV/LV transformer stations where dedicated control measurements (active and reactive power at the secondary side) are available. Forecasting models are trained directly on these transformer-level measurements. A good and a worst-performing timeseries example are shown in Figure 93 and Figure 94.

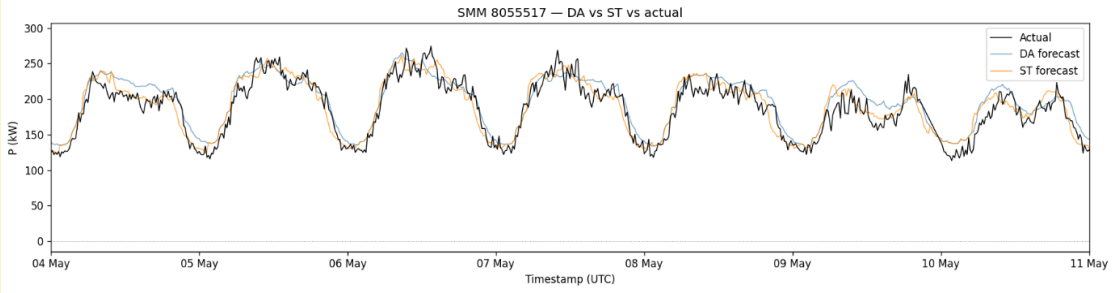


Figure 93: sGRID, control load — good example

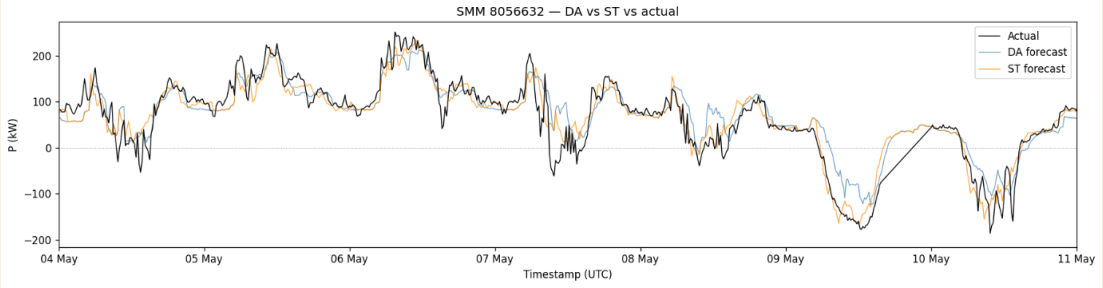


Figure 94: sGRID, Control load — worst example

The KPI distributions are shown in Figure 95. Outliers (2) beyond the 95th percentile of the x-axis range were removed for readability.

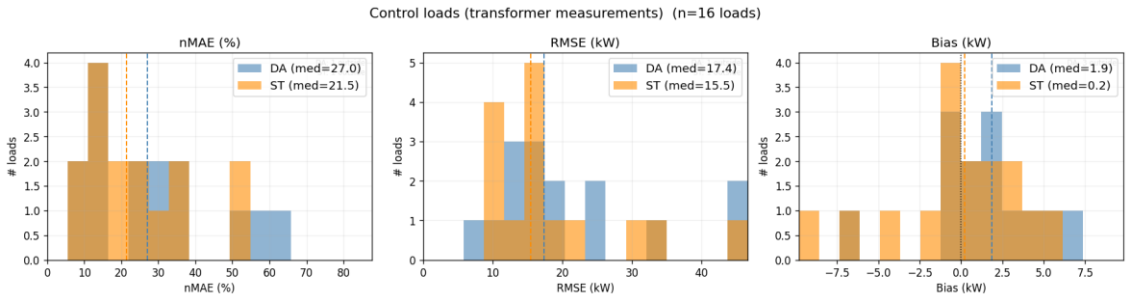


Figure 95: KPI distribution — control loads

Aggregated loads — Aggregated profiles

This category (9 loads) represents transformer stations without control measurements, where the load profile is constructed by aggregating individual smart meter readings of loads connected under the transformer. Good, intermediate, and challenging timeseries examples are shown in Figure 96, Figure 97 and Figure 98.

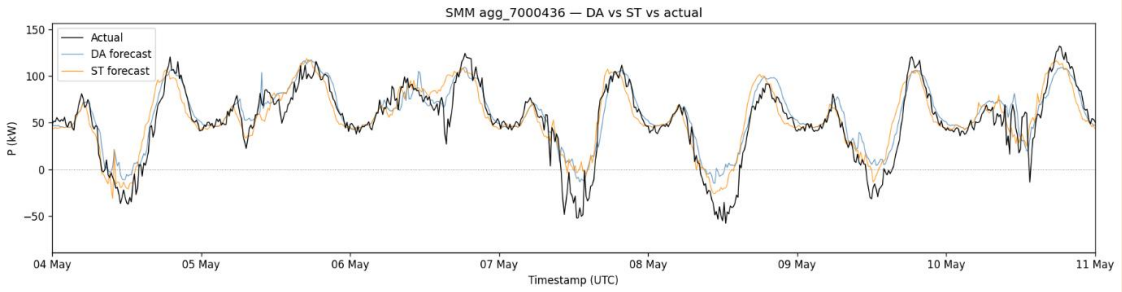


Figure 96: sGRID, aggregate profile load — good example

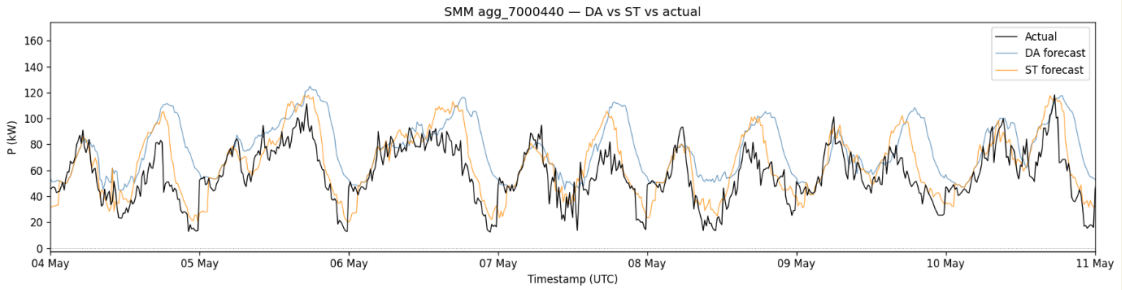


Figure 97: sGRID, aggregate profile load — intermediate example

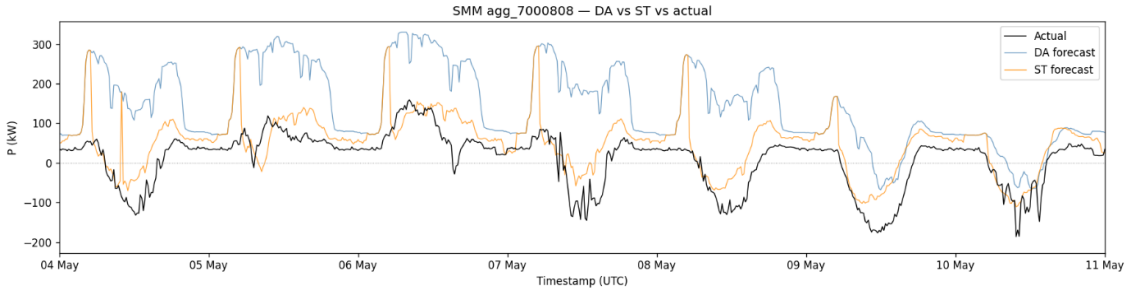


Figure 98: sGRID, aggregate profile load — bad example

The KPI distributions are shown in Figure 99. One outlier beyond the 95th percentile of the x-axis range was removed for readability.

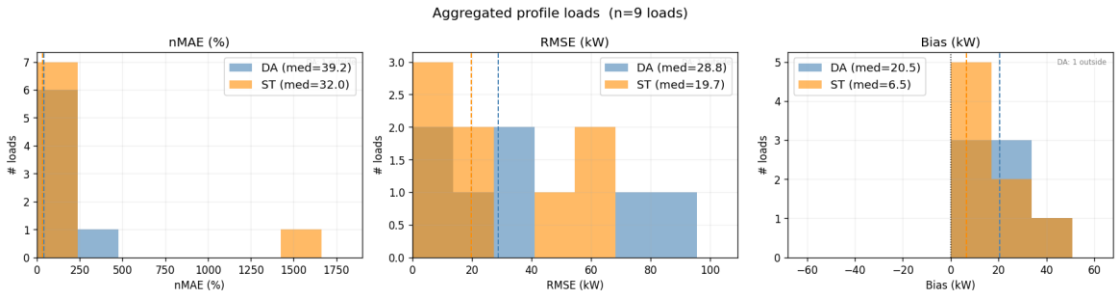


Figure 99: KPI distribution — aggregated profile loads

It should be noted that validation for this category is inherently less reliable, as the reference profile is itself an aggregation of individual smart meter readings from sDATA, which may contain missing data or inconsistencies.

A summary of median KPI values across all categories is given in Table 38.

Table 38: Summary of the median KPI values for different load categories

Category	n	nMAE DA	nMAE ST	RMSE DA	RMSE ST	Bias DA	Bias ST
Ind – small	81	66.3 %	62.8 %	0.6 kW	0.5 kW	0.0 kW	0.0 kW
Ind – med	29	36.0 %	31.4 %	5.5 kW	4.6 kW	0.5 kW	0.1 kW
Ind – large	12	38.2 %	18.0 %	56.9 kW	40.4 kW	-37.5 kW	-11.9 kW
Control	16	27.0 %	21.5 %	17.4 kW	15.5 kW	1.9 kW	0.2 kW
Aggregated	9	39.2 %	32.0 %	28.8 kW	19.7 kW	20.5 kW	6.5 kW

Grid state forecasting results

The grid state is evaluated by comparing the simulated active power from sGRID's power flow (using forecasted load profiles as input) against independent measurements: SCADA for MV feeders and the primary substation, and control measurements for MV/LV transformer stations. Timeseries comparisons for one representative week (4–11 May 2026) are presented for each grid level, alongside KPI tables. On 23 April 2026 a topology correction was applied to the grid model (described in the qualitative analysis) - the MV/LV transformer KPIs are therefore reported for the post-correction period only.

MV/LV transformer stations

Evaluation is limited to the three Obrtna cona transformer stations in the pilot area where control measurements are available. The timeseries comparison is shown in Figure 100.

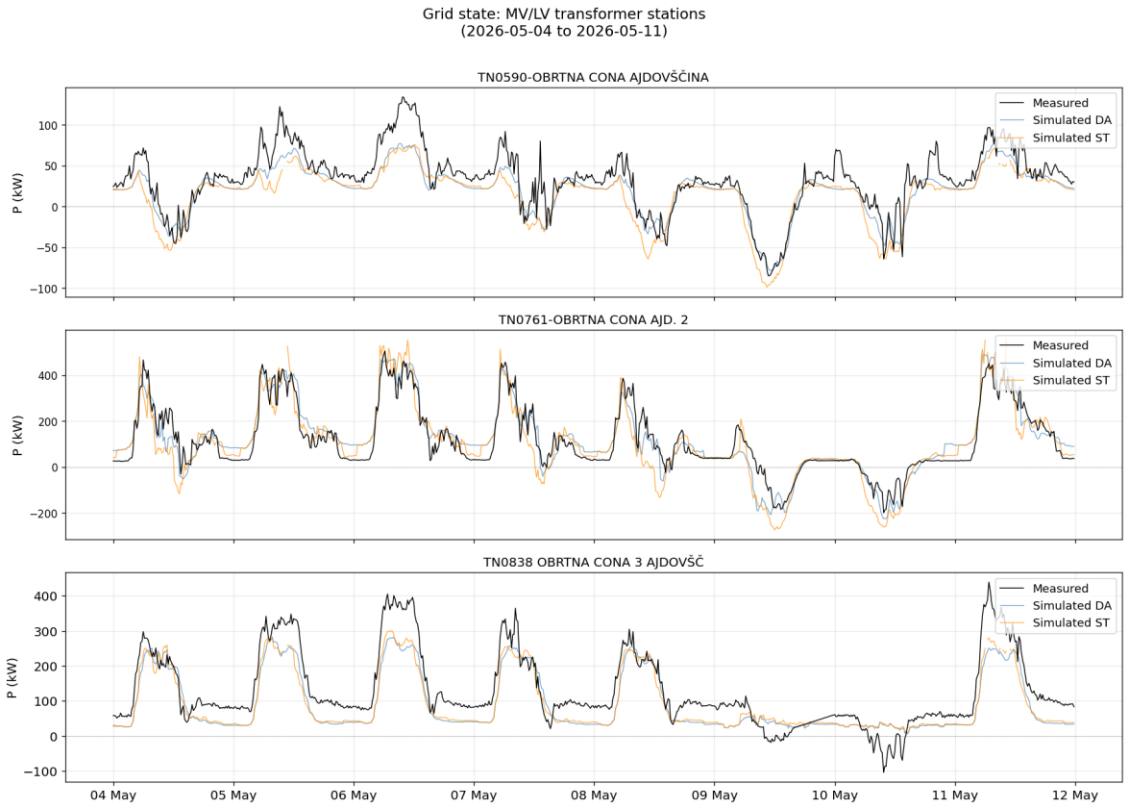


Figure 100: Grid state — MV/LV transformer stations

MV feeders

The timeseries comparison for all four MV feeders (Fructal, Čistilna naprava, Tale, Mirce) is shown in Figure 101.

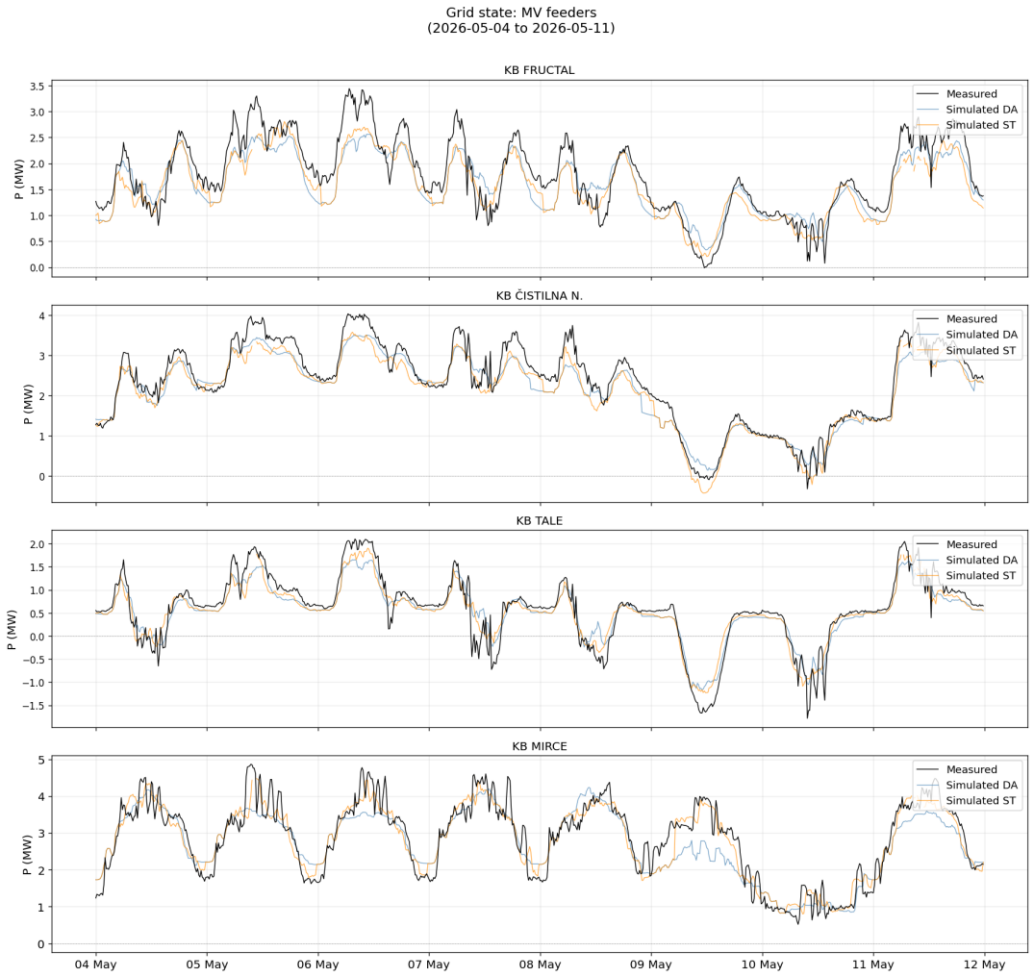


Figure 101: Grid state — MV feeders

Primary substation (HV/MV)

The timeseries comparison for the primary substation RTP Ajdovščina is shown in Figure 102.

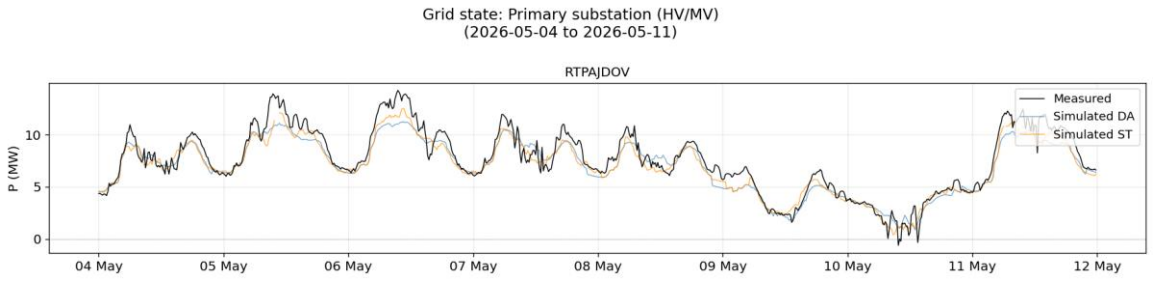


Figure 102: Grid state — primary substation

Qualitative analysis of the results

The evaluation over the presented period demonstrates that sGRID's bottom-up approach to grid state forecasting (meaning forecasting individual loads and running power flow simulations to derive the grid state) is feasible and produces meaningful results across multiple levels of the distribution network. At the MV feeder and primary substation levels, the simulated grid state tracks the measured profiles well, with nMAE values of 13–19% for three of the four MV feeders and approximately 14% (DA) / 13% (ST) for the primary substation. These results indicate that the tool can provide the DSO with a reliable day-ahead and short-term view of the grid state at these levels. Combined with the congestion management workflow validated under SI-UC.02.01, the

results show that sGRID can support the detection of potential grid constraints and the initiation of flexibility-based mitigation through sMART.

However, the results also clearly demonstrate that the accuracy of this bottom-up forecasting approach depends critically on the quality of the underlying grid topology model. The topology correction performed on 23 April 2026, which is described below, illustrates this dependency in concrete terms, and remaining errors at the MV/LV transformer level suggest that additional topology inaccuracies are still present.

Load forecasting performance

The ST forecast consistently improves over the DA forecast across all load categories, with the largest improvement observed for large industrial loads (median nMAE from 38.2% to 18.0%). This improvement is primarily attributable to the lag features used in the ST models, which incorporate recent measured power values as additional inputs. For large industrial loads, which tend to exhibit stable multi-day consumption patterns, these lag features are highly valuable, as a measured value from an hour ago is a strong predictor of the current value. For small loads with irregular and unpredictable patterns, the lag features provide less added value, which explains the modest ST improvement in that category (median nMAE from 66.3% to 62.8%).

The nMAE values for small loads appear high in relative terms (median ~63–66%), but the corresponding absolute errors are very small (median RMSE of 0.5–0.6 kW). This is partly because many small loads have low average consumption, which inflates the relative error metric, and partly because their consumption patterns are inherently irregular and difficult to forecast at the individual level. From the perspective of grid state forecasting, however, what matters is the aggregate accuracy at the feeder or transformer level rather than the accuracy of any single small load. Individual forecast errors partially cancel out when loads are summed, meaning that even imperfect small-load forecasts contribute meaningfully to the overall grid state estimate.

A general observation across all categories is that the forecasts capture the timing of consumption and generation patterns well but can struggle with the magnitude of short-duration peaks. For congestion detection, peak magnitude is the critical parameter: a forecasted peak that is correctly timed but underestimated in magnitude could lead to a missed congestion event. Improving peak forecasting accuracy, for instance through additional features capturing operational schedules or production plans of large industrial consumers, is an area where further work would be beneficial.

The large-load category exhibits a systematic negative bias (median −37.5 kW DA, −11.9 kW ST), indicating that sGRID tends to underestimate these loads on average. The exact cause is not fully identified but may relate to factors not captured by the current feature set, such as internal production schedules or progressive load growth. The ST lag features substantially reduce this bias, confirming their value. For the aggregated profile category, a positive bias is observed (median 20.5 kW DA, 6.5 kW ST). Validation for this category is inherently less reliable than for loads with direct measurements, as the reference profile is itself an aggregation of individual smart meter readings from sDATA, which may contain missing data or inconsistencies.

Grid state forecasting performance

At the MV feeder level, three of the four feeders (Fructal, Čistilna naprava, Mirce) show nMAE values between 13% and 20%, with absolute errors consistent with the scale of the feeder loading. The Tale feeder is an outlier with nMAE exceeding 300%, but this is driven by its low mean actual power (~0.41 MW) rather than disproportionately large absolute errors (among the four MV feeders, this is the only one with reverse power flow present – power can go into negative).

At the MV/LV transformer station level, post-correction nMAE values range from approximately 49% to 79%. While higher than the MV feeder level, this is expected given the smaller scale and the amplified effect of individual load forecast errors at lower voltage levels. The remaining errors are most likely attributable to additional inaccuracies in the topology model, which include loads that are missing, incorrectly connected, or assigned to the wrong part of the network. Further

improvement at this level would require a systematic topology check, comparing the digital model against the physical network configuration.

At the primary substation level, the nMAE of ~14% (DA) and ~13% (ST) represents the best accuracy among all grid levels. This is consistent with the aggregation effect: errors in individual load forecasts cancel out more effectively when summed across all four feeders. While the primary substation is less relevant for localised congestion detection (which occurs downstream at the MV/LV level), an accurate aggregate forecast provides useful information for overall network monitoring and could support other DSO planning and operation applications.

Topology correction and its impact

A key finding of the evaluation period was the detection and correction of a topology error in the grid model, which illustrates both the sensitivity of the bottom-up approach to topology accuracy and the tool's potential to serve as a topology validation instrument.

During the initial weeks of operation, the simulated grid state at the MV/LV transformer level showed large deviations from the control measurements for the Obrtna cona transformer stations. The pre-correction nMAE for Obrtna cona 1 (TN0590) was 224% (DA), indicating that the simulated profile was very different compared to the measured one. To further investigate, the sum of the individual load profiles downstream of each transformer was compared against the transformer-level control measurement. The profiles did not align for two of the three stations. A stacked plot of the LV feeder contributions to Obrtna cona 1 revealed that one feeder (7022105) carried a disproportionately high load whose profile shape matched parts of the Obrtna cona 2 measured profile rather than the Obrtna cona 1 profile. Based on this analysis, the connection of feeder 7022105 was reassigned from Obrtna cona 1 to Obrtna cona 2 in the grid model.

Following the correction on 23 April 2026, the topology validation was repeated and showed a dramatic improvement. For Obrtna cona 2, the simulated and measured profiles became nearly perfectly aligned. The post-correction nMAE for Obrtna cona 1 dropped from 224% to 67% (DA). The remaining discrepancies for Obrtna cona 1 and 3 are most likely due to further topology inaccuracies — loads that are missing or connected in the wrong section of the network.

This finding confirms the concern raised in Section 2.1.6 regarding topology modelling challenges. For a bottom-up forecasting approach that relies on correctly assigning each load to its topological location, even a single misplaced load or feeder can cause significant deviations at the transformer level.

Operational considerations

From a practical deployment perspective, several observations are worth noting. Due to the D-1 data availability constraint at the pilot site, the entire sGRID pipeline operates with a one-day delay: the ST run executed at, for example, 14:00 on day D is forecasting for 15:00 on D-1, using measured lag features from D-1 up to approximately 13:00. From the model's perspective, this is equivalent to having access to close-to-real-time measurements (approximately one hour old) and producing a one-hour-ahead forecast. The ST results reported above therefore already reflect the accuracy that would be achieved with actual near-real-time measurement access in a fully operational deployment. The improvement from DA to ST is most pronounced for large and stable industrial loads and least pronounced for small irregular consumers. From a practical standpoint, this suggests that if a DSO were to invest in upgrading measurement infrastructure to support close-to-real-time data access for a tool like sGRID, a targeted approach (prioritising larger consumers and key transformer stations) would yield the most benefit relative to the cost of meter reparameterization or upgrades.

Experiment number	**SI-UC.06.01**

Name of the experiment	Utilization of flexibility in mFRR
Timeframe	January - June 2026 (M41-M45)
Targets	The goal of this Test Case is to provide available flexibility in the TSO ancillary services market (mFRR) and to successfully activate the requested power when the TSO calls for asset activation.
Actors	• KOL – aggregator • ELES – TSO • Incom Leone, Mlinotest - Asset owners
STREAM products	sFLEX
Assets & systems	Cold storage rooms (Incom Leone), mill (Mlinotest), sFLEX (KOL)
Description of the experiment	One of the primary responsibilities of the TSO is to maintain the balance between energy production and consumption, which is crucial for ensuring system frequency stability and reliable grid operation. To achieve this balance, various balancing services, or reserves, are in place. Among these, the tertiary reserve, known as mFRR, is activated during sustained deviations in the power grid that cannot be managed by other balancing services (such as FCR or aFRR). The mFRR must be fully deployable within 12.5 minutes and sustained for a minimum of 5 minutes. Traditionally, this service has been provided by larger generators, like gas-fired power plants, rather than smaller units. However, at the Slovenian pilot site, we have identified several assets that meet the requirements for capacity and response time, making them suitable for this purpose. **Pre-condition/triggering event:** • The aggregator (sFLEX) periodically receives the measurements from flexibility assets. • The aggregator periodically calculates the baseline and flexibility forecasts for flexibility assets. • A frequency deviation is detected by the TSO in the transmission system, triggering the mFRR activation signal (if mFRR is needed after FCR and aFRR). **Steps:** 1. The aggregator prepares day-ahead bids for capacity mFRR market based on the baseline and flexibility forecasts. 2. The aggregator sends bids to the capacity mFRR market. 3. The TSO accepts capacity bids. 4. The aggregator prepares day-ahead energy bids based on the accepted capacity bid or separately. 5. Frequency deviation -> TSO sends activation signal. 6. The aggregator calculates the optimal combination of assets for activation. 7. The aggregator sends the activation signal to the flexibility assets. 8. The aggregator verifies the correct activation of the flexibility assets and carries out appropriate measures if the assets did not respond

	correctly (manual activation of the controller or call to the asset operator). **Post-condition:** • The frequency is returned to the normal values, or the next ancillary systems reserve is activated. • The flexibility assets return to the state before the activation.
Exception paths and scenarios of the experiment	/
Datasets required for the experiment	• Baseline and flexibility forecasts. • TSO activation signal.
Field data to be gathered	• Measurement data of flexibility assets.
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.06

Results of the ExperimentT

Test case SI-UC.06.01 has been ongoing since 1 January 2026. Within the framework of the test case, the aggregator continuously received 1-minute measurement data from the participating assets, namely the Mlinotest mill and the Incom Leone cold storage facility. Based on the collected measurements, historical operating patterns, and additional operational inputs provided by the asset owners, the aggregator calculates both baseline consumption forecasts and flexibility forecasts.

In the figure below, an example of baseline and flexibility forecasts for the cold storage room of Income Leone is presented. The baseline and flexibility forecasts are calculated on a day-ahead basis and in real time based on the measurements, which are being collected in 1min intervals.

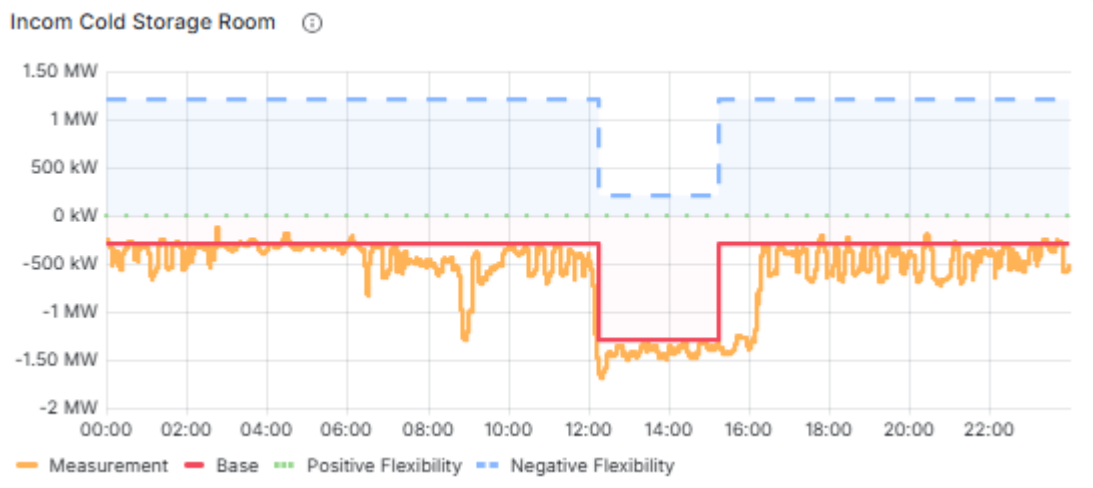


Figure 103: Example of baseline and flexibility forecast of Incom Leone's cold storage room on 16.4.2026.

Based on the calculated baseline and available flexibility, KOL integrates both STREAM assets into its mFRR portfolio and submits day-ahead capacity bids to the balancing market.

In the figure below, a screenshot from sFLEX platform is available – proof of send bid to the TSO.

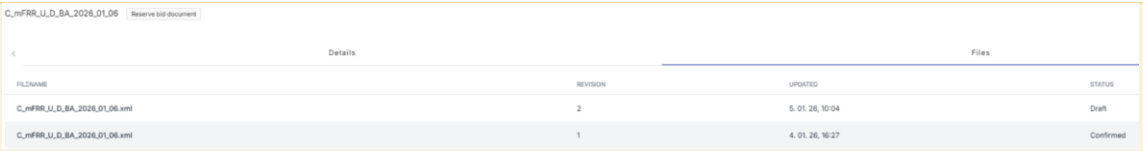


Figure 104: mFRR capacity bid sent through sFLEX

On 6.1.2026 at 17:18, we received an activation signal from ELES, with the start of activation at 17:22 and the end at 18:02.

In the figure below, the activation of Mlinotest's mill on 6.1.2026 is presented.

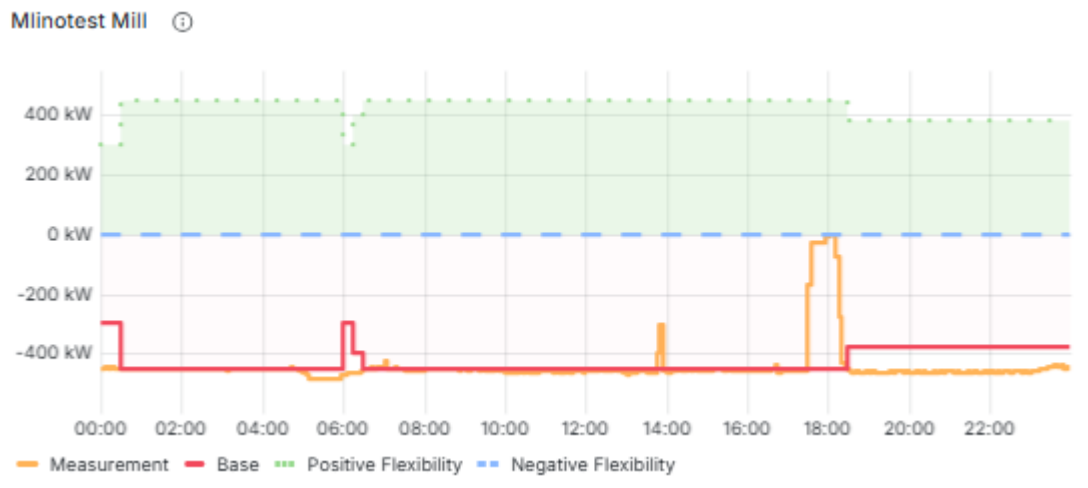


Figure 105: Activation of the Mlinotest's mill on 6.1.2026

In the figure below, a detailed visualisation of the activation of Mlinotest's mill on 6.1.2026 is presented. As presented, the asset reacted at 17:30, which is 8 minutes after the activation start. At approximately 17:34, the response was fully activated, which is within the defined time limits for mFRR.

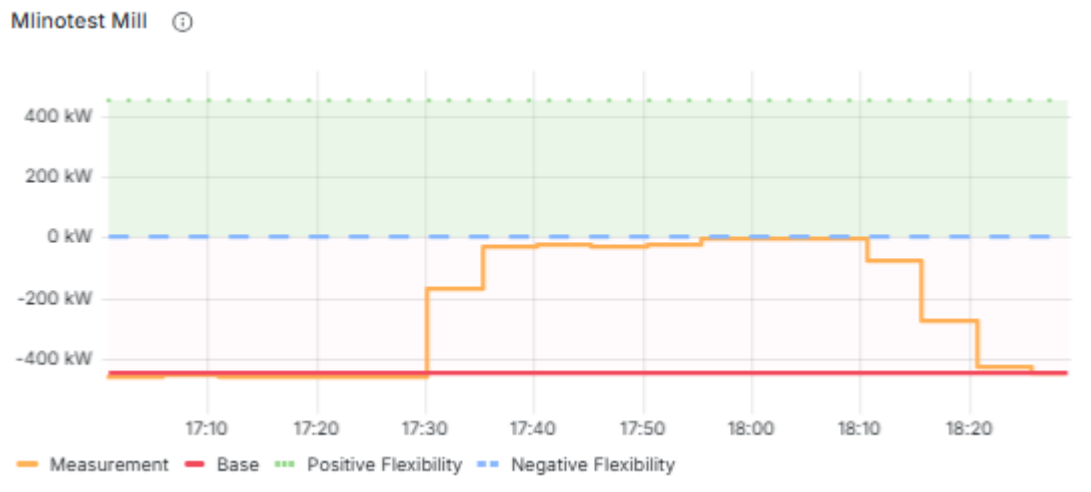


Figure 106: Detailed resolution of the activation from Mlinotest's mill on 6.1.2026

The cold storage room of Incom Leone was not activated in the period between January and now. This could be due to various reasons. For example, increasing consumption or downward activation was not activated at times when cold storage rooms were able to provide it. Furthermore, the requested price per energy bid was presumably too high and other assets were activated before the cold storage room of Incom Leone. However, we performed a test activation of the asset to test the communication and response of the asset.

In the figure below, the test activation of Incom Leone's cold storage room on 1.4.2026 is presented.

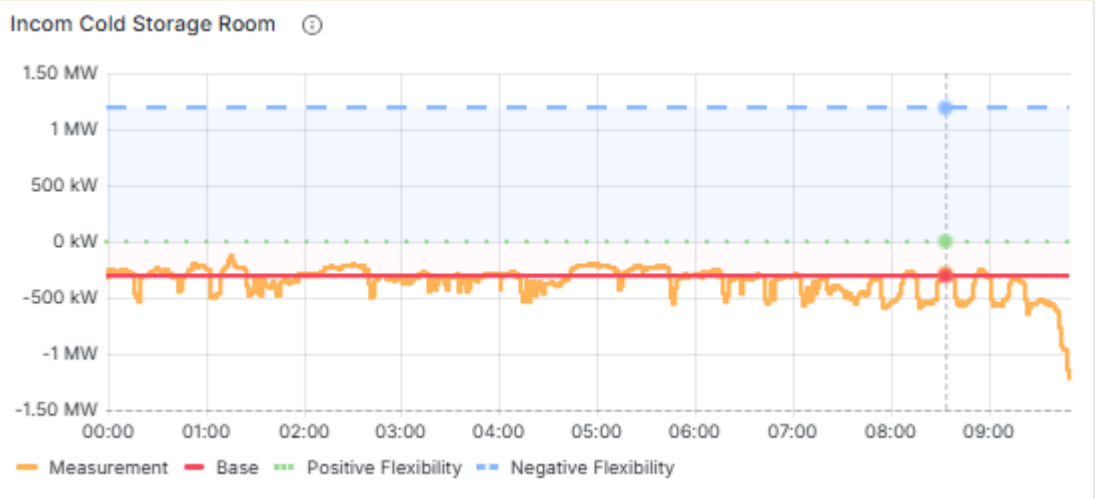


Figure 107: Test activation of Incom Leone's cold storage room on 1.4.2026.

In the figure below, a detailed visualisation of the test activation of Incom Leone's cold storage room on 1.4.2026 is presented. The test activation process started at 9:30. At 9:45, after 15 minutes, the power of the asset was approximately doubled, from 500 kW to 1.000 kW. After an additional 5 minutes, the new compressor turned on, and power was increased to approximately 1.200 kW.

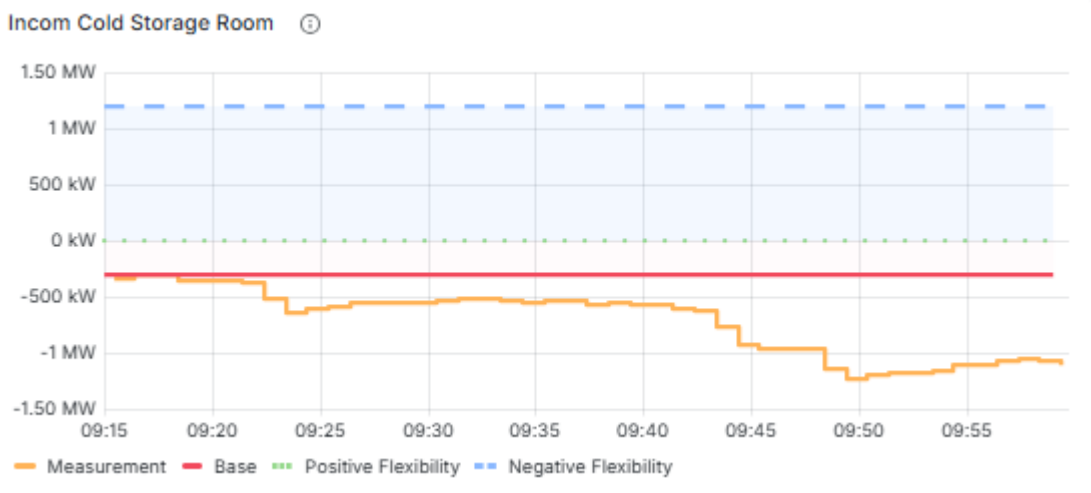


Figure 108: Detailed resolution of the activation from Incom Leonoe's cold storage room on 1.4.2026

Qualitative analysis of the results

The baseline and flexibility forecasts for the assets of Incom Leone and Mlinotest are generated in real time. An example from 16 April 2026 shows that the baseline forecast predicted active cooling operation between 12:00 and 15:00. However, the measured operation indicates that cooling was required until 16:00. In addition, the measured data shows a distinct consumption peak at approximately 09:00, most likely caused by an increase in the storage room temperature. The accuracy of the baseline and flexibility forecasts is strongly influenced by ambient temperature conditions and the quantity of goods stored in the facility. Furthermore, the operational behaviour of Incom Leone reflects increased electricity consumption during periods of lower electricity market prices. The forecasting models are

designed to account for these influencing factors and provide a prediction of the expected electricity consumption for the following day.

The activation of the Mlinotest mill on 6 January 2026 demonstrates the successful execution of the flexibility activation process. The activation signal from the sFLEX platform was transmitted to the mill at 17:18, when it was received by ELES. The activation duration was from 17:22 to 18:02. Following the signal reception, the mill's power consumption started decreasing immediately and reached approximately 0 MW at 17:34, corresponding to a transition time of 5 minutes from full operating power to complete shutdown. The achieved response time was within the prescribed 12,5-minute requirement. During the activation period, the asset successfully maintained the requested 0 MW consumption level for the entire duration of the activation. The activation lasted approximately 30 minutes. After the activation ended at 18:02 and the activation signal was released, the operator gradually restored the mill to its normal operating power.

During the demonstration period, the Incom Leone cold storage facility was not activated by the TSO. However, a test activation was performed by the aggregator in order to evaluate the technical feasibility of the flexibility service. As shown in the figures above, the test activation signal was issued at approximately 09:30. The response of the cold storage unit was gradual, reaching approximately 1 MW within the prescribed 15-minute response period for mFRR activation. In the following 5 minutes, the unit increased its consumption by an additional 0.2 MW, corresponding to the activation of an additional compressor. The test activation confirmed that the cold storage facility is technically capable of providing flexibility services. However, the available flexibility within the initial 15-minute activation window is limited and must therefore be taken into account when defining the bidding strategy and the offered flexibility capacity of the asset.

Experiment number	**SI-UC.06.02**
Name of the experiment	Utilization of flexibility in local flexibility markets (DSO)
Timeframe	May 2026
Targets	The goal of this Test Case is to provide available flexibility in the DSO local flexibility markets and to successfully activate the requested power when the DSO calls for asset activation.
Actors	• KOL – aggregator • EP – DSO • Incom Leone, Mlinotest, Tosla, Metal Design, Petrilč, etc. - Asset owners
STREAM products	sFLEX, sMART
Assets & systems	• Various flexibility assets (Cold storage rooms, mill, PV, etc.)
Description of the experiment	In the Slovenian pilot site, the sMART tool was deployed for congestion management, allowing the DSO to leverage local flexibility assets to address grid congestion. This approach enables the DSO to defer costly reinforcement investments and prioritize efforts in the grid areas in need of upgrades. The

	sMART tool operates alongside sGRID, which forecasts congestion in advance, and sFLEX, which enables aggregators to submit flexibility bids in open auctions. **Pre-condition/triggering event**: • A grid congestion is detected/forecasted by DSO (sGRID) in the distribution system. • sMART receives congestion information and opens a flexibility auction • The aggregator (sFLEX) periodically receives the measurements from flexibility assets • The aggregator periodically calculates the baseline and flexibility forecasts for flexibility assets **Steps:** 1. The aggregator prepares bids for capacity for local flexibility market based on the measurements, availability, baseline, constraints, etc. 2. The aggregator sends bids to the capacity local flexibility market. 3. The DSO accepts capacity bids. 4. The aggregator prepares day-ahead energy bids based on the accepted capacity bid or separately. 5. Grid congestion -> DSO sends an activation signal. ggregator calculates the optimal combination of assets for activation. ggregator sends the activation signal to the flexibility assets. **Post-condition:** • Selected flexibility assets are activated • The grid deviation is alleviated.
Exception paths and scenarios of the experiment	/
Datasets required for the experiment	• Baseline and flexibility forecasts.
Field data to be gathered	• Measurement data of flexibility assets.
Related KPIs	SI.01, SI.02, SI.06
Results of the Experiment	
Test case SI-UC.06.02 has been ongoing since 1 January 2026. Within the framework of the test case, the aggregator continuously receives 1-minute measurement data from the participating assets. Based on the collected measurements, historical operating patterns, and additional operational inputs provided by the asset owners, the aggregator calculates both baseline consumption forecasts and flexibility forecasts. In the figure below, an example of baseline and flexibility forecasts for the PV of Petrič is presented. The baseline and flexibility forecasts are calculated on a day-ahead basis and in real time based on the measurements, which are being collected in 1min intervals.	

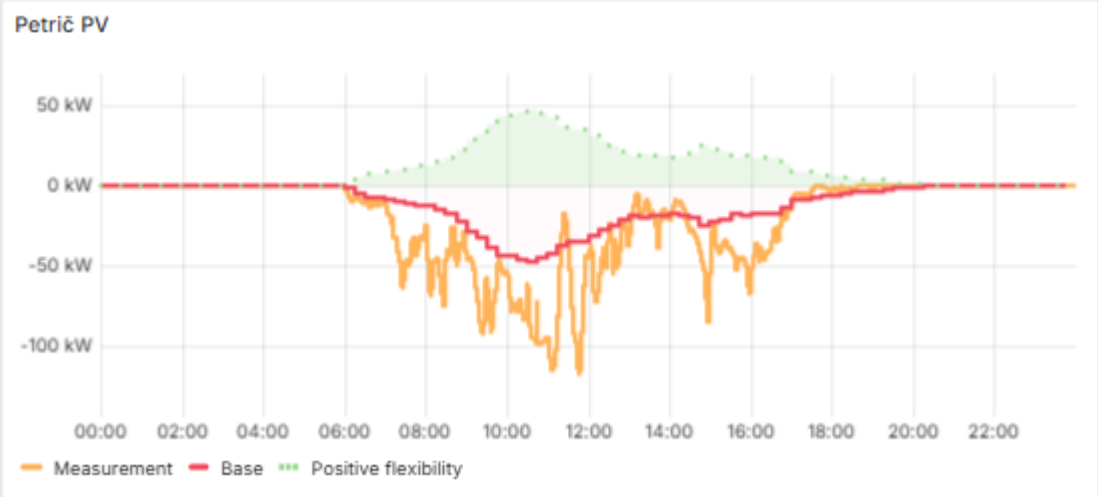


Figure 109: Example of baseline and flexibility forecast of Petrič's PV on 15.5.2026.

The test case SI-UC.06.02 was demonstrated on 21.5.2026. The whole procedure of the test case was already described in SI-UC.02.01, Demonstration 2.

We performed 3 scenarios:

Scenario 1: Secondary substation Obrtna cona Ajdovščina 2, 100 kW downward (12:00–12:15)

Scenario 2: MV feeder Tale, 150 kW downward (12:30–12:45) — partial acceptance

Scenario 3: MV feeder Tale, 250 kW downward (12:45–13:00) — full acceptance

In the figure below, the activation of Petrič's PV on 21.5.2026 is presented.

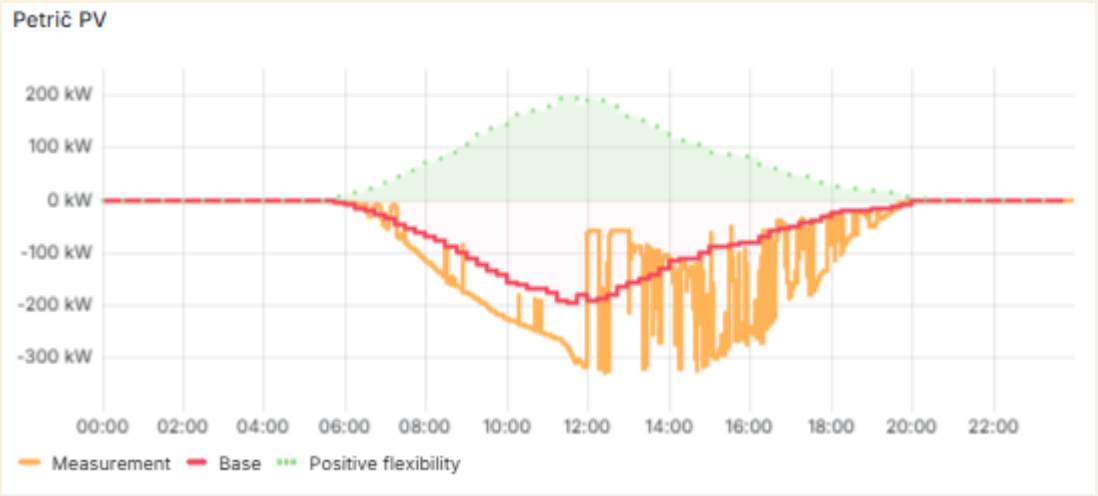


Figure 110: Activation of Petrič's PV on 21.5.2026.

In the figure below, the detailed showing of the activation of Petrič's PV on 21.5.2026 is presented. As seen in the figure, PV from Petrič was activated in the scope of scenario 1, scenario 2 an scenario 3.



Figure 111: Detailed resolution of the activation from Petrič's PV on 21.5.2026.

In the figure below, the activation of Metal Design's PV on 21.5.2026 is presented.

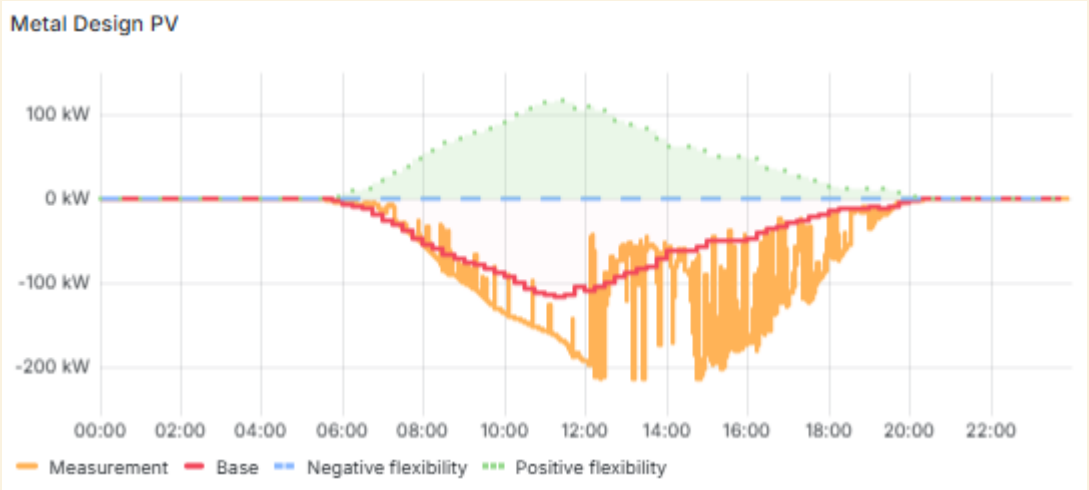


Figure 112: Activation of Metal Desing's PV on 21.5.2026.

In the figure below, a detailed visualisation of the activation of Metal Design's PV on 21.5.2026 is presented. As seen in the figure, PV from Metal Design was activated in the scope of scenario 2 an scenario 3.

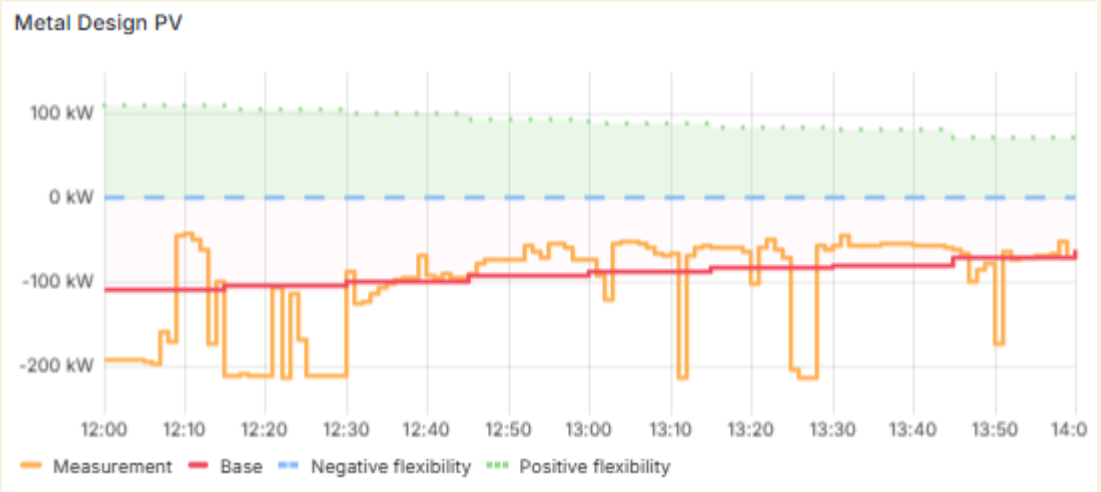


Figure 113: Detailed resolution of the activation from Metal Design's PV on 21.5.2026.

Qualitative analysis of the results

The baseline and flexibility forecasts for the asset system are generated on both a day-ahead and real-time basis. An example from 15 May 2026 shows that the baseline forecast provided a relatively accurate estimation of the minimum expected PV output. However, the variability of PV generation during peak production periods remains highly difficult to predict. Short-term weather changes, particularly cloud movements, can cause significant fluctuations in output power. An example can be observed at approximately 11:30, when the PV output decreased by around 100 kW within a short period of time. The findings indicate that establishing a reliable baseline for PV production is challenging, which consequently limits the suitability of PV assets for the provision of predictable system flexibility services.

The activation results of the demonstration 2 on 21.5.2026 for the Petrič and Metal Design PV systems show multiple activation events in the period between 12:00 and 13:00. During the activations, the output power of the Metal Design PV system was reduced on average from approximately 200 kW to 50 kW, while the output power of the Petrič PV system was reduced from approximately 300 kW to 60 kW. Except for the periods between 12:00–12:15 and 12:30–13:00 at the Petrič PV system, the curtailed output was not maintained at a fully stable level but fluctuated continuously by several kilowatts. The figures further demonstrate that the response of PV assets to activation signals is effectively immediate.

The results confirm that PV assets are technically suitable for applications requiring fast response times, particularly in cases where the distribution grid experiences rapid voltage variations or local network constraints. However, the use of PV systems for capacity-based flexibility services at the TSO level remains challenging due to the limited predictability of the baseline generation profile. On the other hand, PV assets can be suitable for energy-based services where rapid reduction of feed-in power is required.

In addition, the activations indicate that the activated power reduction was achieved primarily through curtailment of PV generation - the complete disconnection of the asset is not needed, and fine regulation is possible. The measured response follows the activation signal closely, despite short-term oscillations caused by changing irradiation conditions. This demonstrates that the control logic and communication pathway operated reliably during the activation period.

Experiment number	**SI-UC.07.01**
Name of the experiment	Registration of Flexibility Devices in Device Registry (DR)
Timeframe	March — April 2026 (M42-M43)
Targets	Test the successful registration process of a Flexibility Device in the DR
Actors	• CYG as technology provider • AVA as Flexibility device owner (FDO) • KOL as Aggregator
STREAM products	DR
Assets & systems	• Flexibility Devices (AVA, KOL)

Description of the experiment	**Pre-condition:** • The DR is operational and accessible. **Steps** 1. A user account representing the Aggregator (KOL) and FDO is created in the DR. 2. Using the FDO/Aggregator account, the device registration is performed for each flexibility device by submitting the required information via the DR registration form (device type, technical specifications, flexibility parameters, etc.). 3. Upon successful submission, the device records are created in the DR and unique identifiers are assigned to each registered device. **Post-condition:** • The flexibility devices are successfully registered in the DR. • Each device is correctly associated with its respective FDO and FSP.
Exception paths and scenarios of the experiment	The information needed for registration is put in the required fields, thus a scenario where obligatory information would not be specified is not possible.
Datasets required for the experiment	• Device information: Technical specifications, location, communication protocols, availability, and flexibility parameters of the flexibility device. • FDO information: Name, contact information, and account details of the Flexible Resource Owner. • FSP information: Name, contact information, and account details of the Flexibility Service Provider.
Field data to be gathered	/
Related KPIs	KPI SI.07, KPI SI.08

Results of the Experiment

The registration of flexibility devices in the Device Registry was carried out over the period of March-April 2026. The process was coordinated by CYG, who gathered the required device information from KOL for PV installations and AVA for EV charging stations, and performed the registration on their behalf using dedicated user accounts.

Account setup and preparation

Prior to the registration, user accounts representing KOL and AVA were created in the DR by the platform administrator (CYG). Account creation was performed manually as a deliberate design choice, given that the DR is hosted on CYG's cloud infrastructure. This approach ensures controlled access to the platform during the pilot phase.

Registration workflow

The registration was performed individually for each device through the DR's web-based registration form. Using the FDO/Aggregator account (e.g., logged in as the KOL user), the operator navigated to the registration form and entered the device details as provided by the respective aggregator/asset owner. The form captures all relevant parameters for each device, including device type, installed capacity, flexibility range, voltage level, metering point ID, location (grid element association). The form structure is identical for all device types – no type-specific adaptations were required for PV installations versus EV charging stations.

Upon submission of the registration form, the system returned a confirmation that the request is being processed. The form enforced input validation (mandatory fields, correct data formats), preventing incomplete submissions. The registration was subsequently reviewed and finalised by the platform administrator.

Establishing real-time communication

In addition to registering the device metadata, a real-time communication link was established between each device and the DR. This step involved configuring the newly developed communication protocols (Reduxi MQTT for PV installations and Avant Car API for EV charging stations) and linking the communication interfaces to the DR so that real-time data exchange would be possible. While a device can be registered in the DR without an active communication link, the established connection is a prerequisite for the subsequent prequalification tests (SI-UC.08.01), which require the DR to send activation commands and receive device response data.

The integration of communication protocols required several iterations, as the process proved more complex than initially anticipated. This challenge has been documented separately in the deployment's challenges section (see section 2.1.6).

Registration Results

13 flexibility devices were successfully registered in the DR across 5 locations:

- Petrič: 3 devices (PV installations)
- Tosla: 2 devices (PV installations)
- Metal Design: 4 devices (PV installations)
- Knauf: 2 devices (EV charging stations)
- SloCar: 2 devices (EV charging stations)

All devices were assigned unique identifiers and correctly associated with their respective FDO and FSP. The registered device information, including metering point IDs, was verified as accessible through both the DR user interface and the DR REST API. Furthermore, the device data was successfully retrieved by sDATA and confirmed to propagate correctly to sMART, ensuring that the registered devices and their parameters are available for bid eligibility validation in subsequent market operation use cases (SI-UC.02.01).

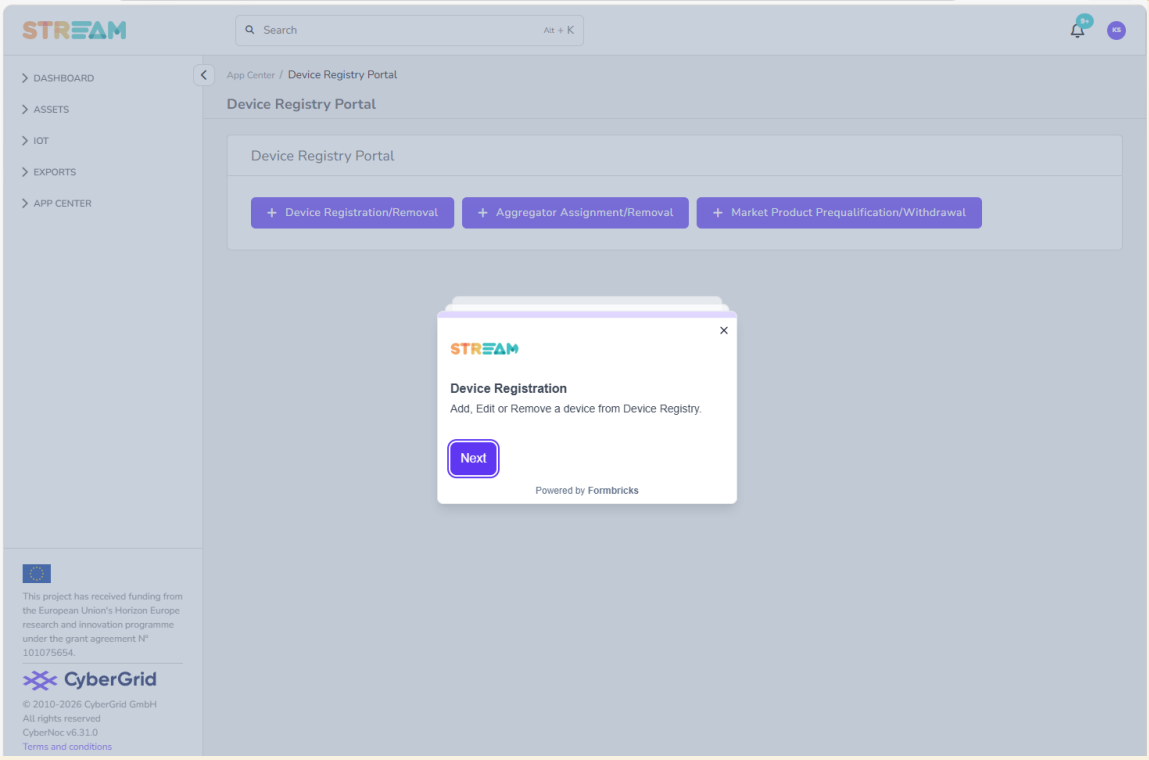


Figure 114: Device Registry - Registration Form

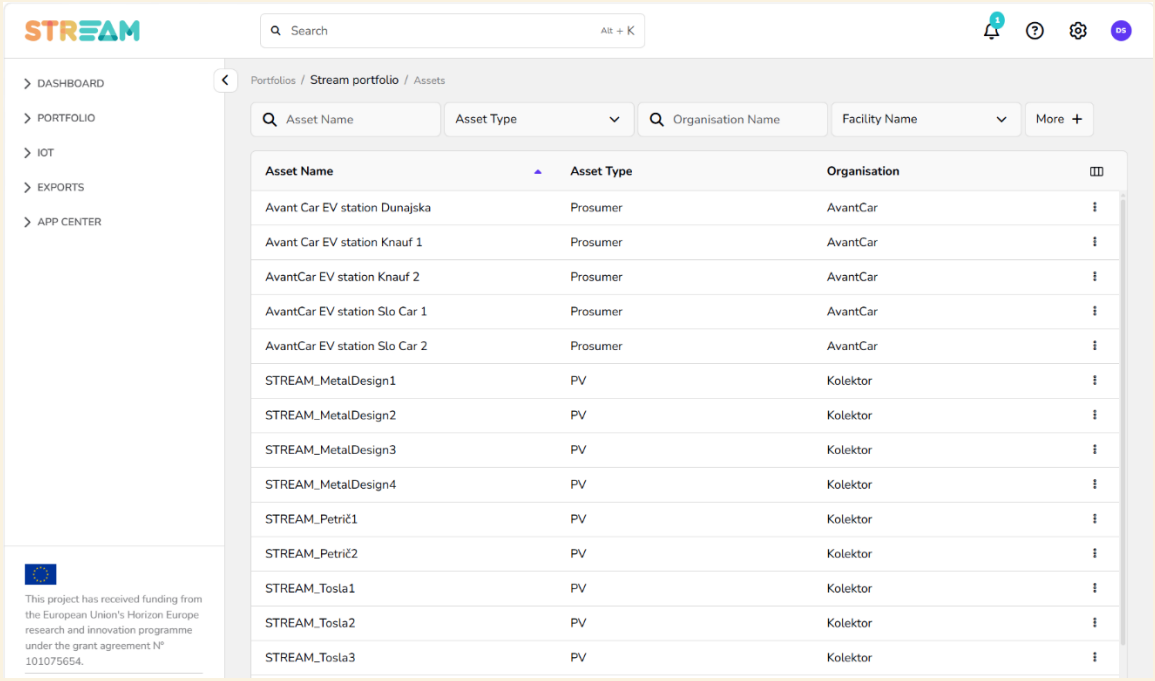


Figure 115: Device Registry - List of registered devices

Qualitative analysis of the results

The registration process was completed successfully for all 13 devices, confirming that the DR can accommodate multiple FDOs and device types within a single platform instance. The end-to-end workflow, from data collection with the aggregators, through form-based registration, administrator finalisation, communication link establishment, and downstream data propagation to sDATA and sMART, operated as designed.

The DR registration form enforced data completeness through mandatory field validation, ensuring that all required parameters were captured for each device. The registration workflow proved to be asset-type agnostic: PV installations and EV charging stations followed the same registration process without requiring type-specific adaptations. The collected parameters (installed capacity, flexibility range, voltage level, metering point ID, grid element association) were sufficient to support all downstream processes, including prequalification (SI-UC.08.01) and bid eligibility validation in sMART.

The data exchange with both aggregators was smooth: KOL and AVA provided the required device information, which was then used directly in the registration form without issues. The coordination worked efficiently for the scope of the pilot.

Both communication protocols used in the pilot, Reduxi MQTT for PV installations and Avant Car API for EV charging stations, ultimately delivered stable and reliable connections for all devices. In a production environment with a larger number of devices, the use of established and standardised communication protocols, rather than implementing or adapting protocols for individual device types, would be expected to streamline the integration process.

Overall, the test case confirmed that the DR provides a functional and reliable platform for flexibility device registration, establishing the foundation for the subsequent prequalification (SI-UC.08.01) and market participation use cases. The successful propagation of device data to sDATA and sMART validates that the DR is correctly integrated into the broader STREAM ecosystem and that registered devices are immediately available for downstream flexibility market processes.

Experiment number	**SI-UC.08.01**
Name of the experiment	Prequalification Test of Registered Flexibility Devices
Timeframe	April 2026 (M43)
Targets	• Test the prequalification process of registered flexibility devices in the DR. • Verify the DR's ability to communicate with the device using related communication protocols. • Validate that the prequalification test accurately assesses the device's performance against predefined criteria. • Confirm that the DR assigns the appropriate prequalification status ("qualified" or "not qualified") to the device based on the test results.
Actors	• CYG as technology provider • AVA as Flexibility device owner (FDO) • KOL as Aggregator
STREAM products	DR
Assets & systems	• Registered flexibility devices (PV, EV charging stations) • The communication infrastructure required to connect to the DR.
Description of the experiment	This test case validates the prequalification process of registered flexibility devices. The DR initiates the prequalification test by sending commands to the device through the established communication protocols. The device responds to the commands to demonstrate its flexibility capabilities. The DR

	monitors the device's response and records it as timeseries data. Based on the results, the device is assigned the appropriate prequalification status. **Pre-condition:** • The flexibility device is successfully registered in the DR (refer to test case SI-UC.07.01). • The prequalification criteria are defined. • The DR has established communication with the device and confirmed its online status. **Steps:** 1. The DR initiates the prequalification test by sending a command to the registered device through Reduxi MQTT and AVA API communication protocols. 2. The device receives the commands and performs the requested activation (increase or decrease power output). 3. The DR monitors the device's response and records the data received. 4. The device's performance is evaluated against the predefined prequalification criteria. 5. The device is assigned the "qualified" or "not qualified" status and the device record is updated accordingly. **Post-condition:** • The registered flexibility device has undergone the prequalification test. • The device is assigned a prequalification status ("qualified" or "not qualified").
Exception paths and scenarios of the experiment	Communication failure: The DR is unable to establish or maintain communication with the device during the test. The test should be aborted, and the device should be marked as "not qualified." Device fails to perform: The device fails to perform the requested actions or provides invalid data during the test. The test should be aborted, and the device should be marked as "not qualified."
Datasets required for the experiment	• Device information: Technical specifications, communication protocols, and registered flexibility parameters of the flexibility device.
Field data to be gathered	• Data received from the device during the test, including performance measurements and timestamps.
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.09, KPI SI.10, KPI SI.11, KPI SI.12
Results of the Experiment	
The prequalification tests of registered flexibility devices were carried out over multiple days. Tests for KOL's PV installations were performed on a separate day from AVA's EV charging stations, as coordination with both device owners was required. For KOL, availability of the PV devices needed to be confirmed in advance, and tests were scheduled around midday to ensure maximum solar generation and thus the highest available flexible capacity. For AVA, alignment on a specific date was necessary, as the AVA partner needed to travel to the location and connect a vehicle to the charging station for the test to be performed. **Test initiation and procedure**	

The prequalification tests were initiated by the platform administrator (CYG) through the DR user interface. For each device, the activation setpoint was determined based on the available flexible capacity at that moment, taking into account the current baseline generation and the minimum power that needed to be maintained. The DR sent a curtailment command to reduce output by a specified amount (in kW) for a duration of 15 minutes.

Prior to the activation, a 15-minute baseline measurement was recorded to establish the device's normal operating power. The activation was then triggered, and the device's response was monitored in real time through the DR's graphical interface, which displays the device's actual power output against the setpoint as a live-updating timeseries.

PV installations (KOL)

For the PV devices, the tests were performed during peak solar generation. Each device was generating at its normal output, and upon activation, the DR sent a curtailment signal to reduce generation by the specified setpoint. The PV inverters responded to the signal and reduced their output accordingly. The response was fast and the devices followed the setpoint well throughout the 15-minute test duration. After the test period, the devices returned to their normal generation levels.

Figure 116 shows the relative reduction in generation for each PV device compared to the baseline, illustrating the prequalified flexible capacity for each installation.

EV charging stations (AVA)

For the EV charging stations, the test required a vehicle to be actively charging at the station. Upon activation, the DR sent a command to stop the charging process. The charging was halted for the duration of the 15-minute test period, after which charging resumed automatically. The EV chargers responded reliably to the activation signal.

Figure 117 shows the charging profile during the prequalification test: the initial charging phase, the reduction to zero during the activation period, and the resumption of charging after the test concluded

Prequalification results

All 13 registered devices (see SI-UC.07.01) successfully passed the prequalification test.

Kolektor:

- Petrič: 3 devices (PV) – qualified
- Tosla: 2 devices (PV) – qualified
- Metal Design: 4 devices (PV) – qualified

Avant Car:

- Knauf: 2 devices (EV charging) – qualified
- SloCar: 2 devices (EV charging) – qualified

All devices demonstrated the ability to follow the activation setpoint within the required tolerance during the 15-minute test period. Upon successful completion, the prequalification status was recorded in the DR and made permanently available to downstream systems. The qualified status is accessible to sMART, enabling bid eligibility validation for subsequent market participation use cases

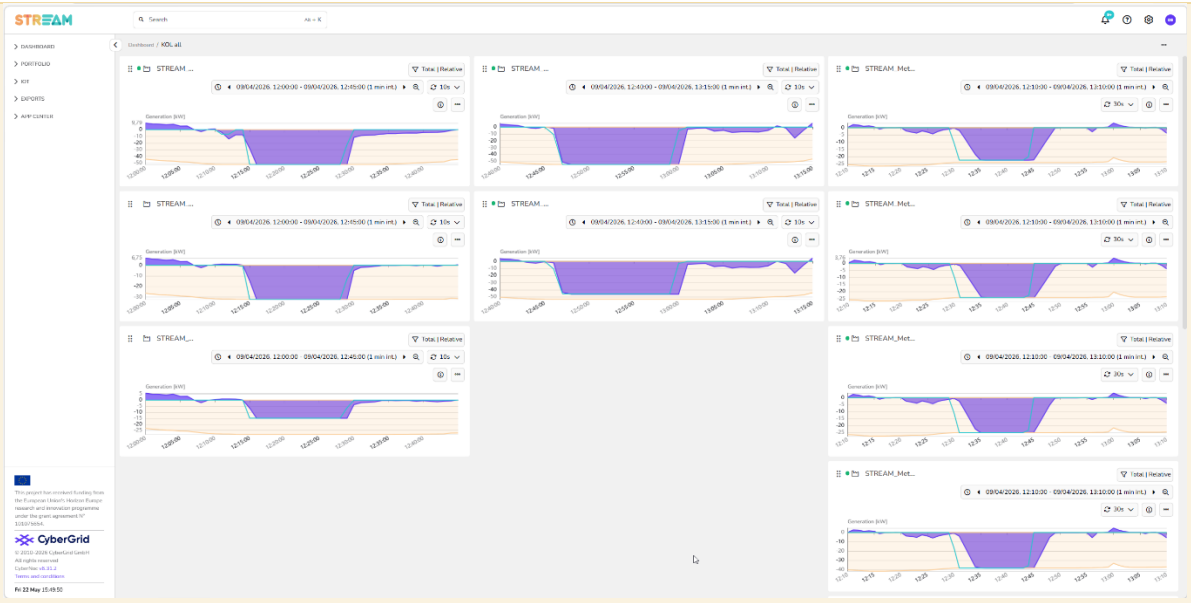


Figure 116: Prequalification tests of Kolektor devices

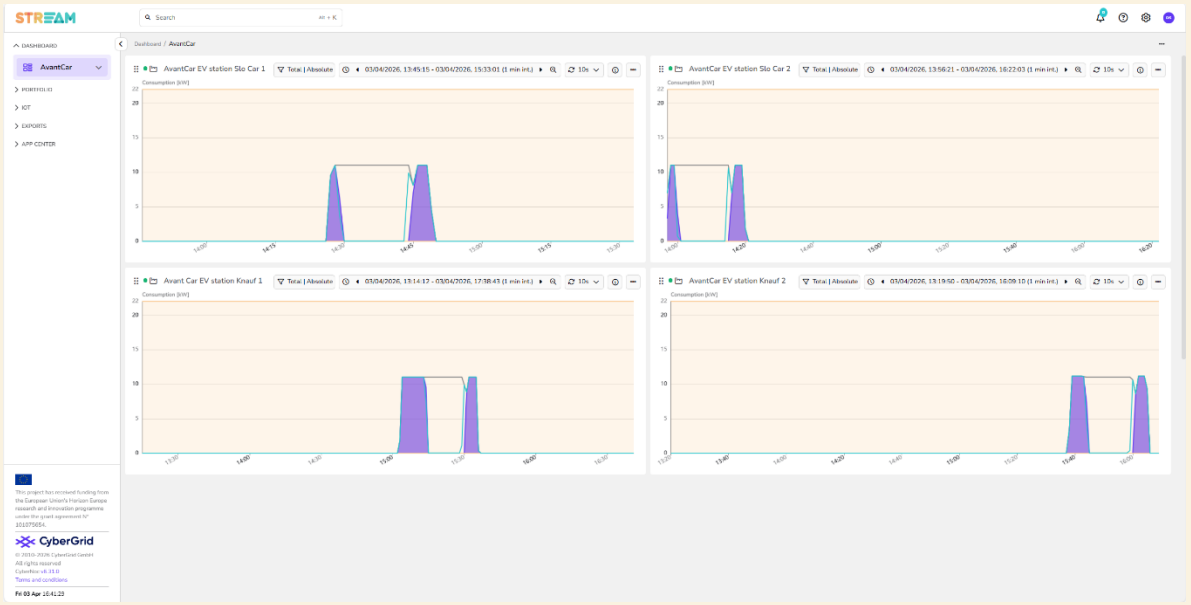


Figure 117: Prequalification test of Avant Car devices

Qualitative analysis of the results

The prequalification tests were completed successfully for all 13 flexibility devices from both partners, with a 100% qualification rate. All devices demonstrated the ability to respond to activation setpoints within the defined +/-10% tolerance over the 15-minute test period, confirming that the DR can effectively manage the end-to-end prequalification workflow – from activation command dispatch, through real-time monitoring of device response, to qualification status assignment.

All devices demonstrated fast response times and maintained their output within the required tolerance throughout the test duration. The real-time monitoring capability of the DR allowed the operator to follow the device response throughout the test duration. The graphical interface displays the device's actual power output against the setpoint as the test progresses, providing visibility into how each device performs during activation.

The two communication protocols used in the pilot, Reduxi MQTT for PV installations and Avant Car API for EV charging stations, both proved reliable for delivering activation commands and retrieving device response data. No communication failures were encountered during the prequalification tests.

The coordination with device owners was an important practical aspect of the prequalification process. For PV installations, tests needed to be scheduled during periods of high solar generation to ensure sufficient flexible capacity was available for curtailment. For EV charging stations, the physical presence of a vehicle at the charging station was required, necessitating advance coordination with the AVA partner. These scheduling dependencies reflect real-world constraints that would apply in any prequalification regime for distributed flexibility assets.

Both device types, PV installations and EV charging stations, were successfully prequalified using the same DR interface and workflow, despite their fundamentally different flexibility mechanisms (generation curtailment vs. load interruption). This confirms the DR's ability to handle heterogeneous device types within a unified prequalification framework.

The recorded timeseries data confirmed that the devices are capable of providing measurable flexibility responses, which is a prerequisite for their participation in flexibility market auctions through sMART. The prequalification results, together with the registration data from SI-UC.07.01, establish the complete device readiness for the subsequent use cases involving bid submission and activation. With the qualified status permanently recorded in the DR and accessible to sMART, the devices are immediately eligible for bid validation in subsequent market activation use cases (SI-UC.02.01), completing the chain from registration (SI-UC.07.01) through prequalification to market readiness.

Experiment number	**sDATA-UC.01.01**
Name of the experiment	Data provider to data user data exchange in the Slovenian pilot site
Timeframe	April 2026 (M43)
Targets	The goal of this test case is to verify the accurate transmission of data from the data source to the data user via the sDATA exchange platform. The experiment aims to ensure that all requested data is fully included and correctly structured. The results will demonstrate whether the data exchange is complete and accurate, with no data loss, and will assess the quality of the transmitted data.
Actors	• EPR and AVA as data providers, • UL and KOL as data users, • IND as technology provider
STREAM products	sDATA, sGRID, sFLEX
Assets & systems	• EPR and AVA database, • EPR and AVA web APIs for sharing data, • sDATA APIs for data exchange • sGRID and sFLEX logic for data acquisition
Description of the experiment	One of the main functionalities of the sDATA platform is a secure and efficient data exchange between data providers (DSO and EV fleet operators) and data users (sGRID and sFLEX tools). This test will assess whether the data transfer between the data source and data user is reliable.

	This test will include testing the grid topology data and historical timeseries measurement data for EPR and EV charging station measurement data for AVA. All datasets will be tested and analysed in depth to confirm that the data transformation and exchange process within the sDATA platform is correct, and to confirm that no data is lost in the process. The test will be repeated multiple times to show that data is successfully exchanged at a sufficiently high rate. **Pre-condition/triggering event**: • Historical timeseries measurement data and grid topology data are saved at the data provider, EPR (DSO). • EV charging station data available in AVA database. • Web APIs, implemented by EPR and AVA are operational for sharing data with sDATA. **Steps:** 1. sDATA requests data from the data provider (EPR, AVA) through integration with data provider's web services. 2. Authentication and authorization processes are performed on the requester to grant data access. 3. The data sent from the data provider is transformed to fit the data model and then saved to the sDATA database. 4. Data user (sGRID or sFLEX) requests selected data and from sDATA through implemented and operational sDATA API. 5. Authentication and authorization processes are being performed on the requester to grant data access. 6. The data is sent as the response of the data user's request. 7. The data received by data user is checked and tested. **Post-condition**: • sGRID receives all the data that is needed for further analyses and processes (e.g. traffic light system). • sFLEX receives EV charging station data
Exception paths and scenarios of the experiment	• Provider API Unavailability: ○ Scenario: The sDATA platform attempts to request data, but the data provider's (EPR or AVA) web API is offline or unresponsive. ○ Test Focus: This tests the system's error handling and retry mechanisms. Does sDATA log the failure correctly? Does it automatically attempt to reconnect and retrieve the data after a specified interval? • Invalid Authentication/Authorization: ○ Scenario: sDATA attempts to access the provider's API using invalid or expired credentials (e.g., an incorrect API key). ○ Test Focus: This verifies that the provider's security is correctly implemented and that sDATA appropriately handles the "401 Unauthorized" or "403 Forbidden" response without crashing. • Data Format Mismatch: ○ Scenario: The data provider sends data in an unexpected or altered format (e.g., a new data field is added, or a data type is changed from a number to a string).

	○ Test Focus: This tests the robustness of sDATA's data transformation logic. Can the system handle the unexpected format gracefully? Does it log an error, skip the problematic record, or does the entire data ingestion process fail? • Incomplete or Corrupted Data from Source: ○ Scenario: The data received from the provider contains missing values in crucial fields or corrupted data points (e.g., negative power consumption where impossible). ○ Test Focus: This evaluates sDATA's data cleansing and validation capabilities. Does the system identify and flag the bad data? How does it handle these records—are they discarded, or is there a process for flagging them for manual review? • Data User Request Timeout: ○ Scenario: A data user (sGRID or sFLEX) requests a very large dataset from sDATA, and the process of retrieving and sending the data exceeds a predefined timeout limit. ○ Test Focus: This tests how sDATA manages long-running queries. Does it provide a meaningful timeout error, or does the request hang indefinitely? Does it support mechanisms like pagination for large datasets?
Datasets required for the experiment	• Historical timeseries measurement data • Grid topology data • EV charging station measurements
Field data to be gathered	• Timeseries measurement data (AMI and SCADA) • Count of successful and unsuccessful API responses
Related KPIs	KPI sDATA.01
Results of the Experiment	
• Roles of Actors: The experiment involved coordinated interaction between data providers, the technology provider, and data users. EPR and AVA acted as the data providers, supplying grid topology, historical timeseries, and EV charging station data. IND (technology provider) managed the sDATA platform, overseeing authentication, data transformation, and API stability. UL (sGRID) and KOL (sFLEX) acted as the data users, requesting and validating the received data. • Data Ingestion and Provision: Data was successfully and periodically requested from the provider web APIs, transformed into the internal sDATA model, and provisioned to the data users through the operational sDATA API.	

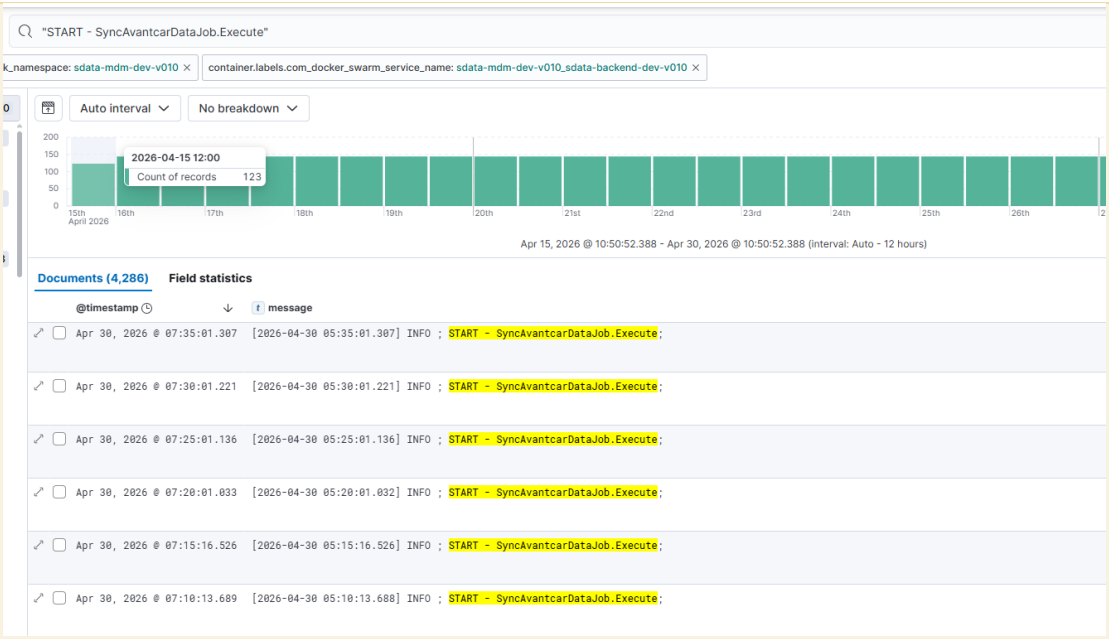


Figure 118: Data request log

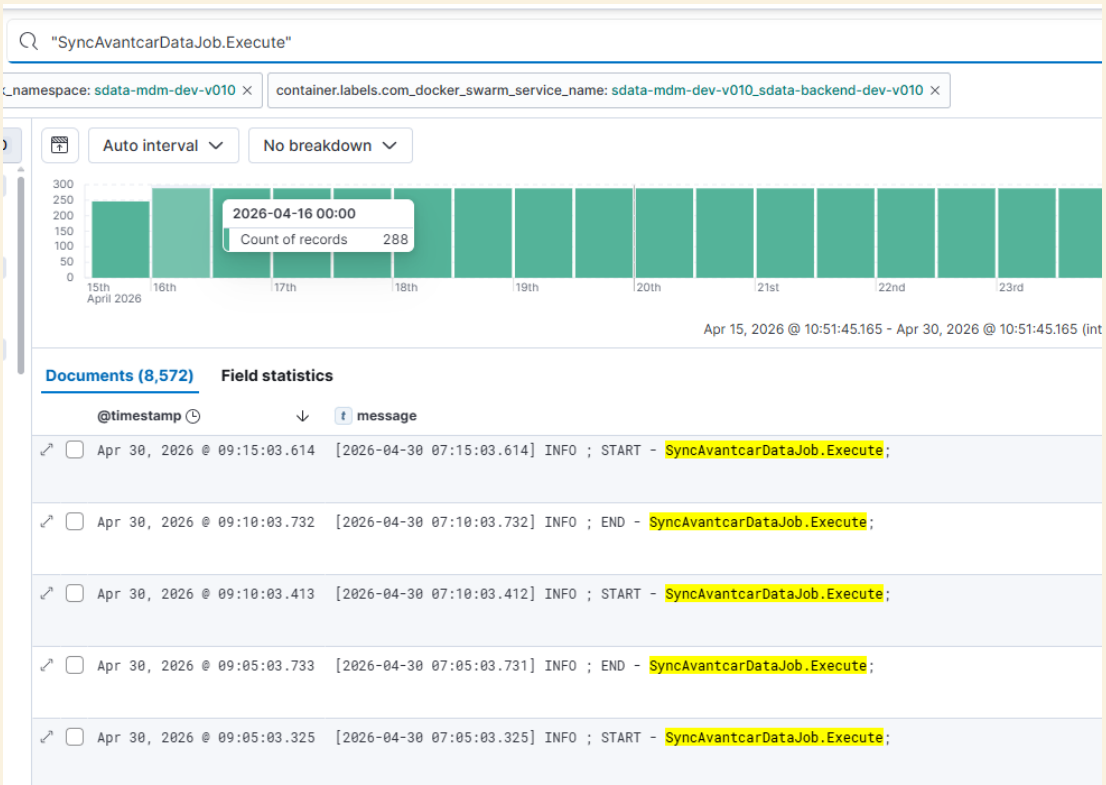


Figure 119: Data request log extended

- Examples of Exchanged Data (Workflow): The end-to-end data transformation and exchange process was validated.

https://sdata-mdm.inden.si/dev/v0.1.0/srv/mdm/elektroprimorska/sync?startTime=2025-07-16%2012%3A00&endTime=2025-07-16%2013%3A00&batchSize=30

- Quantitative Performance Metrics & KPI Measurement:
  - API Response Success Rate: The system actively gathered and counted API responses. Out of 3686 requests made during the test period, 38 encountered errors (99,0% success rate), meeting the KPI targets.

- Latency and Data Volume: The sDATA platform handled high-frequency requests, processing data transformations with an average latency of 350 ms per payload without data loss.

- Exception Paths Testing: Robustness was tested against various exception scenarios:
  - Provider API Unavailability: A simulated offline state for the EPR API resulted in correct failure logging, and the system automatically reconnected and retrieved data after the specified interval.
  - Invalid Authentication: Requests with expired credentials returned graceful "401 Unauthorized" and "403 Forbidden" responses without system crashes.
  - Incomplete/Corrupted Data & Format Mismatch: Altered data formats (e.g., string instead of number) and corrupted data (e.g., negative power consumption) were successfully identified, flagged, and safely discarded/skipped by sDATA's validation capabilities.
  - Data User Request Timeout: A simulated request for an excessively large dataset properly triggered a predefined timeout limit, validating the system's guardrails against hanging queries.

Qualitative analysis of the results

- Reliability and Robustness: The end-to-end data exchange process proved to be highly reliable. The platform consistently handled authentication, data requests, transformation, and provision, demonstrating a mature and stable architecture under repeated, high-frequency testing.
- Interoperability: The test confirmed excellent interoperability between sDATA, diverse data provider systems (EPR, AVA), and data users (sGRID, sFLEX). Standardized APIs and data models were crucial for seamless integration, proving sDATA can effectively act as a central data hub in a heterogeneous environment.
- Data Quality and Trust: A comparative analysis confirmed 100% data integrity with no data loss, corruption, or incorrect transformations detected during transit. This establishes sDATA as a trustworthy platform, fundamental for downstream analytical processes (like sGRID's congestion forecasts) that depend on high-quality input data.
- Observed Limitations and Minor Issues: While the API timeout limits functioned correctly, the system currently lacks an automated pagination feature for exceptionally large dataset requests, which could be implemented in the future to improve the data user experience. Furthermore, setting up proactive administrative alerts for repeated "401 Unauthorized" responses would help administrators diagnose connection issues faster.

Experiment number	**sDATA-UC.02.01**
Name of the experiment	History of data access events in the Slovenian pilot site
Timeframe	April 2026 (M43)
Targets	The objective of this test case is to verify that data access events are accurately logged in the distributed ledger. This ensures a comprehensive history log of all user access events within the sDATA platform. The history log should include essential details for investigative purposes, such as: • Username. • Timestamp. • Actions executed by the user during their session.

Actors	• UL/sGRID and KOL/sFLEX as data users • IND as technology provider
STREAM products	sDATA, sGRID, sFLEX
Assets & systems	• sDATA APIs for data exchange, • sGRID and sFLEX logic for data acquisition
Description of the experiment	The Distributed Ledger provides capturing data during all access events, including logins and the initiation of actions. This data is systematically recorded onto a distributed ledger e.g. hyper ledger, providing a transparent and immutable record of events. The expected outcome of the test is that every data access event is properly stored in the distributed ledger, with a complete and accurate history log that includes all necessary information for future investigations. **Pre-condition/triggering event**: Users must have access credentials and permissions to log into the sDATA platform. The distributed ledger must be properly configured and integrated with the platform. **Steps:** 1. Test user logs into to sDATA platform (for example: Master Data Management platform). 2. Test user initiates multiple access event actions, e.g. opens specific charging station metadata, opens his own profile page, requests time series measurement data of the specific electric meter, logs out. 3. User access events history log is acquired from the distributed ledger. 4. The history log of access events is checked. 5. The confirmation of the consistency and accuracy of the history log related to user activities. **Post-condition**: • Data user receives all the data that is needed for further analyses and processes
Exception paths and scenarios of the experiment	Distributed Ledger Unavailability: Test system behavior when the ledger service is offline. Are events queued and logged later, or are they lost? Corrupted or Incomplete Log Data: Send a malformed event (e.g., with a null username) to test the system's error handling and validation. High-Volume Event Logging (Stress Test): Simulate a high rate of user actions to test the scalability and performance of the logging mechanism under load. Delayed Log Confirmation: Simulate a delay in the ledger's confirmation to ensure the main platform remains responsive to the user.
Datasets required for the experiment	• Master Data management data
Field data to be gathered	/
Related KPIs	/
Results of the Experiment	

- Roles of Actors: During the experiment, the roles were clearly distributed. Data users (UL/sGRID and KOL/sFLEX) acted as the requesters, initiating user actions (login, data requests) and triggering the logging mechanism. The technology provider (IND) was responsible for monitoring the system performance, ensuring the distributed ledger's stability, and querying the API for log acquisition.
- Execution of User Actions: A series of predefined user actions were executed on the sDATA platform. This included user login, navigation to various sections (Master Data Management portal - metadata, user profile), data requests (for timeseries measurements of specific electric meters), and user logout.

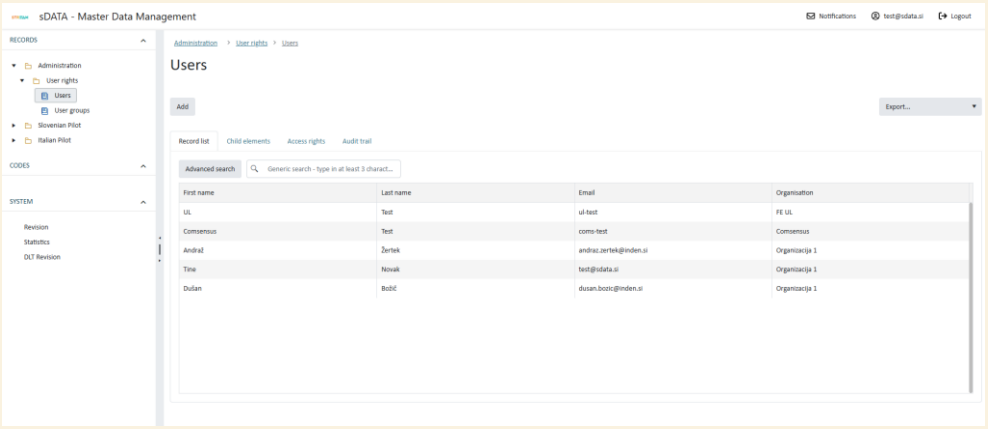


Figure 120: User overview

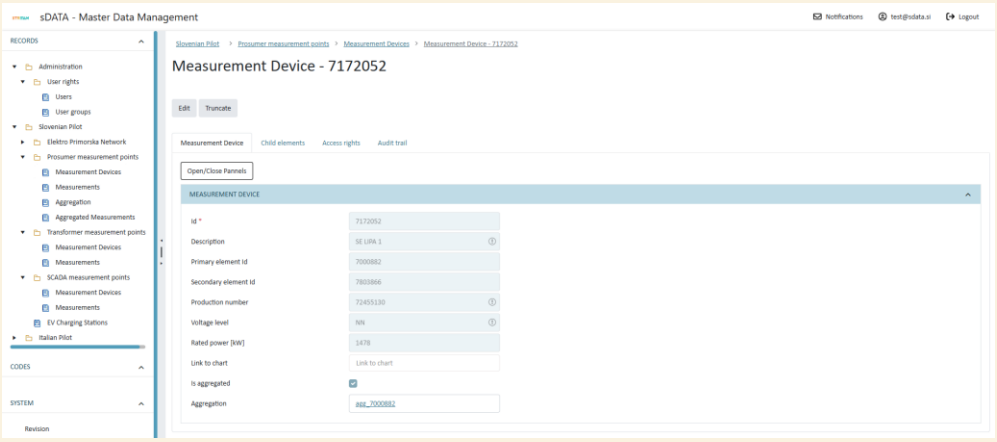


Figure 121: Measurement device metadata

- Examples of exchanged Data (Workflow): The workflow for data access and logging was validated. For example, when UL/sGRID requested historical measurements from the EPR network, the following event was generated and stored in the distributed ledger:

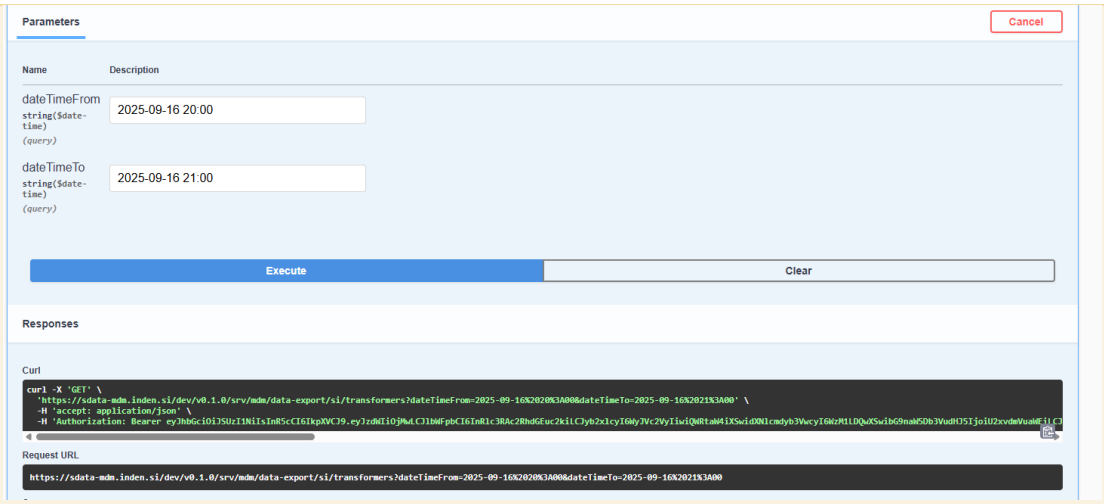


Figure 122: Exchange data example

- Log Acquisition: The history log of user access events was successfully acquired from the distributed ledger via the designated API endpoint for all performed actions.
- Log Content Verification: Each entry in the acquired history log was analyzed and confirmed to contain all the required data points as specified in the test targets:
    - Correct Username of the test user.
    - Accurate Timestamp for each action, consistent with the time of execution.
    - Clear description of the Action performed (e.g., user_login, view_metadata_record, request_timeseries_data, user_logout).

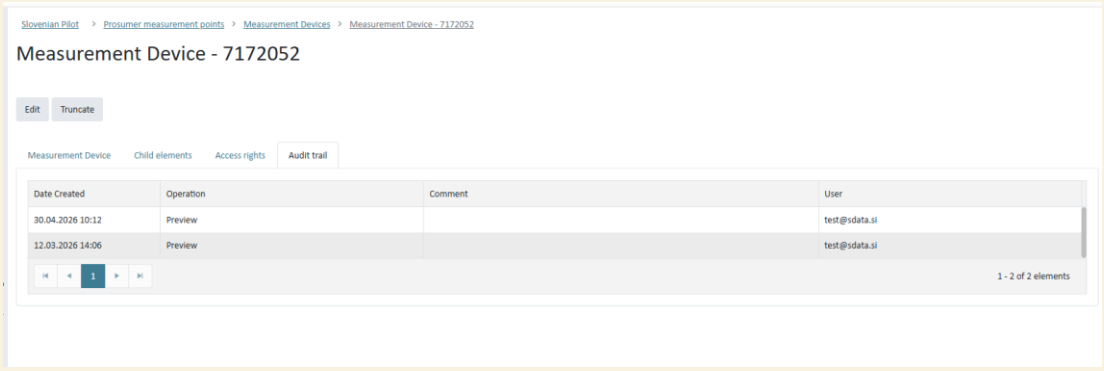


Figure 123: Measurement device overview

- Data Completeness and Accuracy: A one-to-one match was confirmed between the actions performed by the test user and the events recorded in the distributed ledger. No events were missed, duplicated, or incorrectly recorded. The consistency and chronological order of the logs were verified and found to be 100% accurate.
- Exception Paths Testing: Exception scenarios were also executed to test system robustness.
    - Malformed Requests: Actions initiated with missing parameters (e.g., null username) were successfully rejected by the validation layer and logged as failed_action_attempt.
    - Simulated Ledger Delay: A simulated delay in the distributed ledger's confirmation response did not block the sDATA platform's main thread, proving the asynchronous nature of the logging mechanism.

Qualitative analysis of the results

- Reliability of the Logging Mechanism: The experiment demonstrates that the Distributed Ledger technology is highly reliable for capturing and immutably storing data access events. The system consistently recorded all user activities without any data loss, proving its effectiveness as a robust audit trail mechanism, even under the simulated high-volume stress tests.
- Transparency and Trustworthiness: The ability to retrieve a complete and unalterable history log significantly enhances the platform's transparency. This functionality is crucial for building trust among data providers and users, as it ensures that all data interactions are traceable and verifiable. It provides a solid foundation for future investigations, security audits, and dispute resolution.
- System Performance: The process of recording events to the distributed ledger occurred in near real-time and had no discernible impact on the user's experience or the overall performance of the sDATA platform. The retrieval of the history log was also efficient and timely, meeting the quantitative latency targets.
- Observed Limitations and Minor Issues: The current log visualization interface lacks advanced filtering capabilities (filtering logs by specific timeframe combinations), which could be improved in future iterations to assist IND administrators in parsing large data volumes.
- Conclusion: The results confirm that the distributed ledger component is successfully integrated and fully operational. It effectively meets the objective of providing a secure, complete, and accurate history of all user access events, which is a cornerstone of the sDATA platform's data governance and security framework.

Experiment number	sDATA-UC.03.01
Name of the experiment	User access rights configuration in Master Data Management Portal in the Slovenian pilot site
Timeframe	April 2026 (M43)
Targets	The target of this test case is to ensure that the user management system within the sDATA Master Data Management (MDM) portal functions correctly and efficiently. Specifically, the test aims to validate the usability of the system, confirming that administrators and users can easily navigate and utilize the platform. Additionally, the test will verify that user access rights are accurately set and enforced, ensuring secure and controlled access to the sDATA portal based on predefined roles and permissions. This validation is crucial for maintaining the integrity and security of the platform while providing a seamless user experience.
Actors	• EPR as metadata steward, • UL as new data user, • IND as technology provider
STREAM products	sDATA
Assets & systems	• sDATA – Master Data Management portal
Description of the experiment	One of the main components of the sDATA platform is the Master Data Management (MDM) portal. Within this portal, the user management system and metadata records system are key components. The user

	management system is essential for managing user data and access rights, ensuring that access to the sDATA portal is both limited and controlled. By conducting this experiment, we aim to ensure that the sDATA portal provides a secure, efficient, and user-friendly environment for managing master data. **Pre-condition/triggering event**: Administrator must have access credentials and permissions to log into the Master data management platform. The user management system within the MDM must be developed and operational. **Steps:** 1. Administrator logs into the MDM platform and adds a new user in the User section. 2. Administrator sets the new user data and access rights. 3. New user logs into the MDM system. 4. The user attempts to access various sections of the portal that they are authorized to view, verifying that permissions are correctly applied, and that access is granted as expected. **Post-condition**: User access rights are accurately set and enforced within the MDM portal, the usage of the portal is user-friendly.
Exception paths and scenarios of the experiment	• Unauthorized Access Attempt: A user with limited permissions attempts to directly access a restricted administrator-level URL within the MDM portal. • Incorrect Permission Level Action: A user with "Viewer" (read-only) rights attempts to perform an "Edit" or "Delete" action on a record, which should be reserved for "Editor" roles. • Attempt to Add a Duplicate User: The administrator tries to create a new user with an email address that is already registered in the system. • Access Rights Revocation During Active Session: While a user is logged into the platform, an administrator revokes their access rights to a specific module. The user then attempts to navigate back to that module. • Incomplete User Creation: The administrator tries to save a new user profile without filling in all mandatory fields (e.g., email address, name).
Datasets required for the experiment	• Master Data management data
Field data to be gathered	/
Related KPIs	KPI sDATA.03
Results of the Experiment	
• Roles of Actors: The experiment's execution was clearly divided among the designated actors. EPR (metadata steward) acted as the administrator, responsible for navigating the MDM portal, creating the new user account, and configuring granular access rights. UL (new data user) acted as the test subject, logging in to verify that the assigned permissions (Viewer/Editor) and restrictions were accurately enforced. IND (technology provider)	

monitored the backend user management system and the MDM portal's responsiveness during configuration changes.

- User Creation and Login: The administrator (EPR) successfully logged into the MDM portal and created a new user account (UL). The new user was able to successfully log in using the provided credentials.

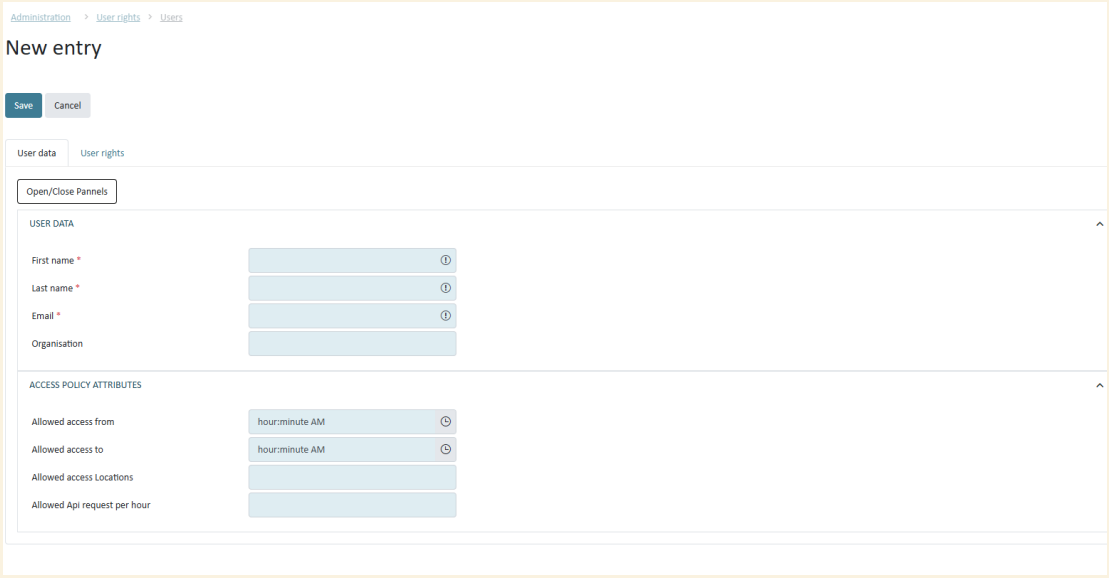


Figure 124: User management

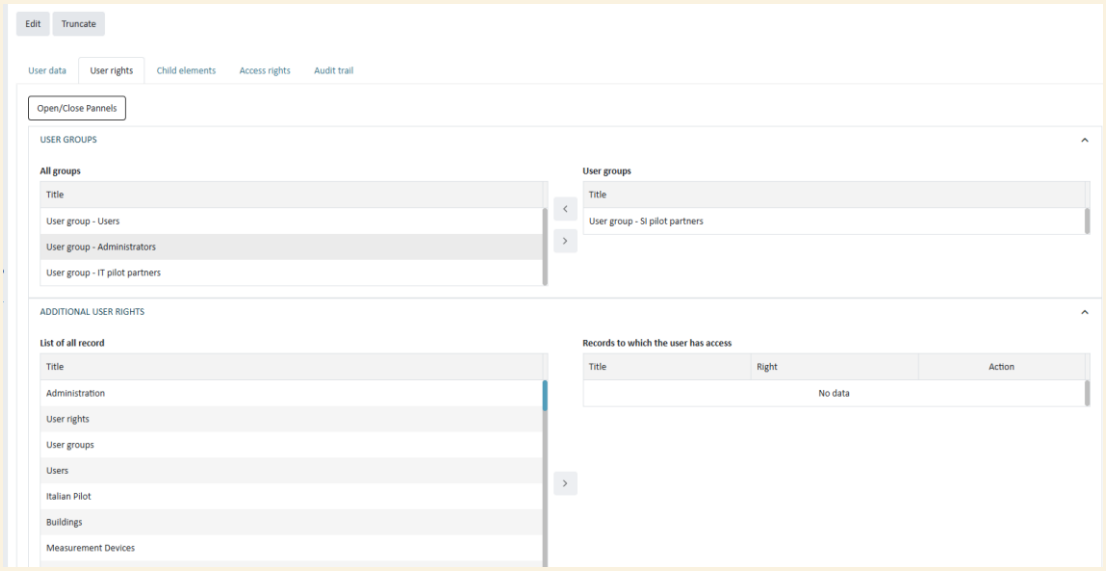


Figure 125: User rights set up

- Examples of Exchanged Data (Workflow): The workflow for defining and saving user permissions was validated. When the Administrator saved the new user profile, the following data payload was processed:

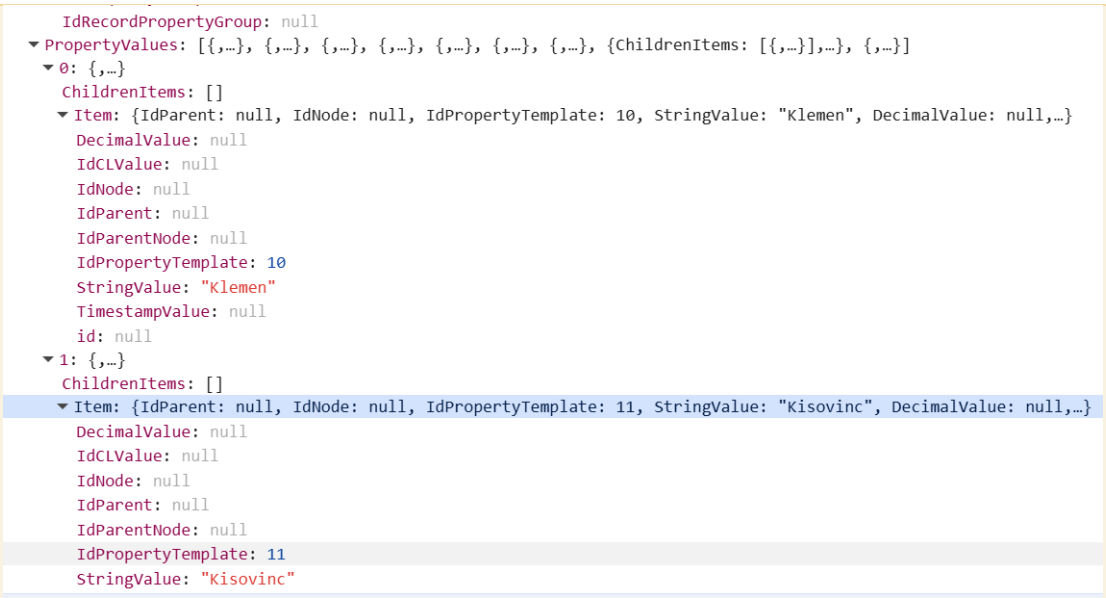


Figure 126: Data request

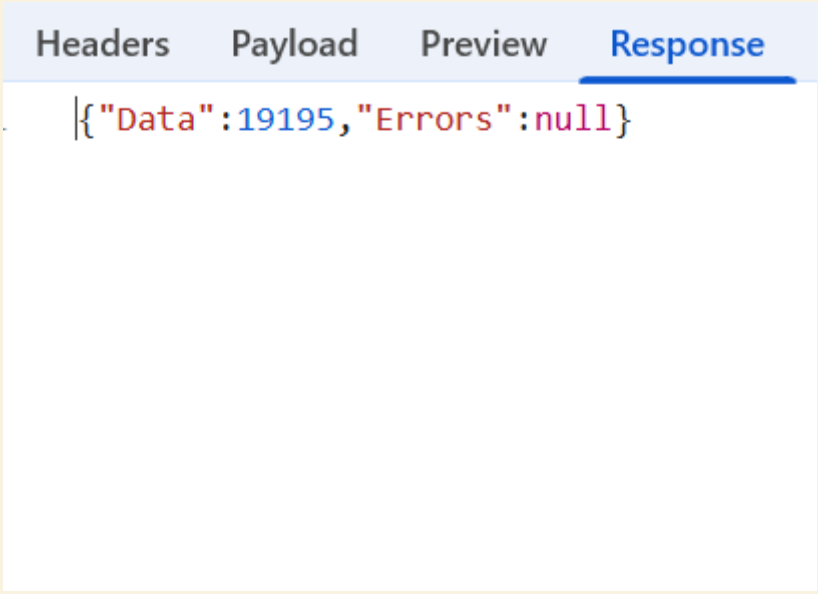


Figure 127: Data response

- Quantitative Performance Metrics:
  - Latency: The system applied access right configurations. The API response time for saving a new user profile averaged 2600 ms.
  - Verification Speed: The latency for checking user permissions upon navigating to a new module by the test user (Klemen) was measured at 400 ms, ensuring a seamless navigation experience without noticeable delays.
- Access Rights Verification (Authorized Access): The new user successfully accessed all sections and data for which they were granted "Viewer" or "Editor" permissions. The system displayed the correct data and enabled the appropriate functionalities (e.g., editing tools were available for "Editor" roles).
- Access Rights Verification (Unauthorized Access) & Permission Level Enforcement: The new user was consistently and correctly denied access to all sections of the portal for which they

had no permissions. In sections where the user had only "Viewer" rights, all "Edit," "Add," and "Delete" functionalities were successfully disabled or hidden.

- Exception Paths Testing: Exception scenarios were executed to test the system's security boundaries:
  - Unauthorized Access Attempt: Attempts to access restricted areas via direct URL resulted in a clear "Access Denied" error.
  - Duplicate User: The system correctly prevented the creation of a duplicate user based on an existing email address.
  - Active Session Revocation: The revocation of access rights during an active user session was successfully enforced on the user's very next action.
  - Incomplete User Creation: The system successfully blocked saving a profile with missing mandatory fields.

Qualitative analysis of the results

- Usability and User Experience: The user interface for managing users and access rights proved to be intuitive and user-friendly. Both the administrator and the test user were able to navigate the portal and perform their assigned tasks without needing additional instructions or support. The process of adding a new user and configuring their permissions is straightforward.
- System Responsiveness and Security: The platform responded instantly to all user actions, including login attempts and access requests. The enforcement of access rights was immediate and robust, with no identifiable security gaps or delays in applying permission changes. Error messages for unauthorized actions were clear and informative.
- Observed limitations and minor issues: To provide a realistic assessment, a minor UI limitation was noted: when access was denied via direct URL manipulation, the system displayed a generic "Access Denied" page rather than redirecting the user back to their previous safe page or the home dashboard. Additionally, while the revocation of rights works on the user's next action, implementing a WebSocket-based instant session termination could further enhance real-time security when an administrator revokes access.
- Overall System Performance: The user management system functions as expected and meets all predefined targets for this test case (including 100% accuracy for KPI sDATA.03). It provides a secure and efficient environment for controlling access to sensitive master data, demonstrating the maturity and reliability of the MDM portal's user management component.

8.2 SPANISH PILOT SITE

Experiment number	**ES-UC.01.01**
Name of the experiment	Grid congestion forecast accuracy and automatic requirement assessment
Timeframe	May - June 2026 (M44-M45)
Targets	This Test Case aims to verify the accuracy of congestion forecasting in the MV and LV grids of the DSO using sGRID. The results of this experiment will ensure that the forecasts are accurate and that the model is reliable to trigger the activation of the local flexibility market.
Actors	• ENER as DSO

	• ETRA as technology provider
STREAM products	sGRID
Assets & systems	• LV and MV grid (ENER) • SCADA (ENER) • AMI (ENER)
Description of the experiment	One of the functionalities of sGRID is the congestion forecast, which serves as a basis to arrange a local flexibility market session upon the detection of a potential congestion in the near-future (48h-ahead). This experiment will assess the accuracy of the forecasts and the correct detection of congestions. **Pre-condition/triggering event**: • The grid topology is integrated in sGRID. • The P, Q, I and V of the lines of the LV and MV grids of the DSO are continuously being monitored by sGRID. **Steps:** 1. sGRID performs the grid forecast for the next 48 hours and detects a congestion in the controlled line. 2. The forecasts are stored in the database for the subsequent analysis. 3. sGRID stores the forecast in the near-real time (1 hour ahead), which is responsible to decide if the activation of flexibility assets is finally required. 4. When the time of the forecasted congestion comes, the real state of the grid is stored in a timeseries dataset. 5. The process is performed continuously during a certain period to gather relevant number of samples for a complete evaluation. 6. These datasets are compared to accurately identify true positives and verify the real state of the grid. **Post-condition**: • The parameters that have been modified are reset to the real values. • Relevant data is logged for analysis.
Exception paths and scenarios of the experiment	No scenarios are contemplated in this experiment.
Datasets required for the experiment	• LV and MV grid topology • Active and reactive power value at grid lines – Historical • Active and reactive power of PV + community battery installation • Community battery SOC • Prosumers' consumption and generation • Generation from EnC collective self-consumption installations • Active and reactive energy of EV chargers • Weather data • Demand and production forecasts at grid level
Field data to be gathered	• Power flows forecast • Congestion forecast • Active and reactive power value at grid lines – Real-time

Related KPIs	KPI ES.02, KPI ES.03

Results of the Experiment

The preparation of this experiment started with the modelling of the complete network of Crevillent, adapted from the data in their Geographic Information System (GIS). This included the information of the MV network and 172 LV networks, with a total amount of 3,500 buses, 2,300 lines, and 15,000 usage points, among other elements.

The integration of the whole network was not part of the initial scope of the pilot, but the opportunity was presented while trying to find a method to keep sGRID up to date with the changes in Enercoop's production systems. A RESTful API to query these data from their GIS was provided by Enercoop, while ETRA implemented a service to periodically query and transform this data into the different data models managed by sGRID.

The transformation of the data was not straightforward, and the process met some inconsistencies in the relationships among elements in the GIS that needed to be overcome by the service. This iterative process between ETRA and Enercoop took longer than initially expected and, although the service is ready to read the updated data periodically, an agreement was reached to freeze the grid model in a snapshot from January 2026, so a stable version could be used for the validation of the tool.

Information from the GIS (buses, lines, transformers, switches, loads, and generators; their characteristics, and the relations among them) is then transformed into three different formats used by sGRID: JSON objects for the tool's real-time repository (MongoDB), a PandaPower model of each MV and LV network for calculation purposes, and a Cytoscape JSON of each network for graphical representation in the tool. These transformations are achieved using HE-OPENTUNITY's Topology Alchemy service, an open-source software for grid model transformation that has also been improved using the network topology data from the pilot.

The next step was to fill the grid model with measurements from Enercoop's system that could be used as input for the calculations. Two main issues were faced at this point:

a. Metering data from the AMI system provided hourly imported and exported energy data for ~15,000 usage points, but the information—used for billing purposes—is updated into the system with a delay of up to 24 hours, i.e. each day we have the measurements from the previous day.

- As the nature of this system prevented sGRID from having an updated/real-time status of the grid, the decision was made to use the historical data available from the usage points in each network to feed a neural network—using NeuralProphet—that provides the evolution (i.e. forecast) of each time series. Instead of generating the forecasts for the next 48 hours starting at the present moment, the service first assesses the last value received for each usage point and extends the petition to cover the gap, thus providing an estimation of the current load or the generation of the metering point, which is then used as an approximation for the real-time calculations.

b. Measurements gathered from Enercoop's SCADA provide the real-time status (5-minute updates) of a subset of key buses in the different networks. The combination of this information with the estimations from the AMI data improves the accuracy of the calculations, as PandaPower takes the data at these points of the grid as fixed and adjusts the values of the rest of the network until the calculation converges.

- The main issue encountered with the SCADA data was the mismatch of identifiers between its signals and the elements in the GIS (i.e. in sGRID's network model).

Again, an iterative process between ETRA and Enercoop took place to solve this issue, which could eventually be solved, and data be associated to the proper points in the network for subsequent use.

With this information integrated into sGRID, power flow calculations are run hourly for the next 48 hours for the LV networks of Crevillent. As this processing takes some computational time, several instances of these services are run in parallel, each of them managing a subset of the modelled networks, which makes if feasible to produce the results in the expected time frame. With the results of these calculations, the same algorithm is run for the MV network, thus covering the whole grid.

For each instance of a calculation (i.e. 1 network, 1 hour), the power flow calculation service obtains:

- I, P, Q of each line, transformer
- V, P, Q of each bus

In addition to these values, PandaPower compares them to the operational limits of the elements—in this case, the maximum supported current of the lines—to detect congestions.

In the course of the testing of the functionality, it has been noticed that congestions are not detected due to the dimensioning of the networks, which accept much higher volume of power than actually registered. To illustrate this experiment, a scenario is created in El Salà LV network where demand from some usage points is artificially increased in order to force a congestion. This same issue in the network will be used as a basis to trigger the solution in ES-UC.01.02.

The status of the network for several hours ahead is available in sGRID. A scenario is created based on one snapshot of the grid 7 hours in the future:

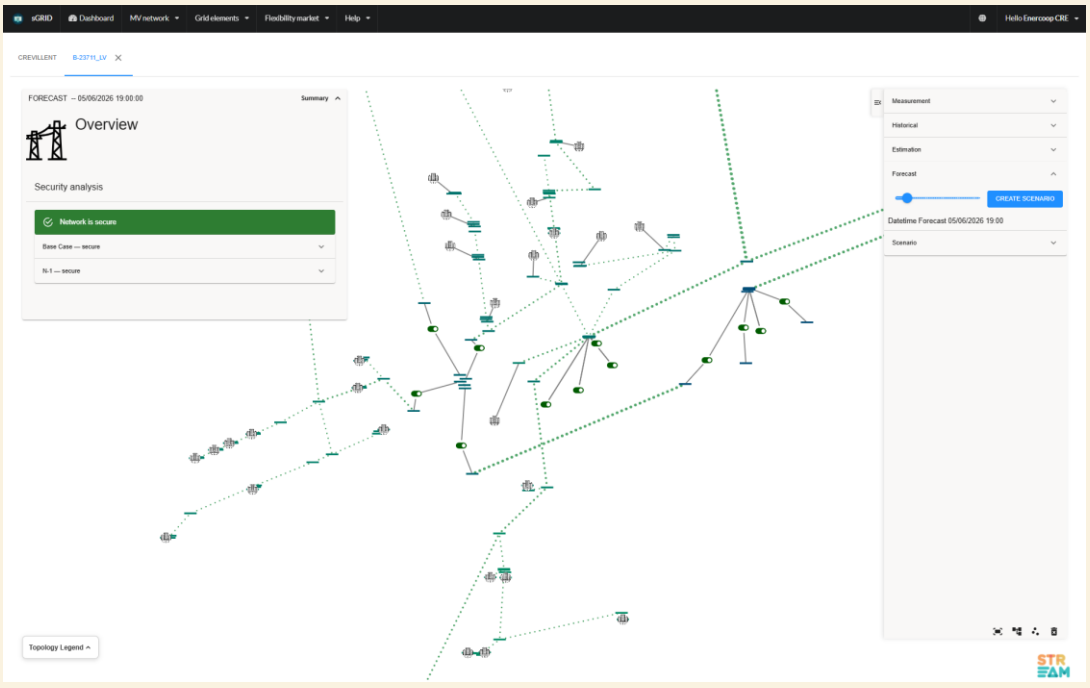


Figure 128: Grid forecast 7 hours ahead

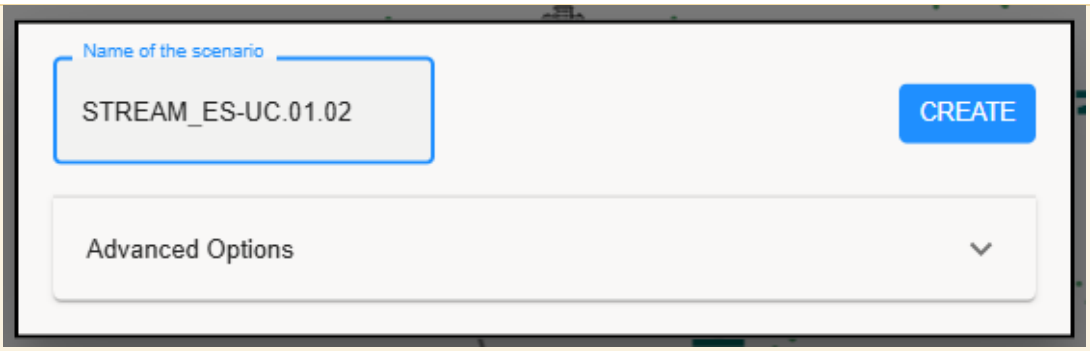


Figure 129: sGRID scenario creation

In order to simulate the congestion, the active power setpoint of a set of usage points are incremented to their nominal power:

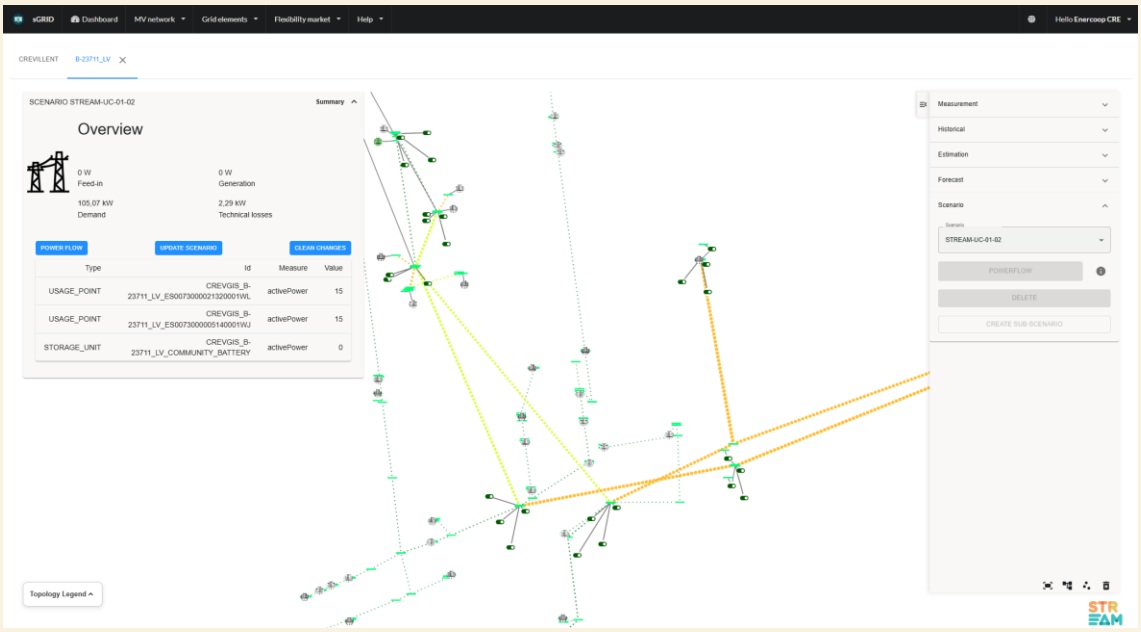


Figure 130: sGRID scenario simulation and visualization

We can see how sGRID detects the issues in the grid by marking those lines at abnormal capacity in another colour, depending on their status. This calculation is performed in the background every hour for the next 48 hours and, when an issue is detected, the pipeline for its mitigation is automatically started by alerting the operator with the creation of a new incident.

Qualitative analysis of the results

As mentioned in the description of the results, the event of actual congestions in the grid is scarce. In this situation, the assessment of the accuracy of the detections is based on the accuracy of the modelling of its parts. The elements that are used for the identification of congestions are:

1. **Network modelling.** The modelling of the networks (MV and LV) is based on the information from Enercoop's GIS, which is trusted to be accurate as it is a system used in real life operation. As mentioned above, the integration of the data was not straightforward, but the inconsistencies found in the process were corrected and the models in sGRID were validated by Enercoop. For this reason, the model is assumed to be correct.
2. **SCADA data.** The information from the SCADA is received in real-time and integrated into sGRID. The data itself is trusted as, again, it comes from a system used in everyday operation. The main point of concern here was the pairing of SCADA signals and elements in the network model, which again was provided and validated by Enercoop.

3. **AMI data.** This might be the main point of concern regarding the accuracy of the calculations. As explained above, metering data from the usage points in Crevillent is available with 24-to-48-hour delay, as the system does not require a closer-to-real-time synchronisation, so a forecast model for each network is used to estimate the real-time and future status of each usage point. Thus, the accuracy of the detection of congestions will strongly rely on the accuracy of these forecasts.
   In order to assess their accuracy, we calculate the following metrics:
   a. MAE: Average absolute difference between predicted and actual values, in the signal's native unit.
   b. RMSE: Like MAE but penalises large errors more heavily by squaring the residuals before averaging.
   c. MAE ratio: MAE divided by the signal's standard deviation (scale-independent).
   d. Loss: NeuralProphet's training objective value (Huber loss) on the training set.

We will separate the evaluation of the models depending on the metric used as objective of the forecast.

activeEnergyImportedDelta (loads, usage points)

Models for 131 feeders were generated, the statistical metrics provided below:

Table 39: Accuracy metrics for active energy imported

Metric	Min	Median	Mean	Max
MAE	0.05	0.20	1.36	145.88
RMSE	0.08	0.33	1.80	184.27
MAE ratio	0.02	0.25	0.27	0.60
Loss	0.01	0.12	0.16	1.14

activeEnergyExportedDelta (generators)

Models for 13 feeders with generators were created, with the following metrics:

Table 40: Accuracy metrics for active energy exported

Metric	Min	Median	Mean	Max
MAE	0.004	0.49	0.88	2.85
RMSE	0.006	0.70	1.34	4.40
MAE ratio	0.02	0.38	0.33	0.54
Loss	0.02	0.09	0.21	1.18

MAE ration quality distribution was for 7 models excellent or acceptable (≤ 0.40), while 6 were borderline (0.40-0.60). This is typical for export/generation signals, which are usually spikier and harder to predict (intermittent solar, irregular export patterns). Further refinement would be needed in order to improve the almost 50% of models that are not as good (although they pass the quality gate).

activePower (generators)

5 addition generators are integrated from a different source and do not provide energy values, so models for active power were created instead:

Table 41: Accuracy metrics for generators

Metric	Min	Median	Mean	Max
MAE	13.1	82.6	72.8	126.9

RMSE	22.3	145.1	124.0	216.3
MAE ratio	0.26	0.36	0.34	0.40
Loss	0.04	0.06	0.06	0.07

100% of the models were acceptable (0.20–0.40). As with high consumers, raw MAE looks large (13–127 kW) but the standard deviation is also large (43–345 kW), so the normalised ratio is consistently in the acceptable band. The loss is notably low and very consistent across all 5 models, showing the most stable training behaviour of the three groups.

Experiment number	**ES-UC.01.02**
Name of the experiment	Community battery response to DSO requirement
Timeframe	May - June 2026 (M44-M45)
Targets	The objective of this Test Case is to evaluate the capability of the community battery to respond to DSO flexibility requests for congestion mitigation purposes, and to assess the impact of the battery activation on line utilization and congestion alleviation.
Actors	• ENER as DSO • ENER as Energy Community Manager • ETRA as technology provider
STREAM products	sGRID, sFLEX
Assets & systems	• Low voltage grid (ENER) • SCADA (ENER) • AMI (ENER) • Energy Community Battery (ENER)
Description of the experiment	When a congestion is forecasted or detected in the local distribution grid, local actions must be taken in order to prevent curtailment of renewable energy production and avoid electricity supply issues that may lead to blackouts at end users' premises, frequency deviations or overvoltage situations. When a congestion is identified by sGRID, the tool automatically generates the flexibility requirement that the DSO sends to the local flexibility market, including: • the code of the affected grid zone (assigned in sMART during the registration of the zone in the market), • the amount of flexibility required to solve the issue, and • the maximum price the DSO is willing to pay for the flexibility service. This Test Case focuses specifically on the validation of the congestion mitigation capabilities of the community battery and the technical flexibility activation workflow. Therefore, the complete local flexibility market process is intentionally simplified. Instead of opening and executing a full market session, sGRID directly sends the flexibility activation confirmation to sFLEX, emulating the confirmation that would normally result from the matching and clearing

processes of the long-term flexibility market in the complete end-to-end demonstrations.

The experiment is executed under controlled conditions in order to avoid jeopardizing the security of the electricity supply. To this end, a congestion scenario is artificially created by increasing the loads of the El Sala LV grid, where the community battery is located. Under these controlled and non-harmful conditions, sGRID forecasts and/or detects the congestion situation in the LV grid and automatically generates the corresponding flexibility requirement. Afterwards, the community battery receives the activation signal and modifies its operation accordingly to alleviate the congestion. The results obtained are analyzed in order to assess the impact of the battery flexibility provision on congestion mitigation in the LV grid.

Pre-condition/triggering event:

- The grid topology is integrated in sGRID.
- The P, Q, I and V of the lines of the LV and MV grids of the DSO are continuously being monitored by sGRID.
- The community battery is integrated and monitored in sFLEX.

Steps:

1. sGRID performs the grid forecast for the next 24 hours.
2. Building on the forecasts, a scenario is created in sGRID, increasing the consumption of the loads connected to the El Sala grid, LV line where the community battery is located, in order to increase the probability of congestions in that section of the grid.
3. When congestion is forecasted in that scenario, sGRID performs a sensitivity analysis to identify the assets that can provide effective flexibility to mitigate the congestion.
4. An automatic requirement is generated by sGRID, identifying:
    - the code of the zone affected by the congestion (which is assigned in sMART when registering the zone in the market),
    - the flexibility needed to address the issue, and
    - the maximum price the DSO is willing to pay for the service.
5. The DSO verifies the accuracy of the bid, ensuring that the affected zone code is correctly identified, the required flexibility quantity, the direction (upwards or downwards), and the price are all accurate.
6. sGRID sends an activation signal to sFLEX to activate the battery.
7. ENER, as operator of the community battery, sends through sFLEX the command to the community battery as requested by sGRID to provide the required flexibility.
8. The community battery switches to charging mode to absorb the excess energy to rebalance the grid.
9. After the congestion period, data is collected on grid performance, including the congestion alleviation, the effectiveness of the battery's activation, and the time response of the battery.

Post-condition:

- The parameters that have been modified are reset to the real values.
- Relevant data has been logged for analysis.
- The battery setpoint is established to its default operating mode.

Exception paths and scenarios of the experiment	**The parameters of the automatic requirement are not correct:** 5a. The DSO detects that the parameters of the automatic bid are not correct. 6a. The DSO modifies the parameters to the correct ones, and sGRID stores the change to posterior analysis.
Datasets required for the experiment	• LV and MV grid topology • Active and reactive power value at grid lines – Historical • Active and reactive power of PV + community battery installation • Community battery SOC • Generation from EnC collective self-consumption installations • Domestic batteries SOC • Active and reactive energy of EV chargers • Weather data • Prosumers' consumption and generation • Community battery setpoint
Field data to be gathered	• Demand and production forecasts at grid level • Power flows forecast • Congestion forecast • Active and reactive power value at grid lines – Real-time
Related KPIs	KPI ES.04, KPI ES.09

Results of the Experiment

Resuming from ES-UC.01.01, we have a scenario in sGRID where selected loads in the LV network of El Salà are increased to force a congestion in a line. When this occurs, an incident is created in the tool that describes the detected problem.

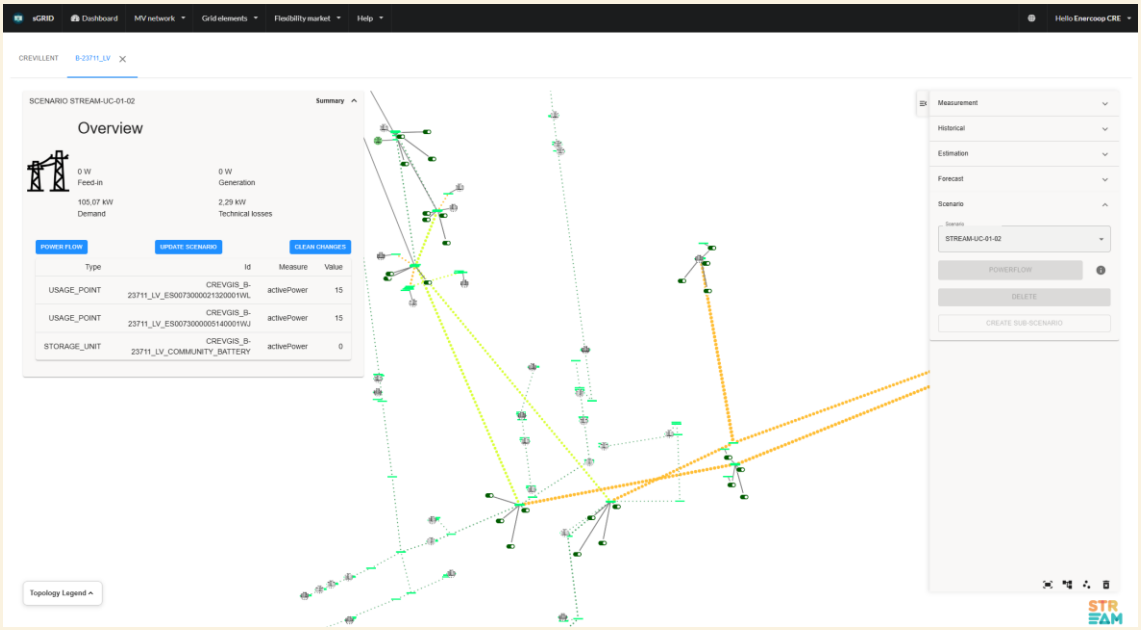


Figure 131: sGRID congestion detection

The operator assesses the problem in sGRID by selecting the time of the congestion and creating a scenario.

The community battery is selected as the most suitable asset to solve the detected issue, and the operator uses the scenario functionality to assess the quantity of energy that will be required to

mitigate the issue (in this case, 40 kW). This requirement is sent directly to sFLEX for consideration in the schedule of the battery.

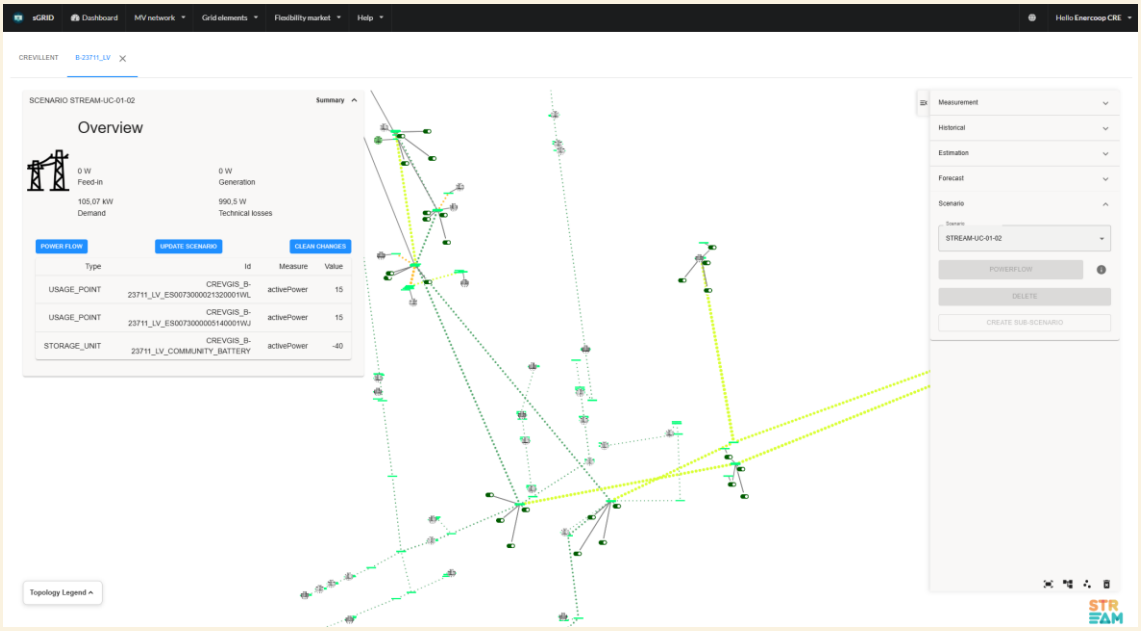


Figure 132: Simulation of the actuation of the battery for congestion mitigation

Prior to the reception of the requirements from the DSO, the normal operation of sFLEX regarding the community battery involves its management as a flexible asset to optimize the energy cost and maximize the use of PV production. Based on the forecasted generation and demand, the energy tariff, and the nominal parameters of the battery, an optimal active power setpoint is calculated for the next 48 hours.

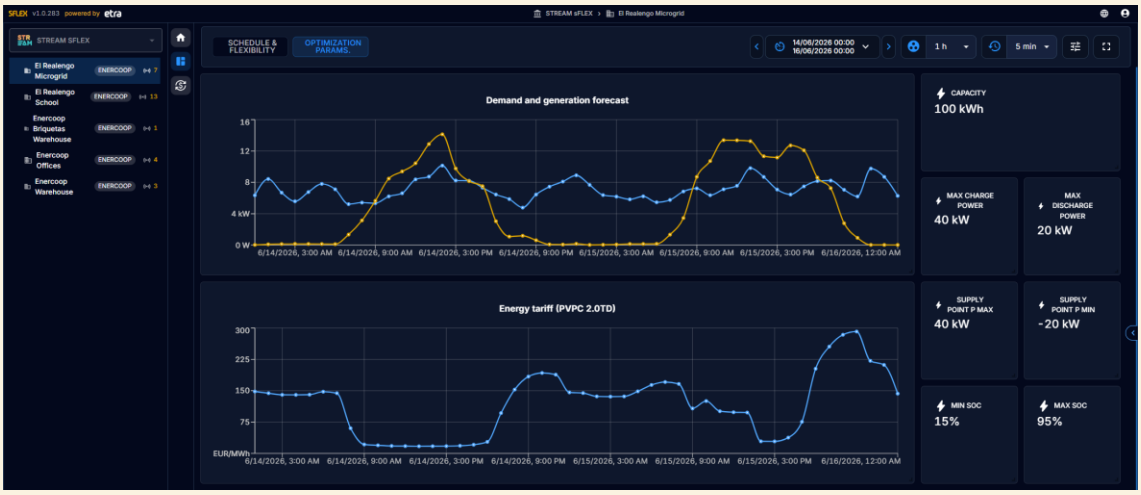


Figure 133: Demand and generation forecast of the battery (above) and energy tariff (below)



Figure 134: Setpoint and state of charge (above) and calculated flexibility (below)

Upon reception of the requirement by sGRID, sFLEX incorporates it as a restriction in the operation of the battery and recalculates its schedule, which now incorporates both its previous baseline and the value requested by the DSO. When the time of the activation comes, sFLEX sends the corresponding command to activate the battery.

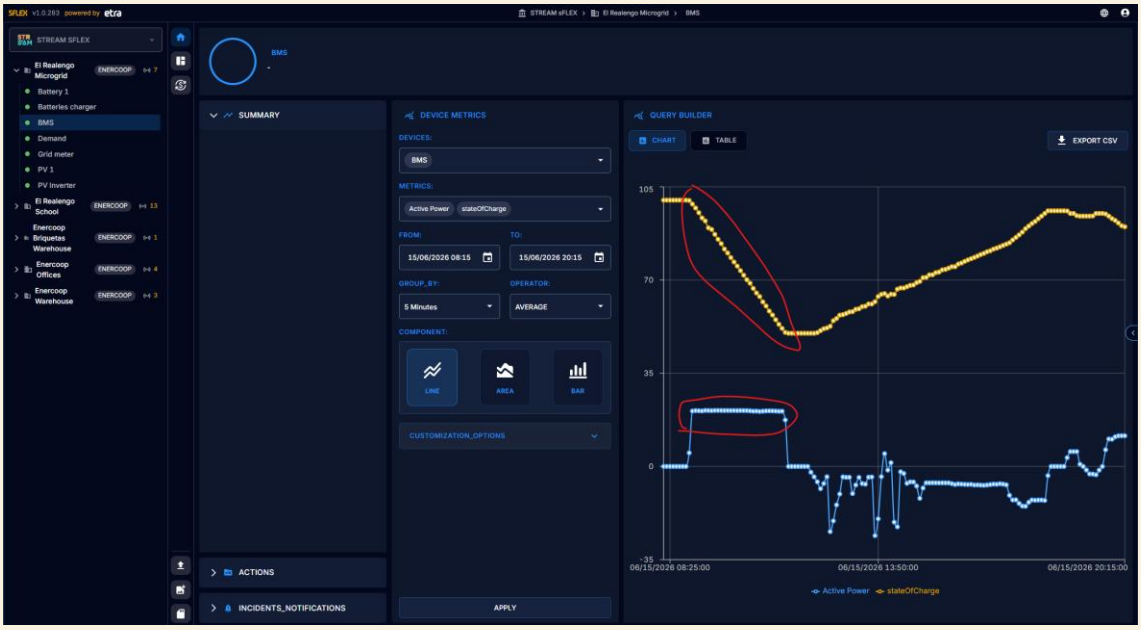


Figure 135: Active power and state of charge of the battery for flexibility provision

The community battery implements the command and changes its mode of operation as reflected in sFLEX. The results of this activation are reflected in both tools for subsequent analysis. (Please note that, although the setpoint calculated by sGRID was 40 kW discharge—which could be applied in normal conditions—, due to the faulty status of the battery during the demonstration period, the maximum discharge power was limited to 20 kW).

Qualitative analysis of the results

With the use of sGRID, the operator is able to identify the potential issue in the grid, and identify the flexibility asset and estimate the amount of flexibility to mitigate it. Communication with sFLEX

allows this solution to be incorporated into the planning of the community battery, which is eventually implemented when the issue arrives. The capability of the asset is validated successfully. The use of the community battery to mitigate congestion problems in local grids is assessed.

Experiment number	ES-UC.02.01
Name of the experiment	Grid voltage deviation forecast accuracy and automatic requirement assessment
Timeframe	May - June 2026 (M44-M45)
Targets	Similarly to test case ES-UC.01.01, this experiment aims to: 1. Verify the correct forecast of the deviation of the voltage out of the boundaries set by regulation (±7% of the nominal voltage) in the MV and LV grids of the DSO through sGRID. The results of this experiment will help determine the optimal lead time for convening a market session, providing sufficient time for the local flexibility market session to be organized, for FSPs providers to send their bids and for the results to be published, ensuring enough accuracy of the forecast. 2. Evaluate the proper generation of automatic bids when a voltage violation is detected or forecasted by sGRID.
Actors	• ENER as DSO • ETRA as technology provider
STREAM products	sGRID
Assets & systems	• LV and MV grid (ENER) • SCADA (ENER) • AMI (ENER)
Description of the experiment	One of the functionalities of sGRID is the voltage deviation forecast, which serves as a basis to arrange a local flexibility market session upon the detection of a potential voltage deviation in the near-future (24h-ahead). This experiment will assess the accuracy of the forecasts and the correct detection of this issue in the network. In order to avoid network issues (since this test case does not take any actions to tackle the voltage deviation), the parameters of one of the lines or the loading conditions are modified to simulate a voltage deviation under controlled and non-harmful conditions for the grid in order not to jeopardize the security of the energy supply. When the voltage deviation is forecasted in sGRID, the tool automatically generates the requirement that the DSO will send to the market, establishing: a. the zone affected by the voltage deviation, b. the calculated flexibility that is required to address the voltage deviation, and c. the maximum price the DSO is willing to pay for the service. This experiment will be run several times in order to obtain, on the one hand, the number of times voltage deviations are correctly forecasted, and

	on the other hand, to observe how the accuracy varies as the forecast approaches the potential voltage deviation moment. Currently, there's a scenario in which a significant voltage deviation can take place, which is when the community battery installed in the El Salá CT does not provide reactive power to the grid. For the purpose of this test case, the battery will not provide reactive battery to analyse the behaviour of the grid and observe the voltage deviation forecast through sGRID. **Pre-condition/triggering event:** • The P, Q, I and V of the lines of the LV and MV grids of the DSO are continuously being monitored by sGRID. **Steps:** 1. sGRID performs the grid forecast for the next 48 hours. 2. The forecasts are stored in the database for the subsequent analysis. 3. A scenario is created for night hours, when PV production is zero and increasing the loads of el Salá. 4. Voltage drops are detected in some of the buses of the grid. 5. When the voltage deviation is detected in the scenario, sGRID performs a sensitivity analysis to identify the grid zones where assets that can potentially alleviate the congestion are registered. 6. An automatic requirement is generated by sGRID, identifying: a. the code of the zone affected by the congestion (which is assigned in sMART when registering the zone in the market), b. the flexibility needed to address the issue, and c. the maximum price the DSO is willing to pay for the service. 7. The DSO verifies the accuracy of the bid, ensuring that the affected zone code is correctly identified, the required flexibility quantity, the direction (upwards or downwards), and the price are all accurate. 8. sGRID stores the forecast in the near-real time (1 hour ahead), which is responsible to decide if the activation of flexibility assets is finally required. 9. When the time of the forecasted voltage deviation comes, the real state of the grid is stored in a timeseries dataset. 10. The process is performed continuously during a certain period to gather relevant number of samples for a complete evaluation. 11. These datasets are compared to accurately identify true positives and verify the real state of the grid. **Post-condition**: • The parameters that have been modified are reset to the real values. • Relevant data is logged for analysis.
Exception paths and scenarios of the experiment	No scenario is expected for this test case.

Datasets required for the experiment	• LV and MV grid topology • Active and reactive power value at grid lines – Historical • Voltage and angle of busbars – Historical • Active and reactive power of PV + community battery installation • Prosumers' consumption and generation • Generation from EnC collective self-consumption installations • Active and reactive energy of EV chargers • Weather data
Field data to be gathered	• Demand and production forecasts at grid level • Power flows forecast • Voltage deviation forecast • Active and reactive power value at grid lines – Real-time • Voltage and angle of busbars – Real-time
Related KPIs	KPI ES.07
Results of the Experiment	
Using the same inputs and functionalities in sGRID as in ES-UC.01.01, a scenario is created where high consumption in a branch of the LV network far away from both the community battery and the MV connection point yields to deviation of voltage in a set of buses. The model of the grid in PandaPower and the results of the power flow calculations identify the voltage deviation ratio in some buses of the LV grid (buses in red). A similar incident like the one from the previous test case is created.	

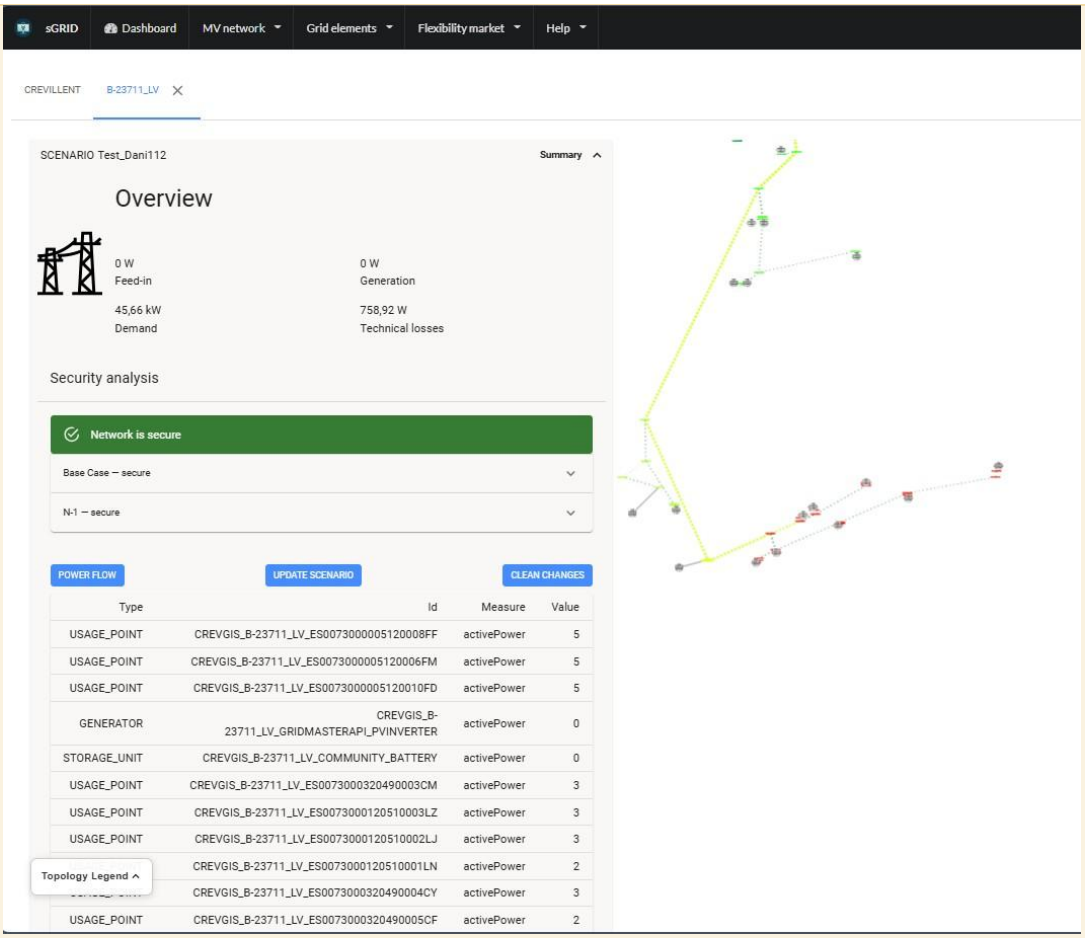


Figure 136: Voltage drops in buses during low local generation hours and high energy consumption

The deviation of voltage is shown in the colour of the buses, similarly to how the load of the lines is represented in the viewer. The specific values for the bus can be accessed in their details.

As in ES-UC.01.01, an incident is generated in sGRID to alert the operator about the detected issue and be able to start its mitigation process.

Qualitative analysis of the results

The validation of the accuracy of the detection of voltage deviations in sGRID is based in the same parameters as ES-UC.01.01: the accuracy of the network modelling, the pairing of the SCADA values with the corresponding buses, and the accuracy of the forecasts of the elements of the AMI.

Experiment number	**ES-UC.02.02**
Name of the experiment	Community battery response to DSO requirement for voltage deviation
Timeframe	May - June 2026 (M44-M45)
Targets	The goal of this Test Case is to evaluate the capabilities of the energy community battery to address voltage deviations in the distribution grid. The

	test case starts with the assumption that a market session has been conducted and the community battery was matched and will be activated.
Actors	• ENER as DSO • ENER as Energy Community Manager • ETRA as technology provider
STREAM products	sGRID, sFLEX
Assets & systems	• Low voltage grid (ENER) • SCADA (ENER) • AMI (ENER) • Community Battery (ENER)
Description of the experiment	When a voltage deviation is forecasted or detected in the local distribution grid, local action must be taken in order to prevent electricity supply issues that can lead to blackouts at the end users' premises, frequency deviations or overvoltage scenarios. This experiment will run in a controlled scenario to avoid jeopardizing the security of the energy supply, maintaining the modified parameters of the previous test case. sGRID will either forecast or detect voltage deviation issues in the LV grid. The command for flexibility will be sent directly through sFLEX to the energy community battery, which will be activated to mitigate the deviation. The results will be analyzed to assess the impact of the battery's flexibility provision on voltage deviation. **Pre-condition/triggering event**: • The community battery is integrated and monitored in sFLEX. • A voltage deviation is detected by sGRID in the distribution system. • sGRID determines the flexibility quantity required to avoid grid instability. • A market session has been conducted and the community's battery bid was matched. **Steps:** 1. sFLEX receives the reactive or active power that has to be injected/absorbed by the battery. 2. ENER, as operator of the community battery, sends through sFLEX the command to the community battery as requested by sGRID. 3. The community battery switches to charging mode to absorb or inject reactive energy to rebalance the grid. 4. After the voltage deviation period, data is collected on grid performance, including the correction of the voltage deviation and the effectiveness of the battery's activation, and the time response of the battery. **Post-condition**: • The parameters that have been modified are reset to the real values. • Relevant data has been logged for analysis. • The battery setpoint is established to its default operating mode.

Exception paths and scenarios of the experiment	No scenarios are considered in this test case.
Datasets required for the experiment	• LV and MV grid topology • Active and reactive power value at grid lines – Historical • Voltage and angle of busbars – Historical • Active and reactive power of PV and community battery installation • Community battery SOC • Prosumers' consumption and generation • Generation from EnC collective self-consumption installations • Domestic batteries SOC • Active and reactive energy of EV chargers • Weather data • Community battery setpoint
Field data to be gathered	• Demand and production forecasts at grid level • Power flows forecast • Voltage deviations forecast • Active and reactive power value at grid lines – Real-time • Voltage and angle of busbars – Real-time
Related KPIs	KPI ES.09
Results of the Experiment	
Analogously to ES-UC.01.02, the scenario functionality of sGRID is used upon detection of a voltage deviation in El Salà LV network to try to assess the solution. The operator simulates the use of the community battery to absorb de excess of PV production that is causing the voltage deviation problem.	

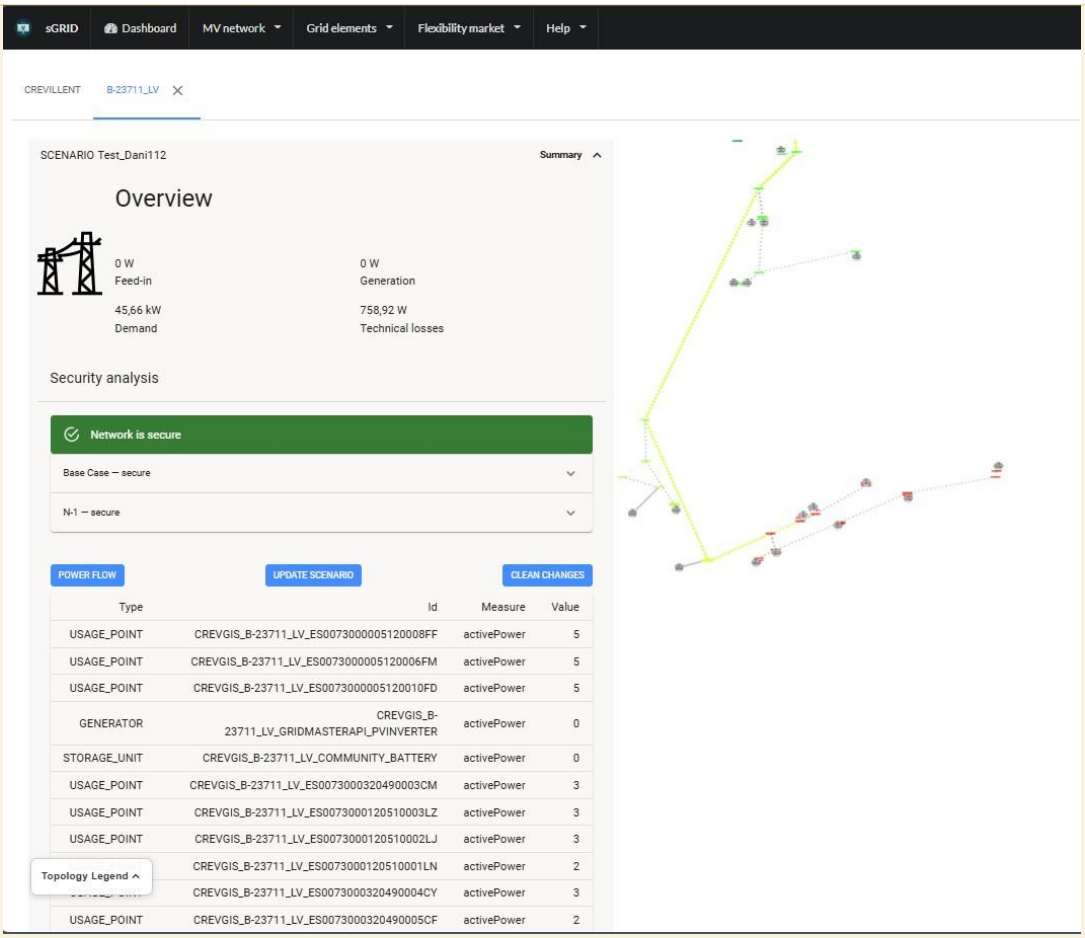


Figure 137: Scenario with voltage deviations for TC UC-ES.02.02

When the issue was forecasted, the scheduled setpoint of the battery was 7 kW of charging. The results of the power flow calculation show that an additional 43 kW of absorption would mitigate the voltage deviation of the problem.

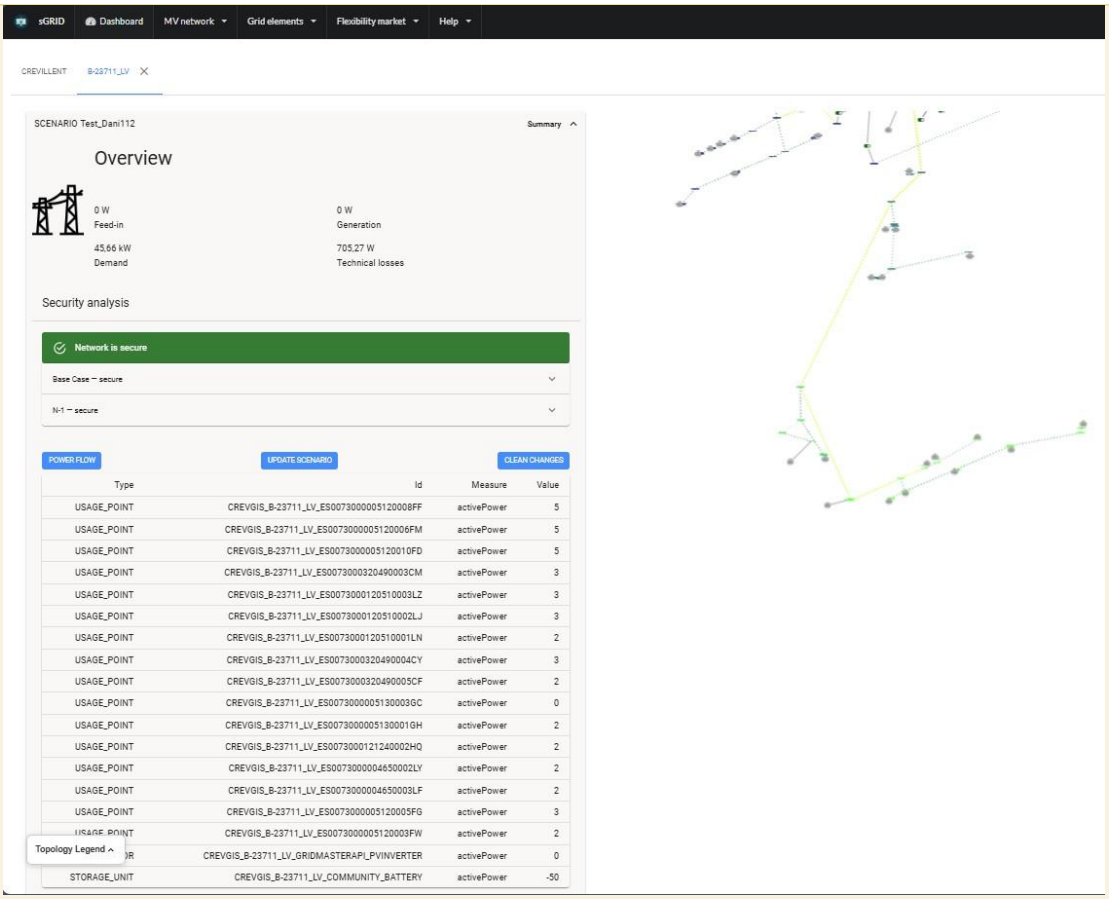


Figure 138: Simulation of the system with the activation of the battery

In real operation, sGRID would send the requirement to sMART and the bidding process would start. We now assume that the market has been cleared and the request has been covered by the community battery. The request is integrated in sFLEX as input in the optimization of the battery, which provides an alternate reconfiguration of its setpoint.

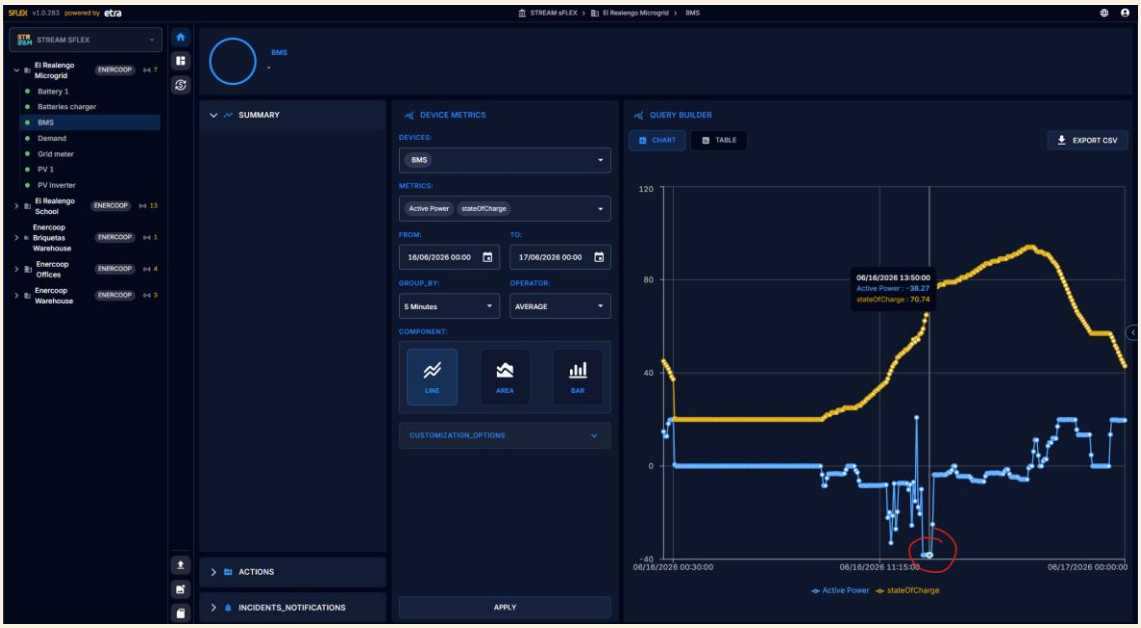


Figure 139: Actuation of the battery to address the voltage deviation

The assessment of this provision of flexibility is registered in both tools, which can be assessed afterwards to confirm the application of the new setpoint. (As with ES-UC.01.02, the modification in the setpoint as requested by sGRID—50 kW setpoint—could not be reached due to technical limitations of the faulty battery, whose maximum charging power was limited to 40 kW.)
Qualitative analysis of the results
The test case demonstrates the coordination of the STREAM ecosystem to solve a second type of problem detected in the network: voltage deviation in buses as detected by sGRID's power flow calculation. The use of the community battery to absorb the excess of production in another point of the network provides capacity of actuation to the grid operator and stability to the network.

Experiment number	**ES-UC.03.01**
Name of the experiment	Device registry and prequalification of the flexibility assets
Timeframe	May 2026 (M44)
Targets	In this test case, the procedure for device regisrty and the subsequent prequalification of the energy assets that will participate in the demonstration activities will be evaluated. This procedure enables FSPs to provide flexibility.
Actors	• ENER as DSO • OMIE as Market Operator • ENER as aggregator • ETRA as technology provider
STREAM products	sGRID, sMART, sENC, sFLEX
Assets & systems	• Energy community battery (ENER) • Energy community members flexibility assets (ENER) • EVs and chargers (ENER)
Description of the experiment	The Energy Community Manager (ENER) has to register the assets owned by the EnC members in sMART in order to provide flexibility services to the market. Once registered in sMART, OMIE as MO has to validate the administrative information of the asset and inform ENER as DSO, in order to proceed with the technical validation of the assets, assessing that the asset information is accurate and that the technologies indicated in the registration are actually installed. Once the user has registered all the assets, the aggregator can associate the small assets as part of an aggregation, which are monitored and managed by sENC, in a common Unit Offer, or leave it as individual assets in a exclusive Unit Offer. Once the prequalification is confirmed, the asset can provide flexibility services in the local flexibility market. **Pre-condition/triggering event**: • OMIE has issued certificates to ENER for accessing sMART as agent and DSO. • Assets and aggregations are already registered in sFLEX and sENC. **Steps:**

	1. ENER accesses sMART using the DSO certificate and registers the DSO and its local zones. 2. ENER accesses sMART as EnC manager to register the new agent and links it to the DSO zones. 3. The aggregator/FSP fills the user registration in sMART. 4. The aggregator/FSP fills in the administrative device registry form for each asset in sMART. 5. The Market Operator validates the administrative documentation. 6. The DSO validates the technical capability of the assets, ensuring: a. The assets are part of the grid. b. The technical data provided is correct. 7. The validation result is communicated to the FSP. 8. sENC provides the information about the aggregations that must be registered in the market, and the assets are linked to aggregated or individual unit offers. 9. sENC and sFLEX retrieve the registered assets per agent and unit offer, checks the correct registration and enables the assets to participate in flexibility services through the market participation modules. **Post-condition**: • The EnC assets are successfully registered in sMART. • The assets are validated (administratively and technically). • The assets are enabled in sFLEX and sENC to generate flexibility offers in the Local Flexibility Market.
Exception paths and scenarios of the experiment	**The DSO does not validate the registration:** 5a. The DSO does not validate the technical capability of the asset(s), and indicates the reason. 6a. The FSP receives the denied validation with the message of the DSO indicating the reason. 7a. The FSP corrects the validation form, modifying the mistaken information provided. 8a. The DSO validates the technical capability. 9a. Confirm validation to FSP
Datasets required for the experiment	N/A
Field data to be gathered	N/A
Related KPIs	KPI ES.08
Results of the Experiment	
To have access to the LFM, OMIE as Market Operator (MO) generates and send access certificates, for this purpose, both the DSO and the LFM agents must register on the platform. The certificates have different profiles: One of them is intended for the Market Operator, who is responsible for registering DSOs and LFMs, as well as prequalify and qualify assets. Another one for entities acting as DSO, which grants access to register flexibility zones, prequalify and qualify flexibility assets and	

generate local requirements; and one for entities acting as flexibility services providers, enabling them to register their flexibility assets, see open market sessions and send flexibility bids. This experiment begins with ENER receiving both type of certificates.

To complete the registration, the DSO must sign up on sMART and create its corresponding profile. To complete this process, the agent must fill in a form that links the user to the DSO's legal entity. The DSO representative must also provide contact information to receive market-related notifications, as well as proof of authorization to ensure that the person has the capacity to represent the entity.

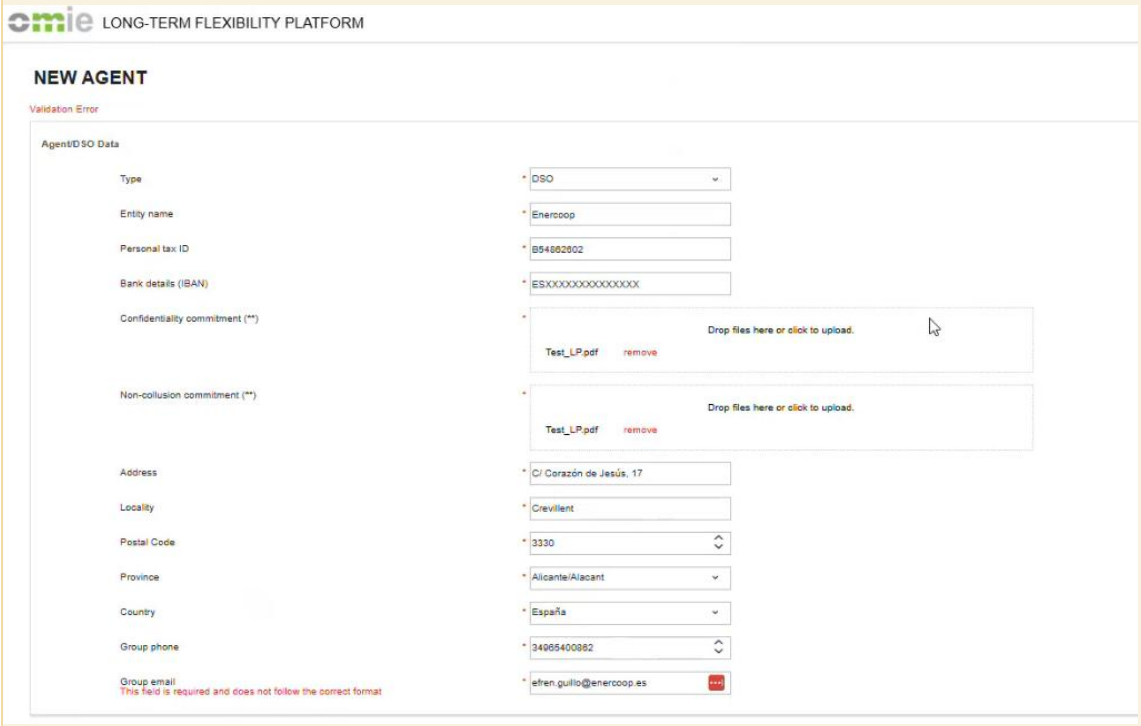


Figure 140: DSO agent registration in sMART - part 1

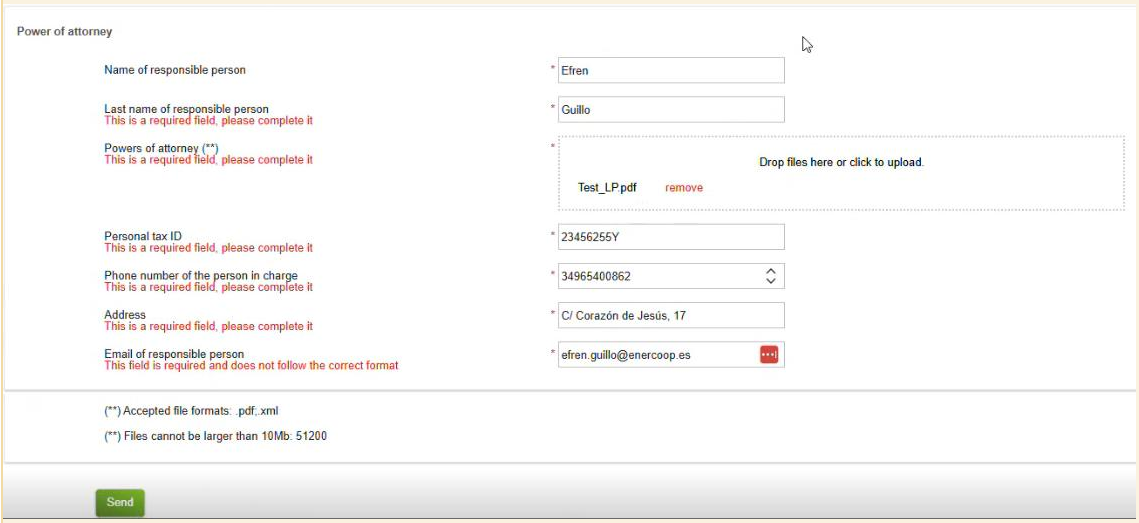


Figure 141: DSO agent registration in sMART - part 2

Once the registration request is sent, OMIE as MO has to validate the new agent registration and assign a certificate that is sent to the responsible person once the registration has been validated.

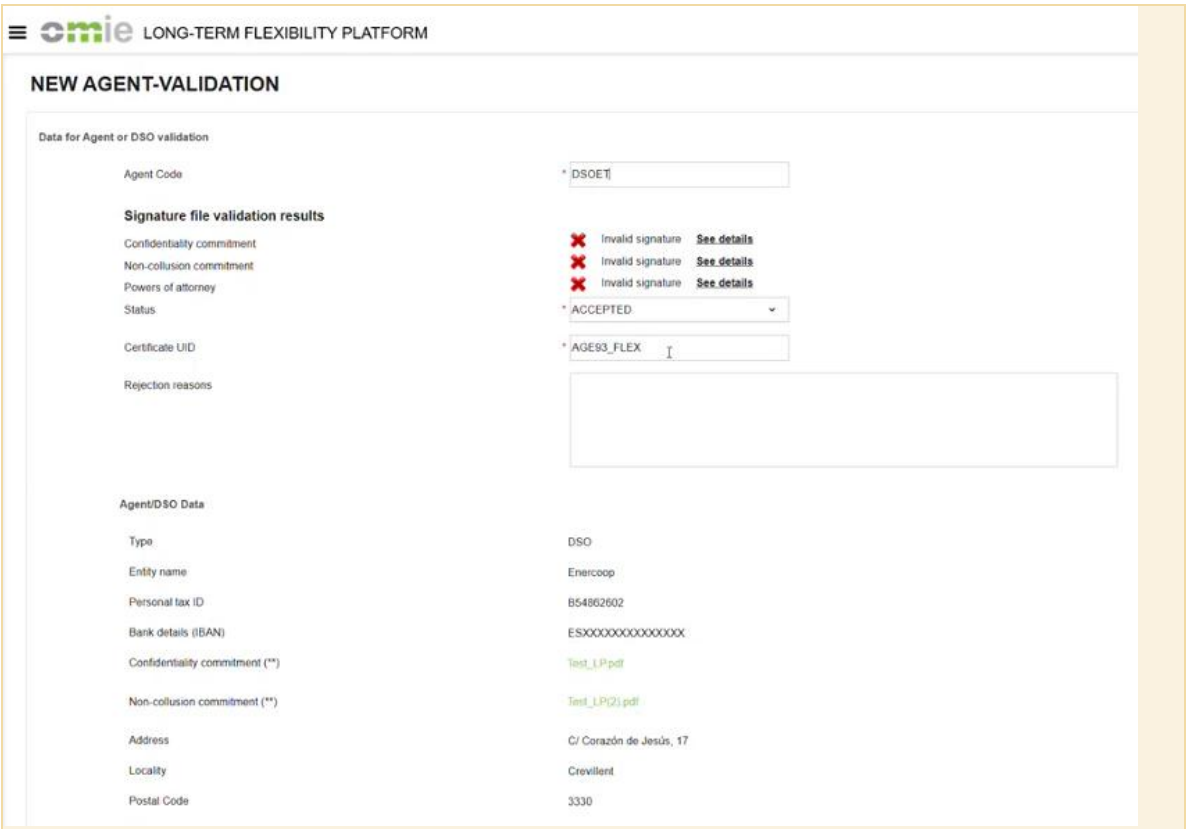


Figure 142: sMART agent validation - part 1



Figure 143: sMART agent validation - part 2

When the agent is validated, the DSO can access to the platform using their certificate and register their flexibility zones. In sMART, the administrative zones are created per ZIP code. The two ZIP codes are included in the DSO. As it will be seen in the test case ES-UC.04.01, the technical zones are defined for each season according to the feeder affected by the congestion.

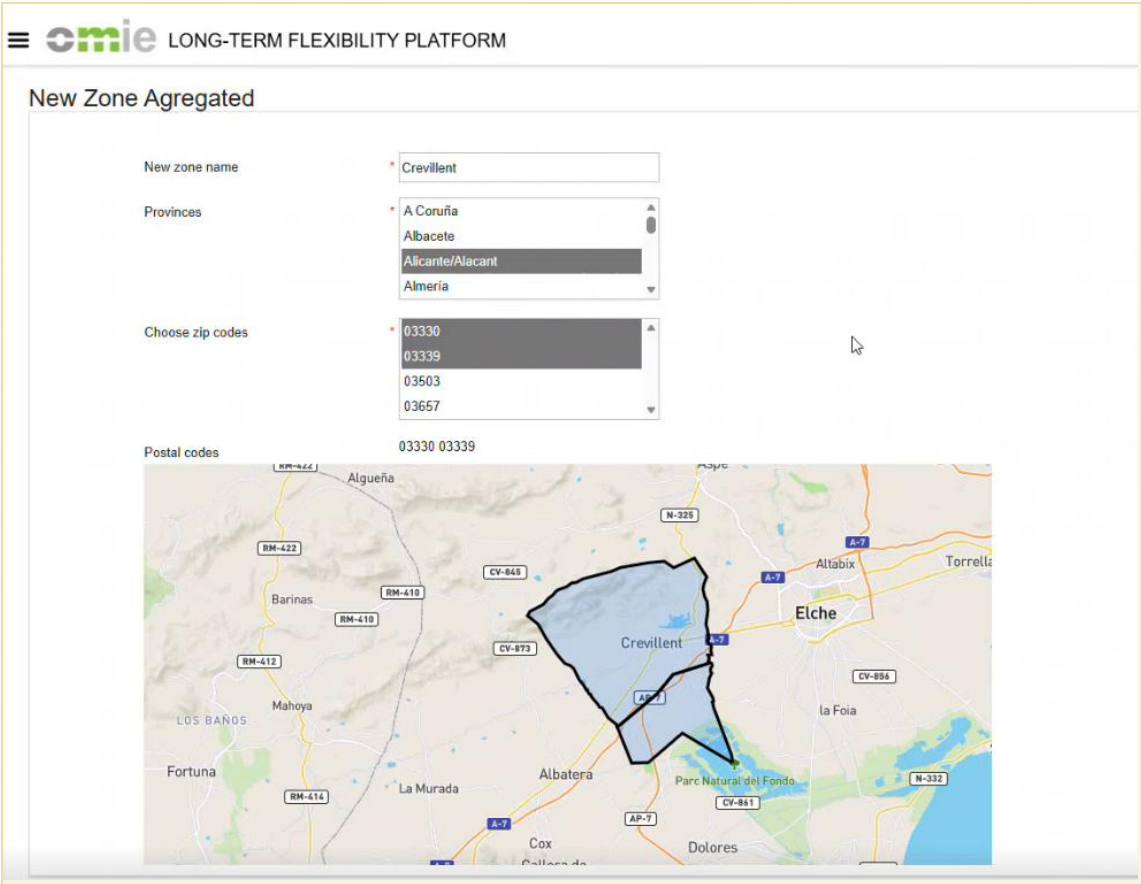


Figure 144: DSO zones registration

Once the DSO and its zones have been registered, the agent can proceed with its registration. The registration of the FSP is similar to the DSO, using the same form, only changing the profile type, as can be seen below.

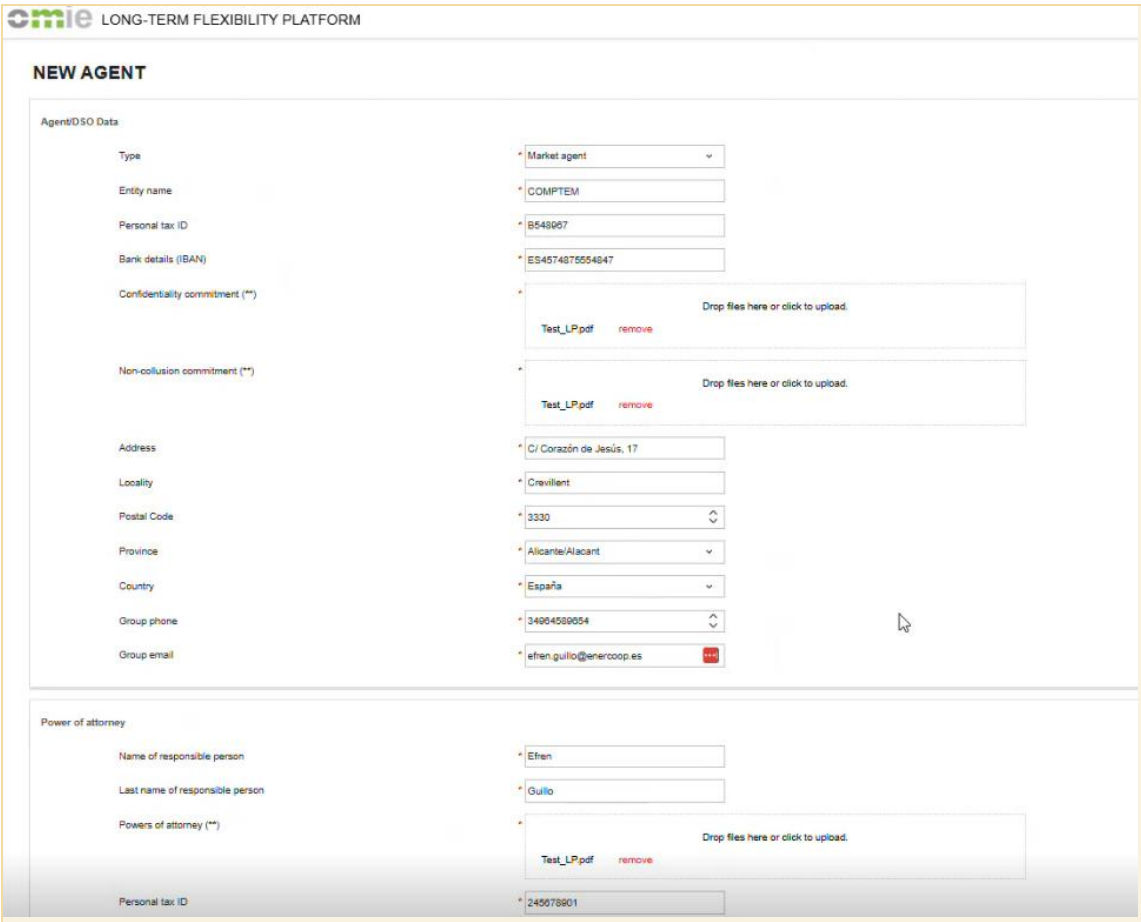


Figure 145: FSP agent registration - part 1

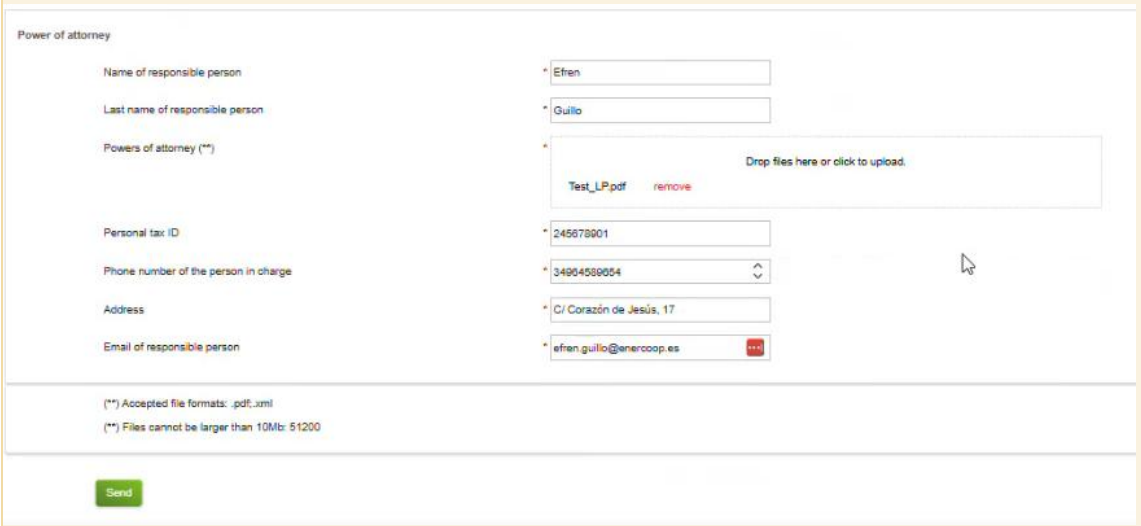


Figure 146: FSP agent registration - part 2

Similarly to when registering the DSO, the MO has to validate the new agent registration and assign a certificate.

Upon validation, the FSP is able to log in using its certificate and register the new assets, associated to the DSO in which grid the asset is located.

The form to register the assets links the asset with the DSO to enable bidding in the associated sessions and provides the technical information the DSO must validate (the identification of the metering point, its capacity, technology type, activation time and response time, see Figure 147).

The process has been repeated for all the assets, and the agent can see all the requests and their status (see Figure 148).

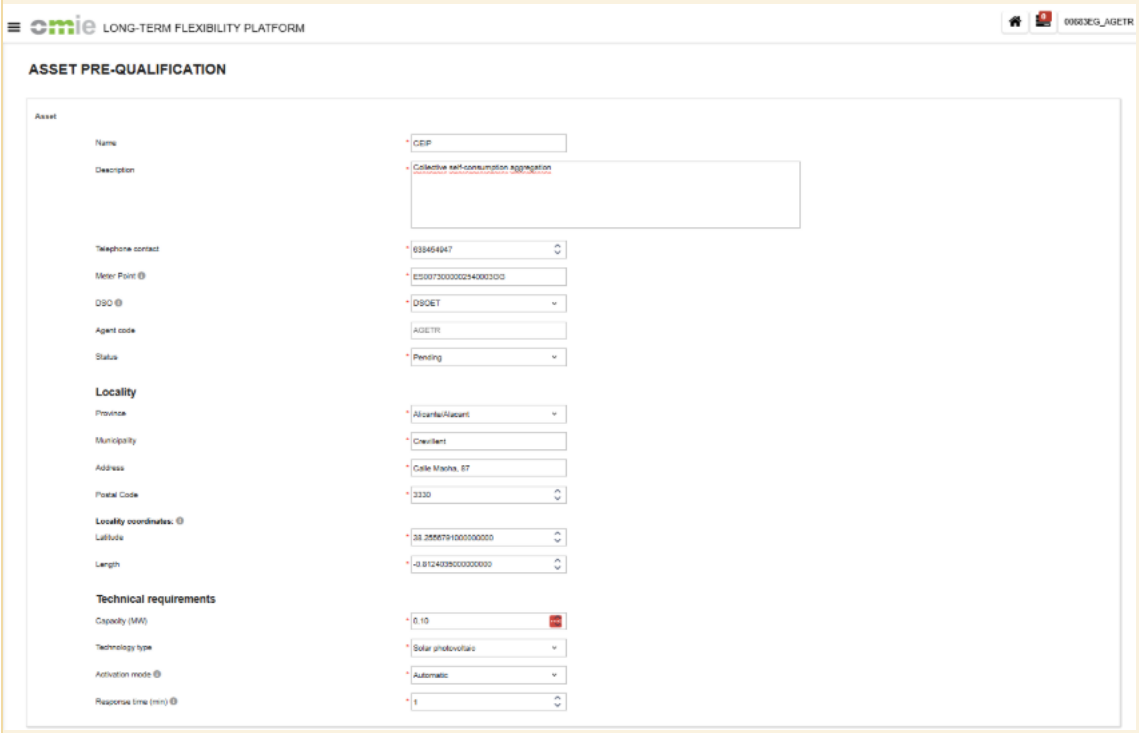


Figure 147: Device registry in sMART

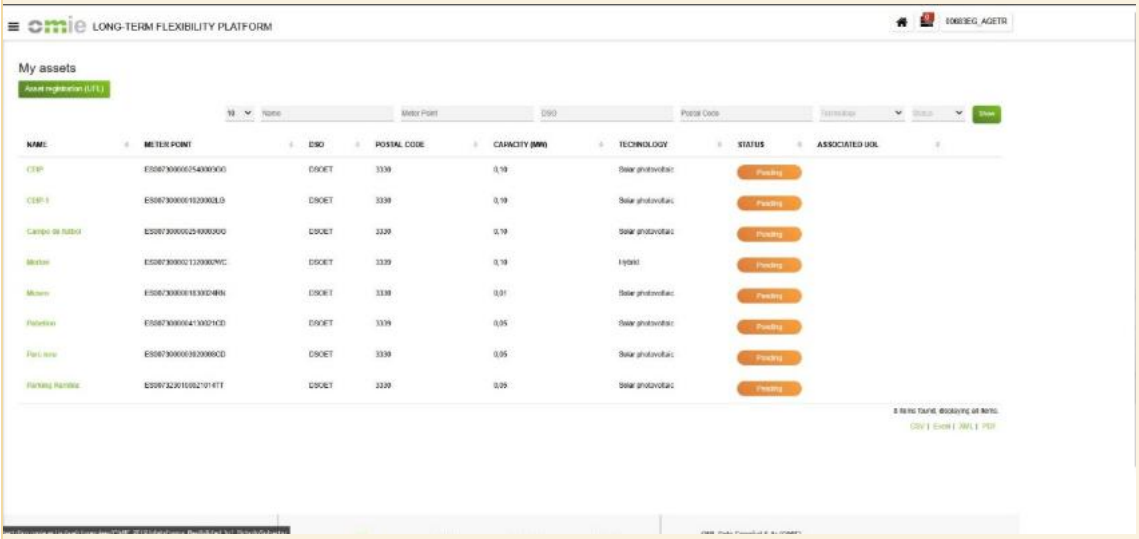


Figure 148: Device registry requests and status

The registration of the assets sends automatically a prequalification request both to the MO (for market prequalification) and to the DSO (for technical prequalification). For the market prequalification, the MO assesses the financial capacity and availability of guarantees of the agent to bid in the market. It must be noted that, since this is a pilot project, no real financial capacity is assessed, nor guarantees are deposited in the market.

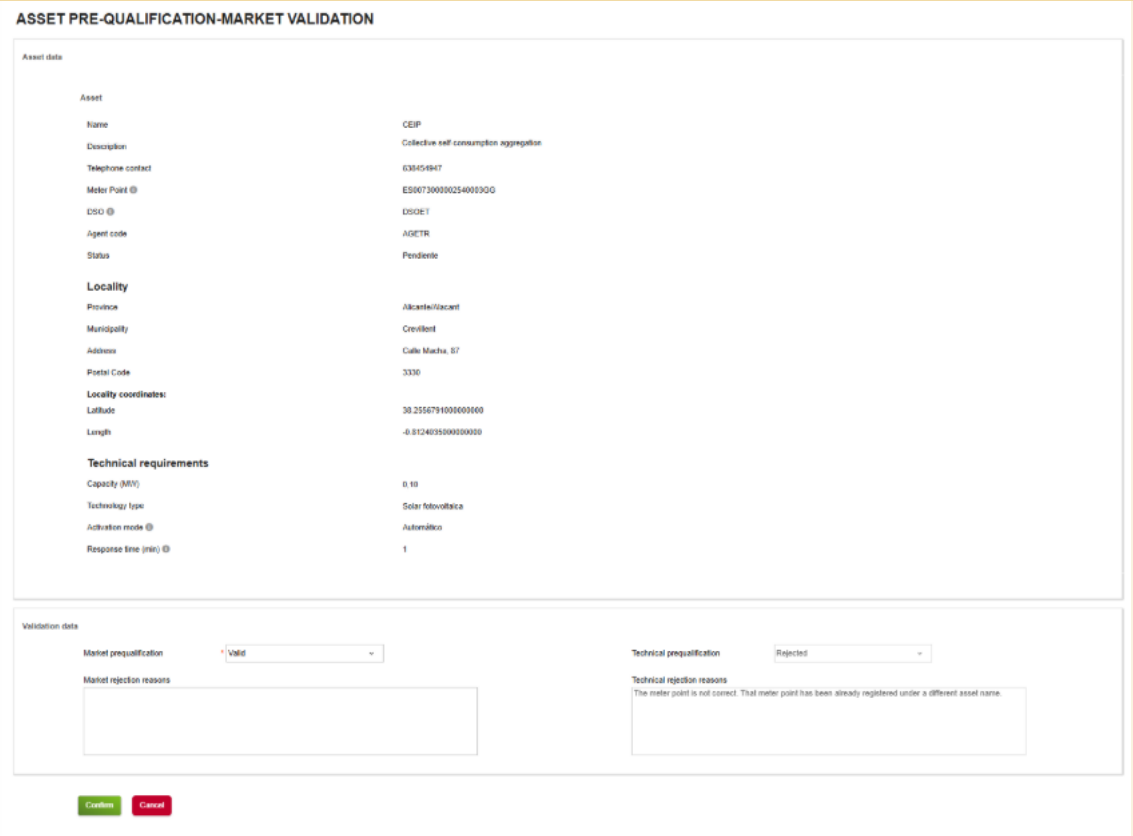


Figure 149: Asset prequalification - market validation

For the technical prequalification, the DSO verifies through sGRID if the data provided for the flexibility asset is real, meaning that the DSO checks if the meter point is actually part of the zones of the DSO, the point has the indicated technologies and is able to respond in the indicated time and mode. In this case, for the meter point ES0073000002540003GG, the DSO checks through sGRID that the asset is part of its greed at C.T. MACIA ABELA, identifier of the LV grid B-3212_LV, and that it's a PV generation point with 100kW of nominated power.

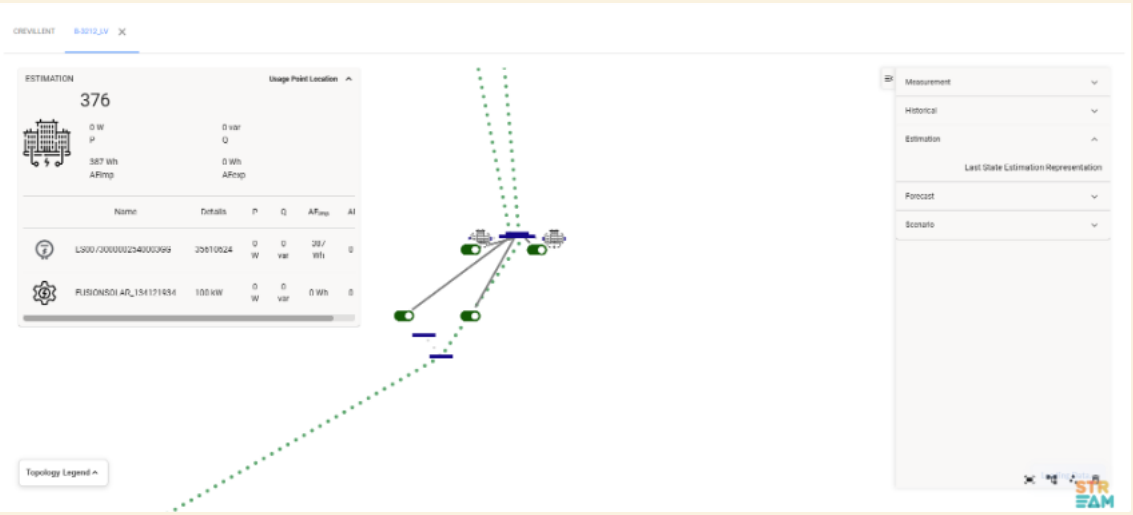


Figure 150: Asset prequalification - DSO technical check in sGRID

After this verification, the DSO can, through sMART, validate the technical prequalification of the asset.

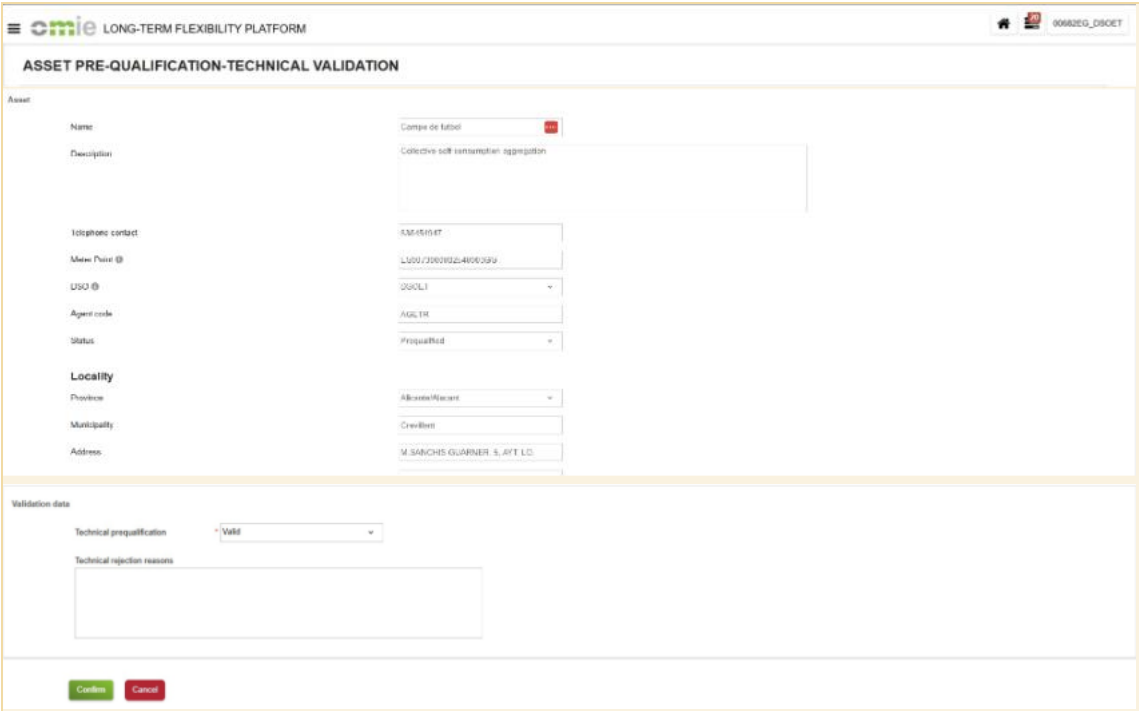


Figure 151: Asset prequalification - Technical validation

Only if both prequalifications are validated the asset is enabled to participate in the market.

If the prequalification is rejected, the FSP receives a rejection notification, indicating the reason why the request has been rejected and enabling the user to resend the request with the modifications required. An example of this alternative path has been also tested, being in this occasion rejected by the DSO because the associated meter point was already registered. The first picture shows how the DSO rejects the request, and the second picture displays the notification received by the agent.

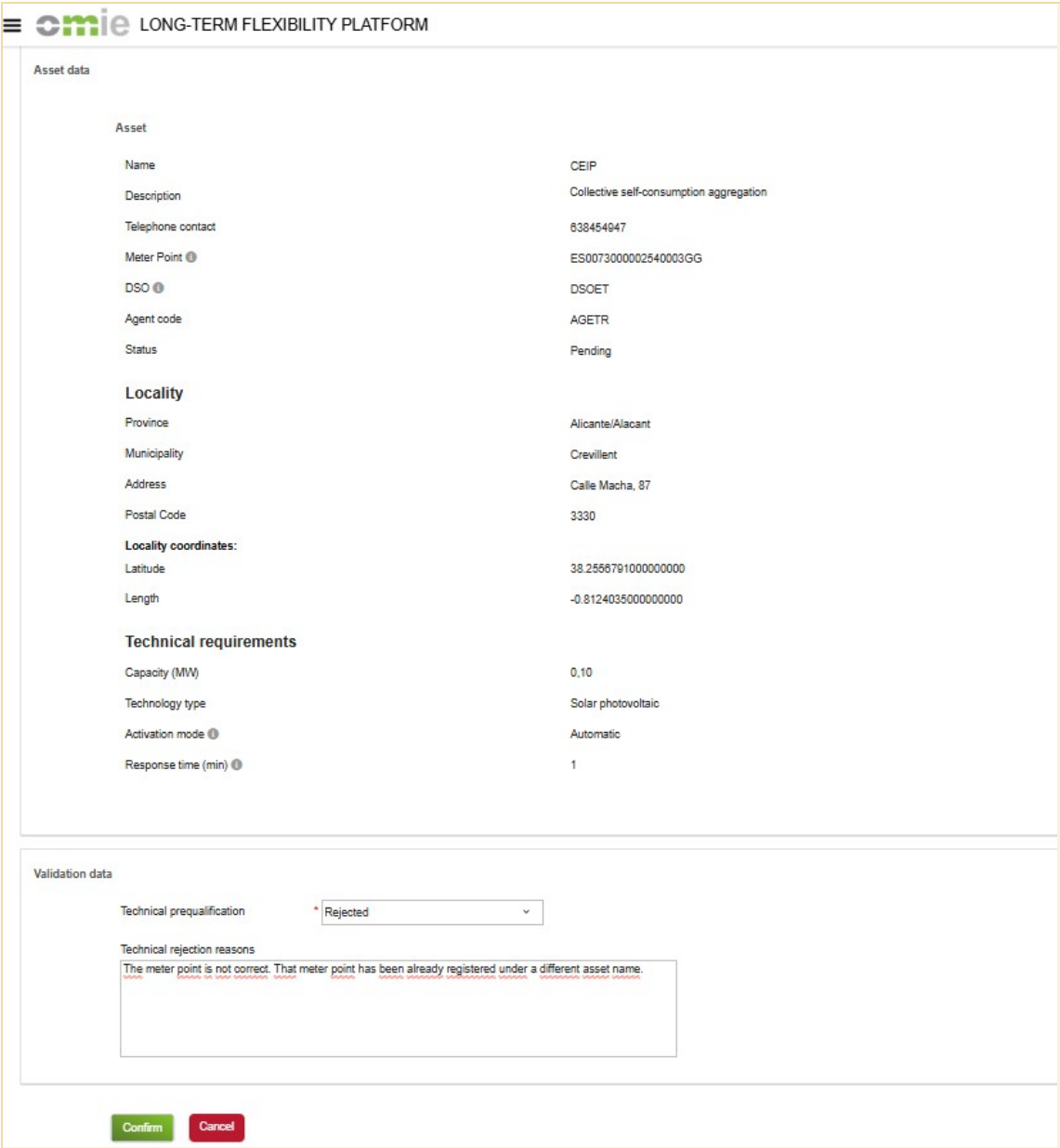


Figure 152: Asset prequalification - Technical rejection

The device registry and prequalification was successfully passed, having all the desired assets registered in sMART. Once this has been completed, as previously mentioned the small assets can be aggregated in unit offers. In the case of the Spanish pilot site, the energy community members without self-consumption installations have been intrinsically included as part of the associated collective self-consumption installations. On the other hand, the prosumers with PV and BESS have been aggregated to provide meaningful flexibility to the market as part of the "COMPTEM Users" unit offer. This aggregation has been applicated both in sMART (first picture) and in sENC (second picture), ensuring alignment between the tools.

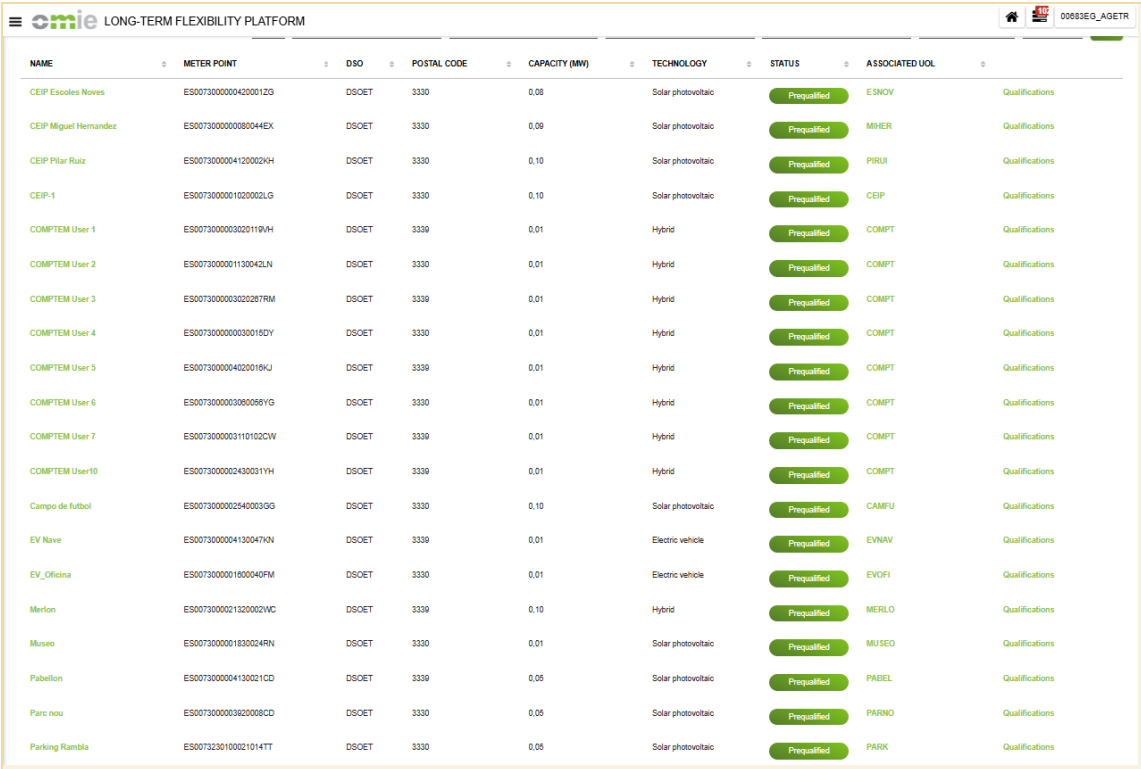


Figure 153: Assets successfully registered and prequalified

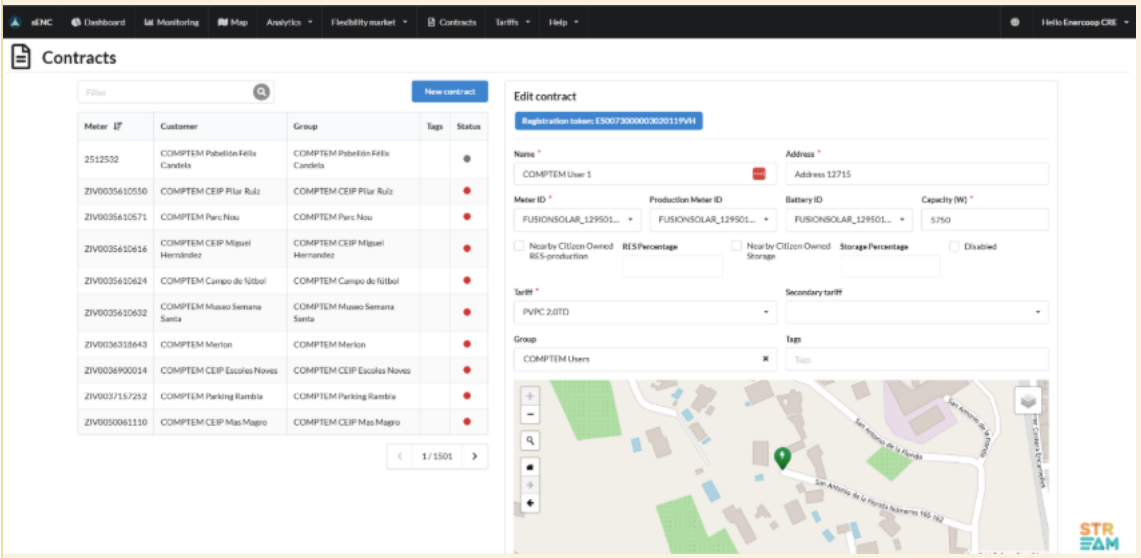


Figure 154: Assets prequalified and mapped in sENC

The successful execution of this test case has enabled the correct registration and prequalification of the assets of 20 different flexibility assets, allowing them to send flexibility offers as shown in the next test case.

Table 42: Assets registered in sMART

Name	Meter Point	Capacity (MW)	Technology	Associated UOL
CEIP Escoles Noves	ES0073000000420001ZG	0,08	Solar photovoltaic	ESNOV
CEIP Miguel Hernandez	ES0073000000080044EX	0,09	Solar photovoltaic	MIHER

CEIP Pilar Ruiz	ES0073000004120002KH	0,10	Solar photovoltaic	PIRUI
CEIP-1	ES0073000001020002LG	0,10	Solar photovoltaic	CEIP
COMPTEM User 1	ES0073000003020119VH	0,01	Hybrid	COMPT
COMPTEM User 2	ES0073000001130042LN	0,01	Hybrid	COMPT
COMPTEM User 3	ES0073000003020267RM	0,01	Hybrid	COMPT
COMPTEM User 4	ES0073000000030015DY	0,01	Hybrid	COMPT
COMPTEM User 5	ES0073000004020016KJ	0,01	Hybrid	COMPT
COMPTEM User 6	ES0073000003060056YG	0,01	Hybrid	COMPT
COMPTEM User 7	ES0073000003110102CW	0,01	Hybrid	COMPT
COMPTEM User10	ES0073000002430031YH	0,01	Hybrid	COMPT
Campo de futbol	ES0073000002540003GG	0,10	Solar photovoltaic	CAMFU
EV Nave	ES0073000004130047KN	0,01	Electric vehicle	EVNAV
EV_Oficina	ES0073000001600040FM	0,01	Electric vehicle	EVOFI
Merlon	ES0073000021320002WC	0,10	Hybrid	MERLO
Museo	ES0073000001830024RN	0,01	Solar photovoltaic	MUSEO
Pabellon	ES0073000004130021CD	0,05	Solar photovoltaic	PABEL
Parc nou	ES0073000003920008CD	0,05	Solar photovoltaic	PARNO
Parking Rambla	ES0073230100021014TT	0,05	Solar photovoltaic	PARK

Qualitative analysis of the results

As described in the results, the process of access, registration and prequalification within the Local Flexibility Markets (LFM) has been successfully implemented in the Spanish demonstrator. The assessment of its performance is based on the validation of its main components, which ensure that only authorized agents and technically compliant assets participate in the market. These elements are:

1. **Access and registration framework.** OMIE, as Market Operator (MO), manages access through certificates with different roles (MO, DSO and FSP), ensuring secure and structured participation. The registration process, including validation by the MO, has proven to be secure and aligned with real operational requirements, enabling DSOs to define flexibility zones and FSPs to register their assets.
2. **Asset registration and prequalification.** Assets must provide detailed technical information and undergo a dual validation process: market prequalification by the MO and technical prequalification by the DSO. Although financial requirements have been relaxed due to the pilot nature of the project, technical validation through sGRID ensures that assets are properly connected and capable of delivering the declared flexibility.
3. **System interoperability.** The tools involved, sMART and sGRID, have demonstrated adequate performance in data validation and the management of inconsistencies, providing feedback in case of rejection. In addition, the aggregation of small-scale assets into local bidding units has been successfully implemented, ensuring consistency between the sMART, sFLEX and sENC platforms and enabling meaningful participation in the market.

Experiment number	**ES-UC.04.01**

Name of the experiment	Provision of flexibility services to the local flexibility market
Timeframe	May – June 2026 (M44-M45)
Targets	The long-term flexibility market in the Spanish pilot site is designed to serve as a flexibility capacity reservoir for DSOs during peak consumption/generation hours, when congestions are more likely to happen and when congestions are detected in a . The activation of the matched flexibility capacity will depend on the real state of the grid. Therefore, this test case will evaluate the correct functioning of this capacity market, exploring the cases where the activation is required, and where it is not.
Actors	• ENER as DSO • OMIE as Market Operator • ENER as Energy Community Manager • ETRA as technology provider
STREAM products	sGRID, sMART, sFLEX, sENC
Assets & systems	• Energy community battery • Energy community members flexibility assets • EVs and chargers • AMI system
Description of the experiment	This test case will explore the correct functioning of the end-to-end local flexibility market workflow. The long-term market will be activated when the DSO detects a future (more than 48h ahead) problem in the grid (congestion, unavailability of a grid asset due to maintenance works, detecting reiterative seasonal peak loads in the grid that might jeopardize the energy supply security, etc.) that will jeopardize the operation of the network. After this detection, the DSO can send a flexibility capacity requirement. The capacity does not necessarily imply the activation of the flexibility during the delivery period, since it will depend on the actual state of the grid. Once the DSO sends this requirement, a long-term bidding auction is open, allowing the flexibility assets contained in the zone to offer flexibility capacity to the grid. The offers are matched with the requirement in sMART, and sMART settles the session paying for the capacity that has been offered. 24h before the delivery period, sGRID forecasts the estate of the grid for the following day. If a congestion is forecasted, the DSO sends a requirement through sGRID to sMART to open a short-term auction to adjust the flexibility that must be activated and to find a more economical solution. The maximum price will be the matched price of the long-term session in order to optimize the price. The test case finalizes with the activation of the flexibility assets and the payment of the associated revenues. **Pre-condition/triggering event**: • Flexibility assets of the Energy Community members are registered and validated in sMART and sGRID. • Long-term and short-term market functionalities are available in sMART.

	• ENER, in its role as DSO, analyses grid behaviour and identifies periods where congestion is likely (peak hours close to technical limits).
	Steps:
	1. ENER, as DSO, submits a long-term flexibility requirement through sMART, requesting availability during the identified period.
	2. ENER, as Aggregator (EnC manager), analyses forecasted flexibility availability.
	3. ENER, as Aggregator, sends a qualification request to ENER in its role as DSO for the candidate assets.
	4. sGRID performs the sensitivity analysis to identify the assets that can provide effective flexibility to reduce the congestion.
	5. ENER, as DSO, performs the qualification process, validating that the assets can provide the requested flexibility service according to the sensitivity analysis.
	6. ENER, as Aggregator/FSP, submits bids to the long-term market.
	7. sMART clears the market, matching bids with the requirement and defining contracted flexibility availability.
	8. sMART notifies the results to ENER (as DSO) and ENER (as FSP/Aggregator).
	9. Before the delivery period (e.g. day-ahead), sGRID analyses updated forecasts to assess expected congestion.
	10. If congestion is confirmed, sGRID sends a short-term flexibility request via sGRID to sMART, adjusting the requirement to the updated congestion forecast. The maximum bid price is the long-term contracted price in order to optimize the final activation price.
	11. sMART opens a short-term market session.
	12. sENC and sFLEX analyses available flexibility and submits offer.
	13. sMART clears the short-term market and notifies the activation volumes to ENER (as FSP/Aggregator).
	14. If the short-term market does not fully cover the required flexibility, the remaining demand is fulfilled using the flexibility contracted in the long-term market.
	15. During the delivery period, the assets are activated and monitored by sENC and sFLEX.
	16. sGRID compares baseline vs. actual consumption/generation to verify delivered flexibility and sends compliance results to sMART.
	17. sMART settles the market considering:
	  ○ Delivered flexibility (short-term activation)
	  ○ Contracted availability (long-term commitments)
	18. ENER, as Aggregator, distributes revenues to asset owners proportionally to their contribution.
	Post-condition:
	• Long-term and short-term market sessions are completed and settled.
	• Asset qualification, activation, and delivery are validated.

	• Grid congestion is mitigated and the system operates within technical limits. • Assets return to their baseline operation. • All relevant technical and market data is stored for analysis.
Exception paths and scenarios of the experiment	/
Datasets required for the experiment	• Active and reactive power of PV + community battery installation – Historical • Community battery SOC • Prosumers' consumption and generation – Historical • Domestic batteries SOC • Active and reactive energy of EV chargers • Weather data • Community battery setpoint • Generation from EnC collective self-consumption installations • EVs SOC • Prosumer's energy tariffs • Wholesale market price • Consumption, generation and flexibility forecasts
Field data to be gathered	• Flexibility bids, asks and requests • Flexibility market results • Active and reactive power of PV + community battery installation – Real-time • Prosumers' consumption and generation – delivery period • Active and reactive energy of EV chargers – delivery period • Flexibility delivery compliance
Related KPIs	KPI ES.05, KPI ES.09, KPI ES.11, KPI ES.14

Results of the Experiment

After analysing the behaviour of the grid, it was detected by the DSO through sGRID that, during summer periods, the grid reached its peak grid utilization during the following periods:

- Peak solar generation hours due to the self-consumption and large PV installations connected to their LV grids, which were coincident with lower consumption hours. This was for weekdays, from 10h to 18.
- Lower generation hours, due to the zero local generation during night hours and higher consumption. This was for all the days of the week, from 19h to 23h.

This meant that the periods of time were flexibility would be more necessary was during those scenarios, the first one requiring downwards flexibility (reduce generation/increase consumption) and the second one requiring upwards flexibility (increase generation/reduce consumption).

Building on top of these scenarios, the test case began with the DSO sending long-term requirements in sMART in order to ensure flexibility availability during these periods.

The first thing the DSO must do is selecting a day for the auction to take place among the available auctions enabled by the MO (see Figure 155).

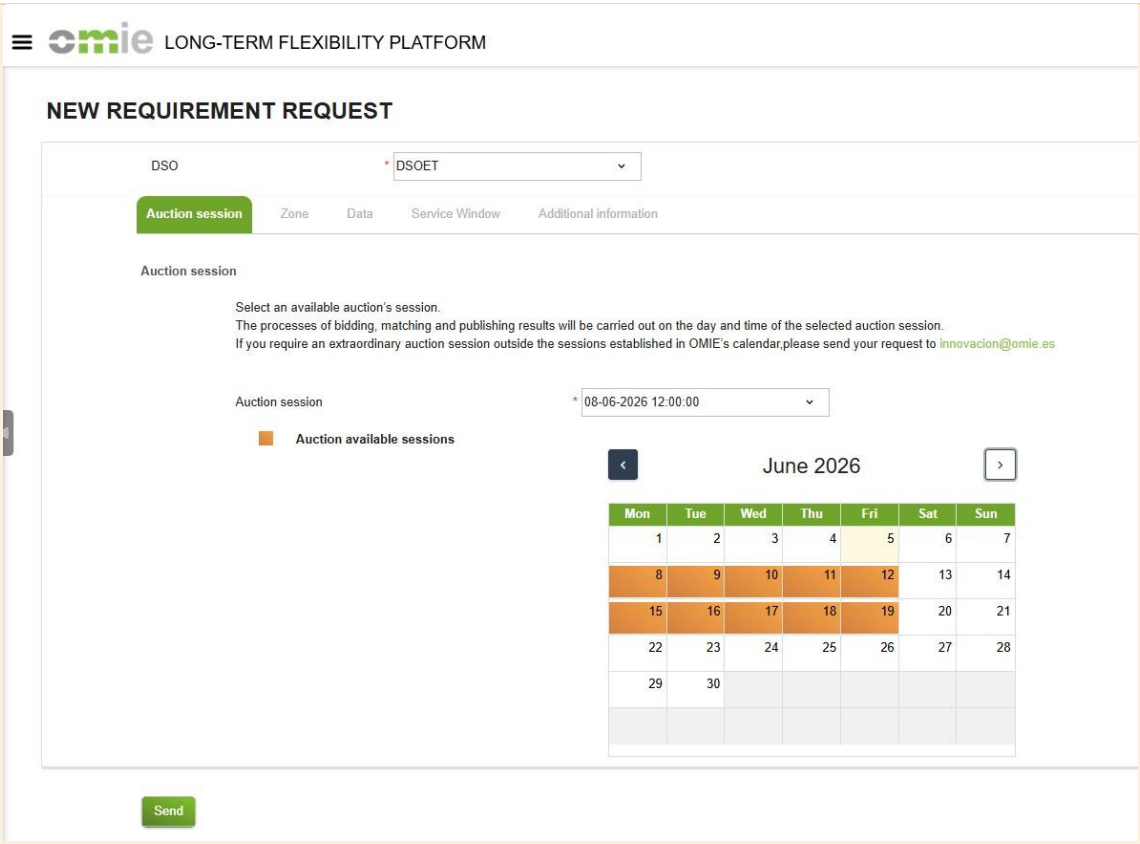


Figure 155: DSO long-term requirement request - auction session selection

Two different sessions were open, one for the first scenario and the other one for the second. Figure 156 shows the data inputted for the first scenario, including the product category (in this case availability, non-firm since flexibility activation might not be finally required), the required capacity (0.5MW as a test case), the direction (for this scenario, it will be necessary to lower generation and/or increase the consumption), the minimum required power (0.01MW in order for small assets to be able to submit offers), the limit availability price (this price will be paid for all the assets with flexibility offers matched in this auction) and the limit price for activation (in case activation is finally required). It is noteworthy that Enercoop, as DSO, did a thorough analysis to provide realistic limit prices as follows:

The DSO derived flexibility price limits from a reinforcement-based benchmark, calculating the annualised cost of the alternative grid investment (~12.9 k€/year) and translating it into equivalent availability and activation price caps per MW, considering expected congestion duration (≈480 h/year) and required flexibility (≈70 kW).

To account for uncertainty and risk in substituting traditional reinforcement with flexibility, a risk factor (0.7) was applied, resulting in final limit prices of approximately 66.98 €/MW for availability and 200.9 €/MW for activation in the flexibility market design.

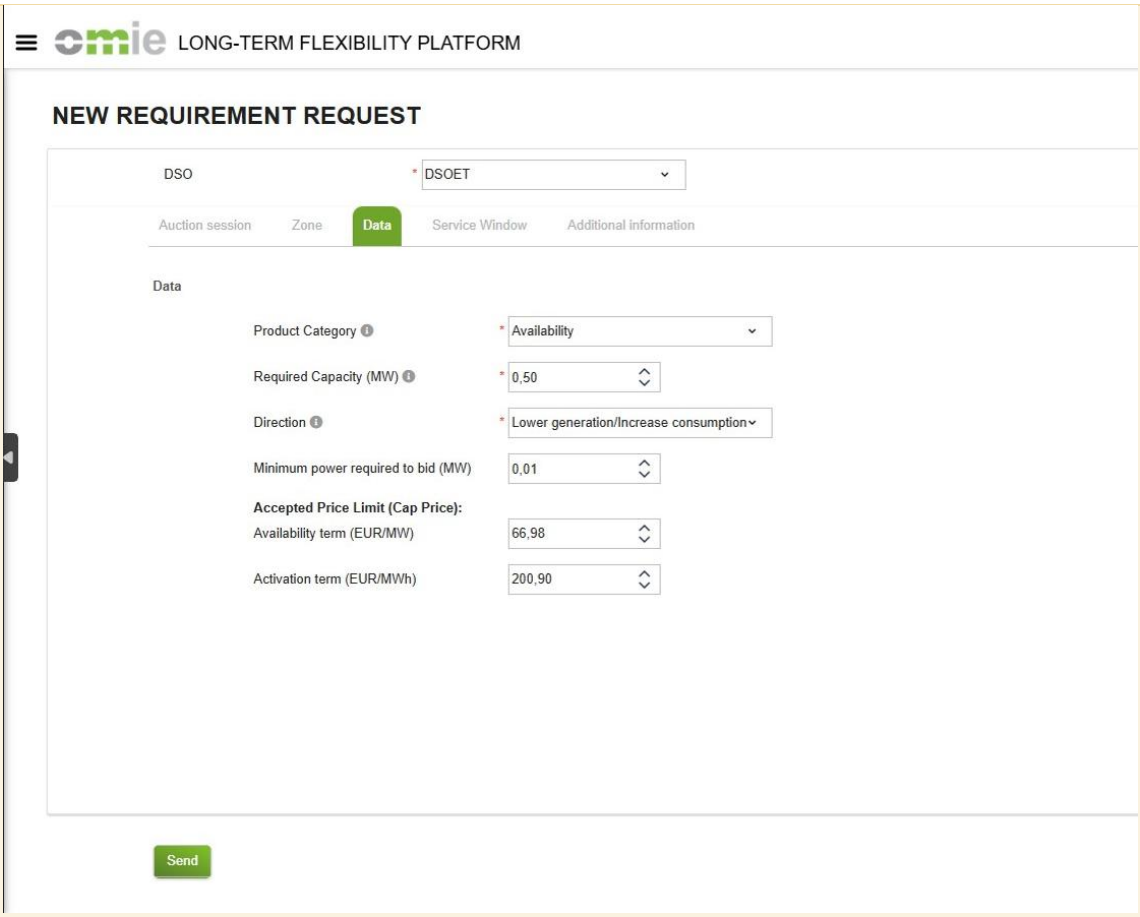


Figure 156: DSO long-term requirement request - Requirement data

Figure 157 shows the data that the DSO inputted related to the time window, in this case for the first scenario.

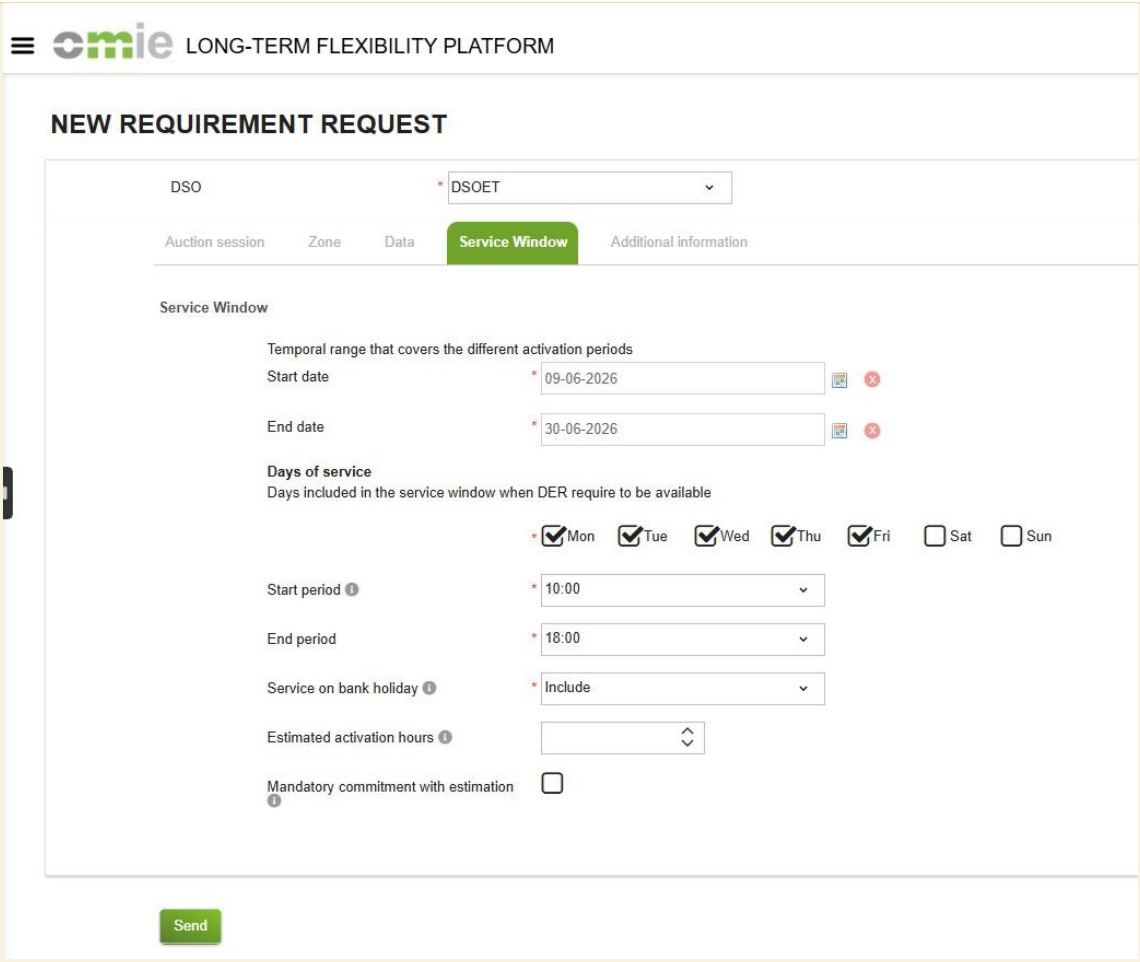


Figure 157: DSO long-term requirement request – Service window data

Once the DSO sends these long-term requriments, the flexibility agent can see these upcoming auctions in order to proceed with the qualification requests for their assets (Figure 158).

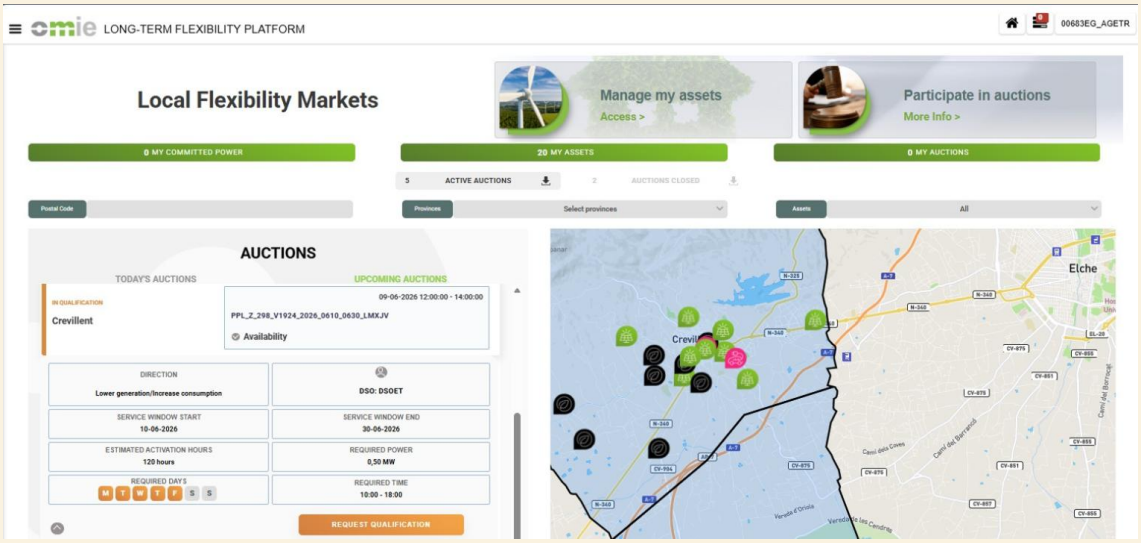


Figure 158: Flexibility agent long-term requirement bidding - Upcoming auctions view

The flexibility agent can submit qualification requests only for upcoming auctions. To do so, the agent must select the asset to be qualified, specify the power capacity to be offered, and provide a guarantee document. Figure 159 illustrates the qualification request for the community battery. It is worth noting that the requested qualification capacity does not necessarily need to match

the total installed capacity of the asset. In this case, due to previously identified technical constraints, the battery cannot deliver its full nominal power, and the qualification request therefore reflects its currently available (reduced) capacity.

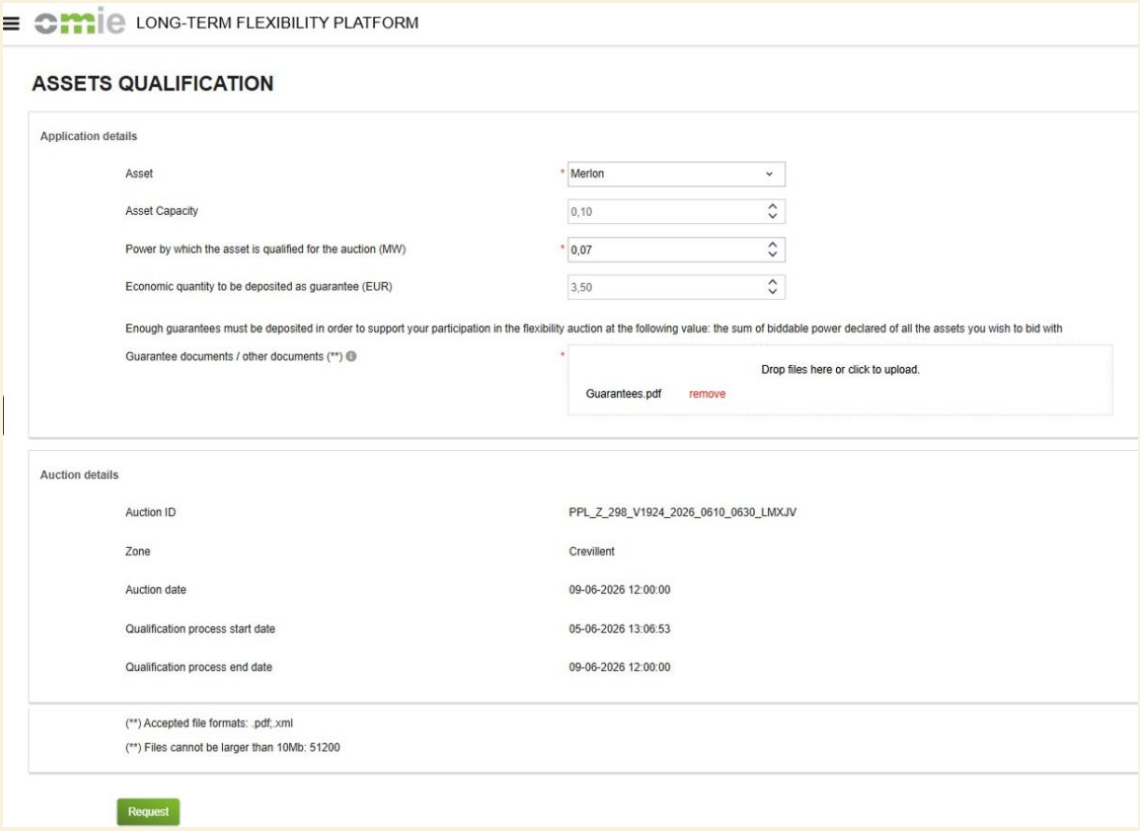


Figure 159: Flexibility agent long-term bidding - Asset qualification request

When the agent sends qualification requests, the DSO and the MO receive a notification to qualify the asset technically (Figure 160) and administratively (Figure 161), respectively.

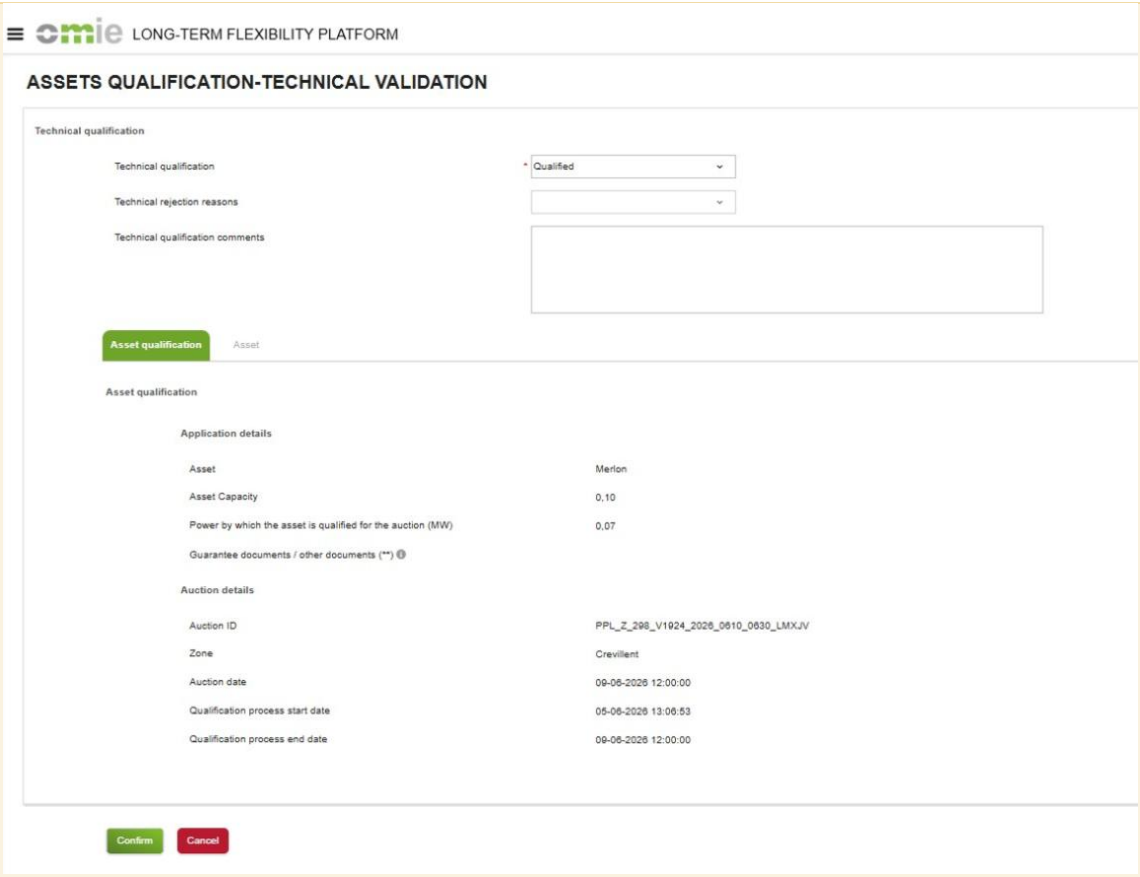


Figure 160: DSO long-term qualification- Technical validation

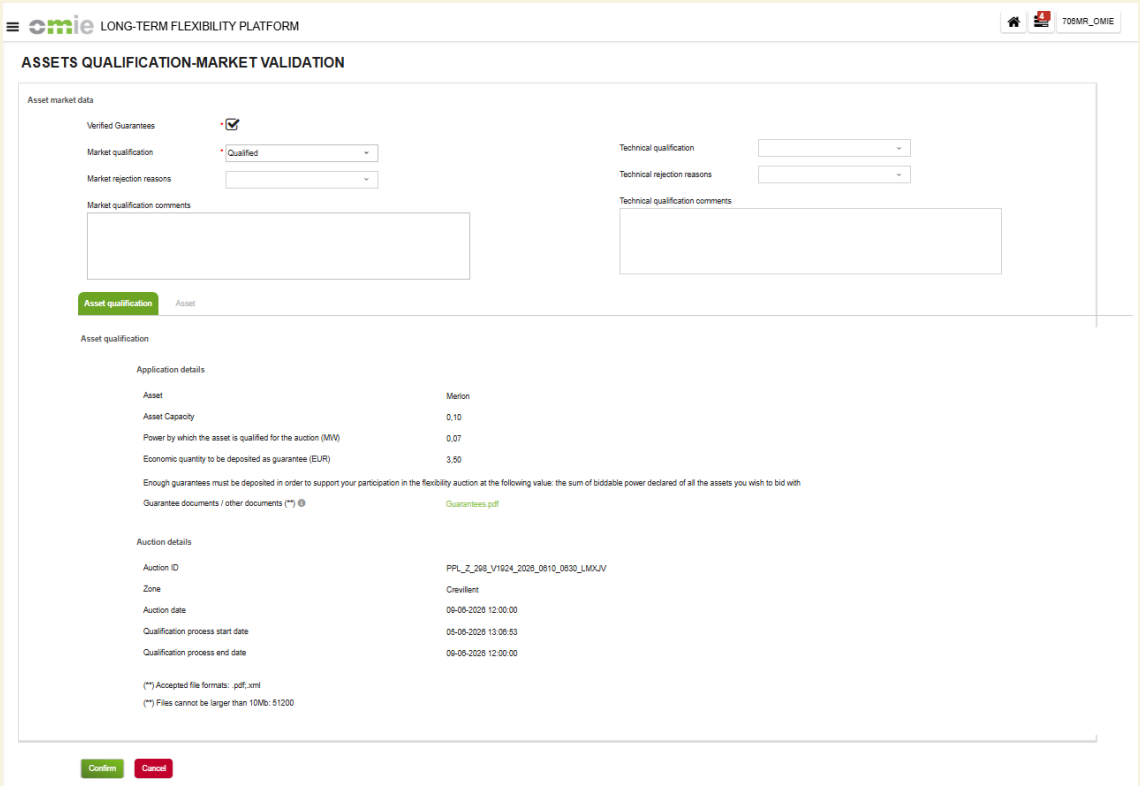


Figure 161: MO long-term qualification - Market validation

For the first scenario (reduce the generation), all the assets were qualified because PV assets are able to reduce their generation, the hybrid installations (PV + BESS) can regulate its energy injection/consumption and EVs can charge and discharge according to the grid necessities. However, for the second scenario (increase the generation/reduce the consumption) only EV chargers and hybrid installations were qualified since the PV plants are not able to increase their generation, as this scenario covered night hours. In the event a PV plant tries to be qualified for this second case, the DSO rejects the qualification as it is not technically feasible, as showed in Figure 162.

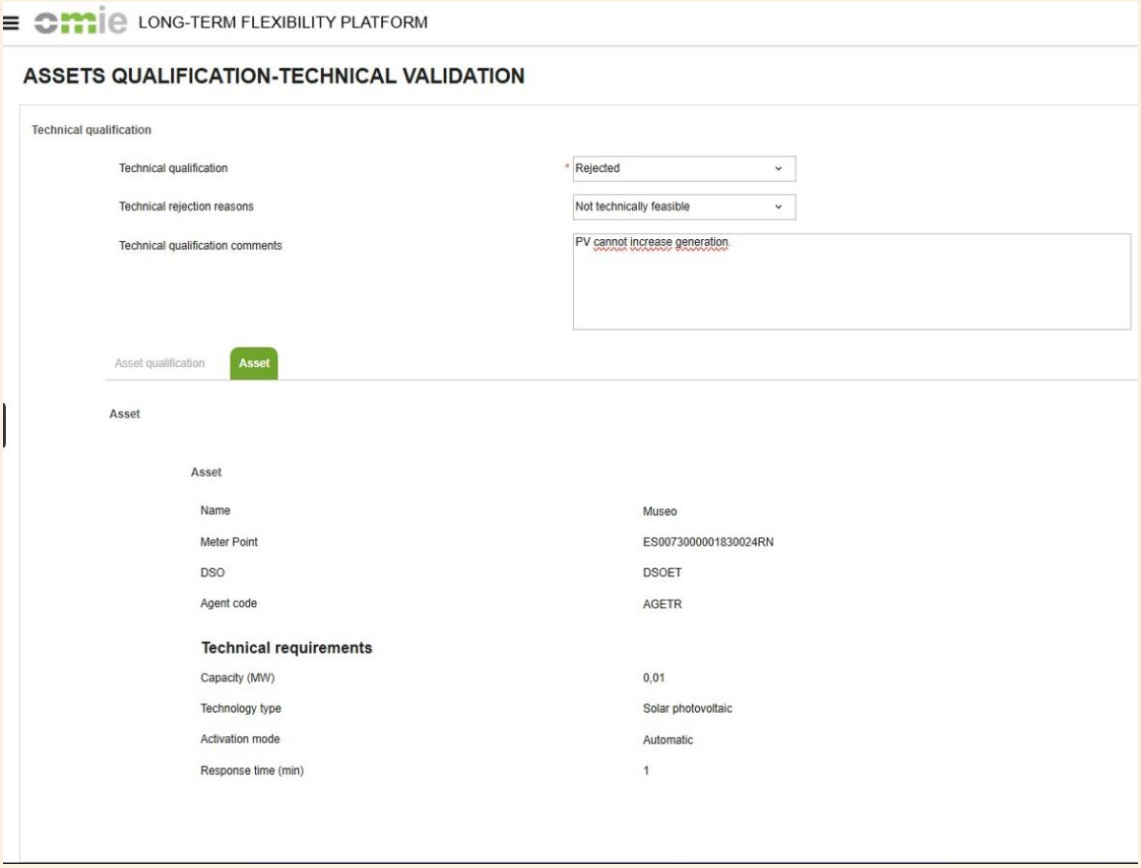


Figure 162: DSO long-term qualification - Technical rejection

When the auction is open, the flexibility agent can submit availability bids for previously qualified assets. Figure 163 shows a bid preparation for the community battery, where the agent specifies the bidding quantity, availability price, and activation price. In this case, since submitting availability implies that the battery must guarantee the committed capacity throughout all weekdays within the service window, only a portion of the available capacity is offered. This ensures that sufficient reserve remains for normal operation. Accordingly, a total of 0.01 MW is bid. It should be highlighted that qualification is performed at asset level, while bids are submitted per local unit offer, this is per aggregation group.

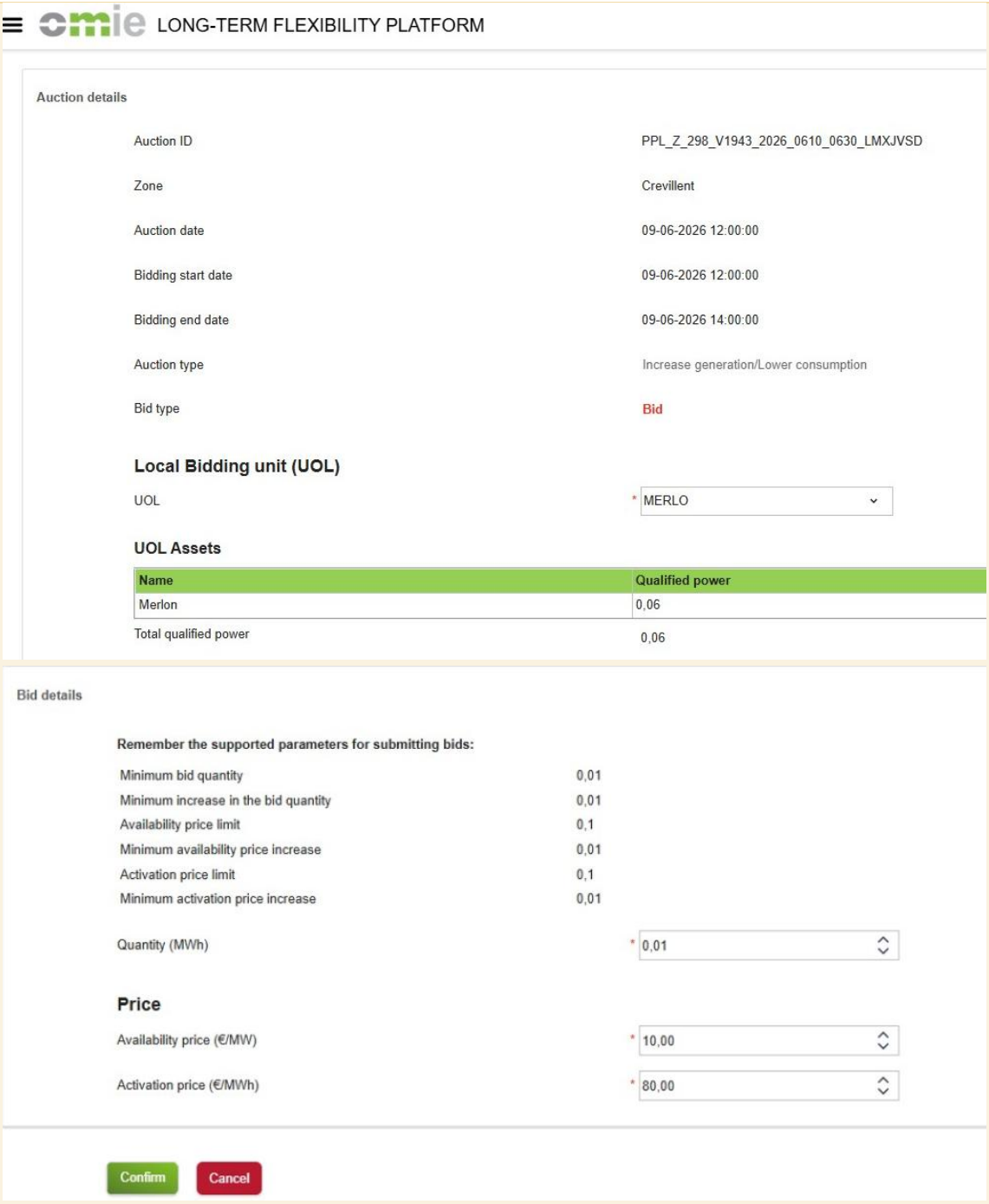


Figure 163: Flexibility agent long-term bidding - Bid preparation

A bid was submitted for each unit offer across both sessions, as shown in Figure 164. It is worth noting that, for the PV plants, only 10% of their nominal capacity was offered, since the service window includes hours outside peak GHI conditions and, therefore, full curtailment capability cannot be guaranteed. In addition, as the service spans an entire month, variability in weather conditions, particularly cloudy day, introduces additional uncertainty, which further justifies the conservative bidding strategy.

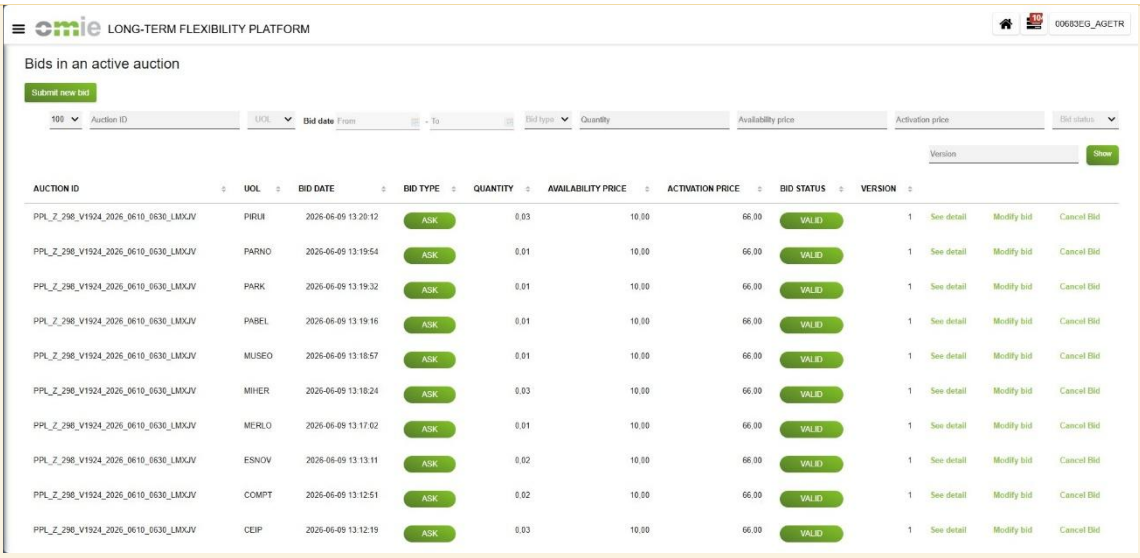


Figure 164: Flexibility agent long-term bidding - list of bids for active auctions

When the auctions close, the agent is not able to submit any further bids since the matching procedure is ongoing (see Figure 165).

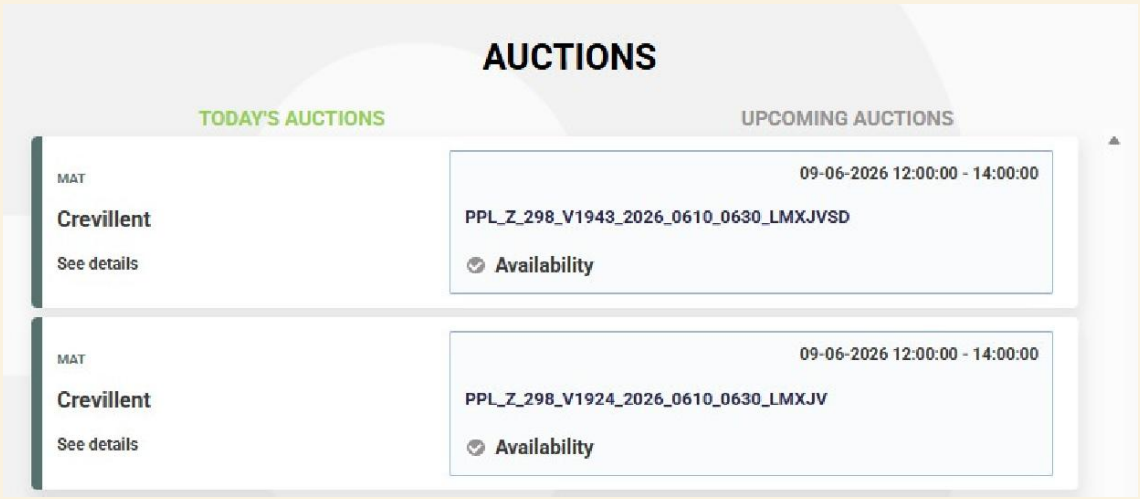


Figure 165: Flexibiltiy agent long-term bidding - Sessions matching

After approximately 15 mintues, the market is cleared and the results are provided by the MO, displaying the bids matched and, consequently, the availability flexibility that must be ensured by the assets, the availability prices and the activation (if finally required) prices. All the bids were matched since in all of them both the availability and activation prices were below the limit established by the DSO.

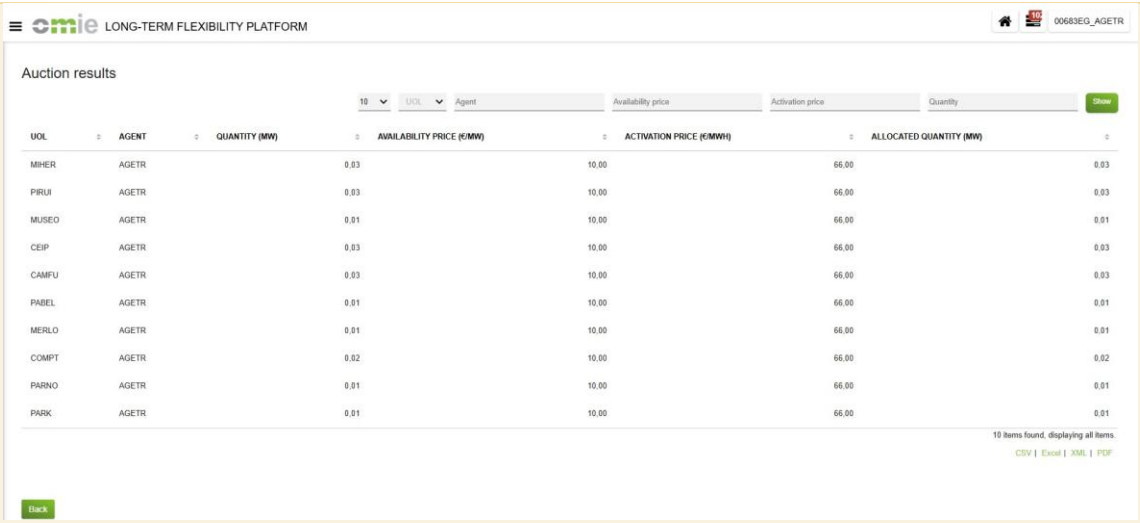


Figure 166: Flexibility agent long-term bidding - Auction results

The results from the long-term market are incorporated by sFLEX and the battery schedule is re-calculated:



Figure 167: Baseline battery schedule (no market participation)

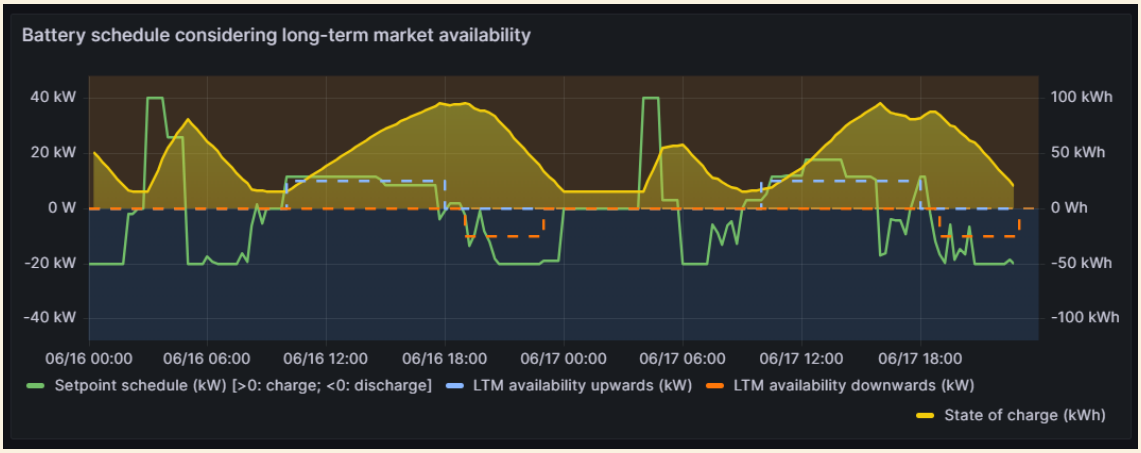


Figure 168: Battery schedule considering the results of the long-term market (blue for upwards provision, orange for downwards provision)

In the re-scheduled plan, sFLEX considers the requested availability of 10 kW in sun-peak hours and -10 kW in early night hours as restrictions in the supply point, i.e. reserved headroom for potential activation of flexibility.

The market restriction starts at 10 am, an hour earlier than the scheduled, generation- and price-based start of the battery charge. This anticipation modifies the behavior prior to that start, by fully charging the battery at minimum price in order to cover the demand before PV production starts. From 10 am to 6 pm, the 10 kW upwards availability from the market is fulfilled by reducing the pace at which the battery is charged from generation, so that at any time, there is enough headroom to activate this flexibility.

When the upwards window ends, the battery starts discharging, but an hour later (7 pm), the downwards flexibility availability starts for the next 4 hours. This also affects the discharge setpoint schedule, whose pace is also increased to cover the forecasted demand but always leaving headroom for potential activation.

This schedule is re-assessed every 15 minutes with updated forecasted values and inputs from the market.

The execution of the test case continues with the scheduled operation of the assets until 10 am, when the DSO detects a requirement of flexibility of 0.5 MWh for the same day at 2 pm. As the requirement exceeds the potential activation of the available flexibility form the long-term market, the DSO goes to the short-term market to find a solution.

A requirement is sent to sMART with the specific time and amount of energy required. The bidding is open at the beginning of the next hour (11 am) for 45 minutes.



Figure 169: DSO requirement sent to sMART

When the time arrives, all flexible assets from sFLEX and sENC that have any potential flexibility send their bids to the market automatically. The minimum bid is 10 kWh (0.01 MW). When the bidding window closes, the results are available in sMART and the matched bids are communicated to the corresponding tool/bidder for internal acknowledging.

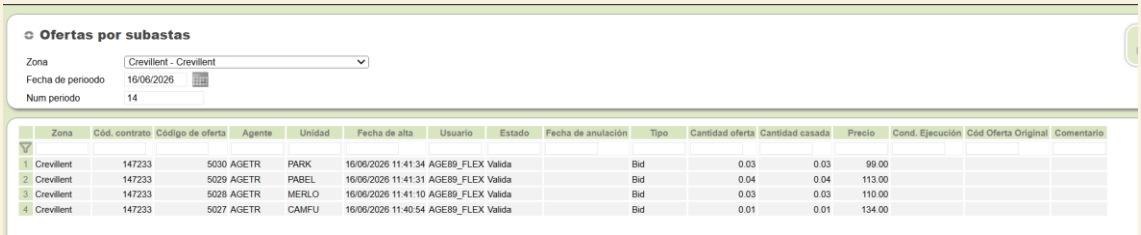


Figure 170: Flexibility bids and matches in the short-term market

The matched bids are:

Table 43: Matched bids in the short-term flexibility market

Asset	Associated UOL	Capacity (MW)	Technology	Bid quantity (MW)	Matched quantity (MW)	Price (EUR/MWh)

Parking Rambla	PARK	0,05	Solar photovoltaic	0.03	0.03	99
Pabellon	PABEL	0,05	Solar photovoltaic	0.04	0.04	113
Merlon (community battery + PV)	MERLO	0,10	Hybrid	0.03	0.03	110
Campo de futbol	CAMFU	0,10	Solar photovoltaic	0.01	0.01	134
			TOTAL	0.11	0.11	

Due to the low number of flexibility assets in the market, the total matched quantity does not cover the requirement. However, the flexibility matched is acknowledged by sFLEX (in the case of the community battery) and sENC (the community PV installations) and schedules are modified accordingly. When the time comes, each tool sends the modified commands to the corresponding asset, so the market agreements are fulfilled.

In the case of sFLEX, the setpoint of the community battery is modified to charge an additional 30 kW from the baseline ("increase consumption"). Sign of the setpoint in this case is negative for charging, positive for discharging:

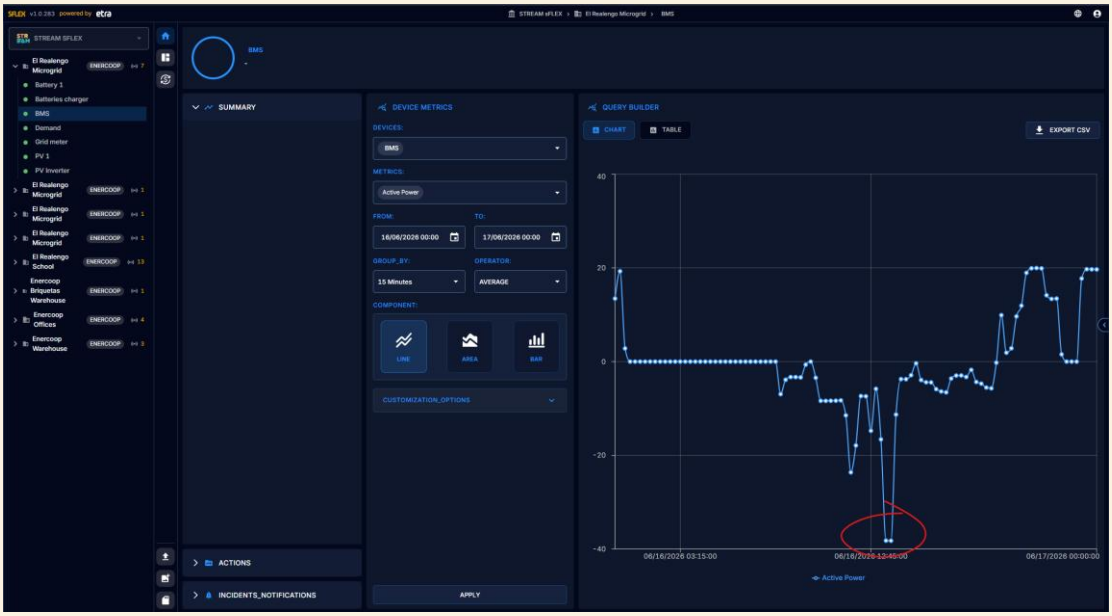


Figure 171: Battery activation for flexibility requirement

In the case of sENC, the three PV installations are limited during the delivery hour ("reduce consumption"):



Figure 172: Limitation of PV self-consumption installations for flexibility provision

In both cases, the normal operation is restored once the delivery window is closed, at 2 pm local time.

Qualitative analysis of the results

The experiment successfully demonstrated the end-to-end operation of the local flexibility market for congestion management, validating both the market workflows and the coordinated interaction among the four pilot tools (sGRID, sMART, sENC and sFLEX). The test case showed that local flexibility markets can be used not only to activate flexibility when a congestion is expected, but also to secure the availability of flexibility in advance during the time windows where the DSO anticipates higher network stress.

In this regard, the long-term flexibility market proved to be an effective mechanism for the DSO to reserve flexibility capacity during critical periods, such as the summer season in Crevillent, when the distribution grid is subject to higher stress due to increased PV generation during daytime hours and increased consumption during evening and night-time periods. From the flexibility service providers' perspective, this mechanism also enables an additional revenue stream by remunerating the availability of flexibility during the service window. In operational terms, this commitment was integrated into the optimization and scheduling of the flexible assets. For the community battery and EV chargers, the committed capacity was considered as a constraint in order to reserve sufficient operational margin and state of charge to deliver the service if activation was eventually required. In the case of the PV installations, the commitment did not require any modification of their operation, but rather ensured that a minimum generation level would be available during the service window so that downward flexibility could be offered if needed. The test case also confirmed that the different assets can provide different flexibility products depending on their technical capabilities: while the battery and EV chargers were able to offer both upward (increase consumption/reduce generation) and downward (reduce consumption/increase generation) flexibility, PV installations could only provide upward flexibility during the periods in which they were generating.

The short-term market complemented this mechanism by enabling the DSO to send specific flexibility requirements whenever a congestion was actually forecasted by sGRID in the day-ahead horizon, defining the exact time periods and grid zones affected. In turn, flexibility service providers were able to update their bids according to the latest forecasts of asset availability and generation, while taking into account the commitments already compromised in the long-term

market. Once the short-term market was cleared, the resulting flexibility activations were translated into concrete control actions on the assets, thereby validating the complete chain from grid need identification to market-based flexibility activation. In this respect, the test case demonstrated the capability of the participating assets to respond in a timely and coordinated manner, confirming the suitability of DERs and EnC assets to support congestion management in local distribution grids.

Overall, the experiment validated the complementarity between long-term and short-term local flexibility market mechanisms: the former provides the DSO with a preventive tool to secure flexibility availability in advance, while the latter enables the actual activation of the most suitable flexibility offers when a congestion is forecasted. Beyond the validation of the market logic itself, the test case also demonstrated the interoperability of the STREAM toolchain and the potential of coordinated local flexibility markets to mobilise distributed energy resources in support of distribution grid operation.

Experiment number	**ES-UC.06.01**
Name of the experiment	Local Flexibility Market establishment and operation between peers of the Energy Community
Timeframe	May – June 2026 (M44-M45)
Targets	The objective of this test case is to design, implement and validate a local peer-to-peer (P2P) flexibility market within the Energy Community, enabling members to trade surplus self-generated energy (individual or shared) among peers. The experiment aims to assess the effectiveness of the market mechanisms in optimizing energy costs, increasing local self-consumption, and improving overall community energy efficiency.
Actors	• ENER as Energy Community Manager • ETRA as technology provider • OMIE as Market Operator
STREAM products	sENC, sMART
Assets & systems	• AMI • Production assets owned by the Energy Community • Energy community members
Description of the experiment	This test case focuses on enabling peer-to-peer (P2P) energy exchange within the Energy Community to maximise the local consumption of self-generated renewable energy. sENC forecasts the generation of the collective self-consumption installations and the consumption of the associated supply points. Based on these forecasts and the predefined allocation coefficients, sMART calculates the expected energy surplus (this is, allocated generation for a member is greater than the expected consumption) or deficit (expected consumption greater than allocated generation) for each participating member. When a surplus is identified, the corresponding energy is offered in the P2P market, while expected deficits are translated into purchase bids. sMART matches local supply and demand among Energy Community members,

	enabling the exchange of renewable energy within the community before energy is imported from or exported to the external grid. The test case evaluates the capability of the STREAM ecosystem to support local energy exchanges, increase self-consumption levels, and improve the economic value of locally generated renewable energy for Energy Community members. **Pre-condition/triggering event:** • Collective self-consumption assets and associated consumption points are registered in sENC and sMART. • Consumers are grouped in sMART into aggregations corresponding to each collective self-consumption scheme. • Allocation coefficients defining the distribution of generated energy among consumers are available. • sENC is able to generate forecasts for both generation (per installation) and consumption (per demand point). • The P2P market functionality is available in sMART. • sENC generates updated forecasts of generation and consumption, identifying expected energy surplus or deficit within each collective self-consumption aggregation. **Steps:** 1. sENC generates forecasts of generation for each collective self-consumption installation and consumption for the associated demand points. 2. Based on these forecasts and the predefined allocation coefficients, sENC calculates the expected energy balance (surplus or deficit) for each member. 3. sENC sends the energy position (surplus/deficit) to sMART: a. If a surplus is identified, the member submits sell offers to the P2P market through sMART. The selling price of the offer is higher than the compensation of the retailer to increase their welfare. b. If a deficit is identified, the member submits buy bids to the P2P market through sMART. The buying price of the offer is lower than the price of the retailer to increase their welfare. 4. sMART matches buy and sell bids between aggregations within the Energy Community. 5. sMART notifies the results of the P2P matching to the participating members. 6. During the delivery period, energy exchanges are virtually allocated according to the matching results and monitored by sENC. 7. sMART performs settlement based on the matched energy exchanges. **Post-condition:** • The wasted energy is reduced or even avoided. • Both consumers and producers perceive an increase of their economic welfare.
Exception paths and scenarios of the experiment	No exception paths are considered in this test case.

Datasets required for the experiment	• Active and reactive power of PV + community battery installation – Historical • Community battery SOC • Prosumers' consumption and generation – Historical • Community battery setpoint • Generation from EnC collective self-consumption installations • Domestic batteries SOC • Active and reactive energy of EV chargers • Weather data • Prosumer's energy tariffs • Consumption, generation and flexibility forecasts • Self-consumption allocation coefficients
Field data to be gathered	• Flexibility bids, asks and requests • Flexibility market results • Active and reactive power of PV + community battery installation – delivery period • Prosumers' consumption and generation – delivery period • Active and reactive energy of EV chargers – delivery period
Related KPIs	KPI ES.13

Results of the Experiment

For the execution of this experiment, we will consider one of the collective self-consumption installations integrated in sENC, namely the one in the Museo de la Semana Santa (Holy Week Museum), which has 15 kWp of installed PV power and whose generation is split among 20 users. The test will be run for one week, in 1-hour daily sessions from 8 am to 19 pm, coinciding with PV generation hours.

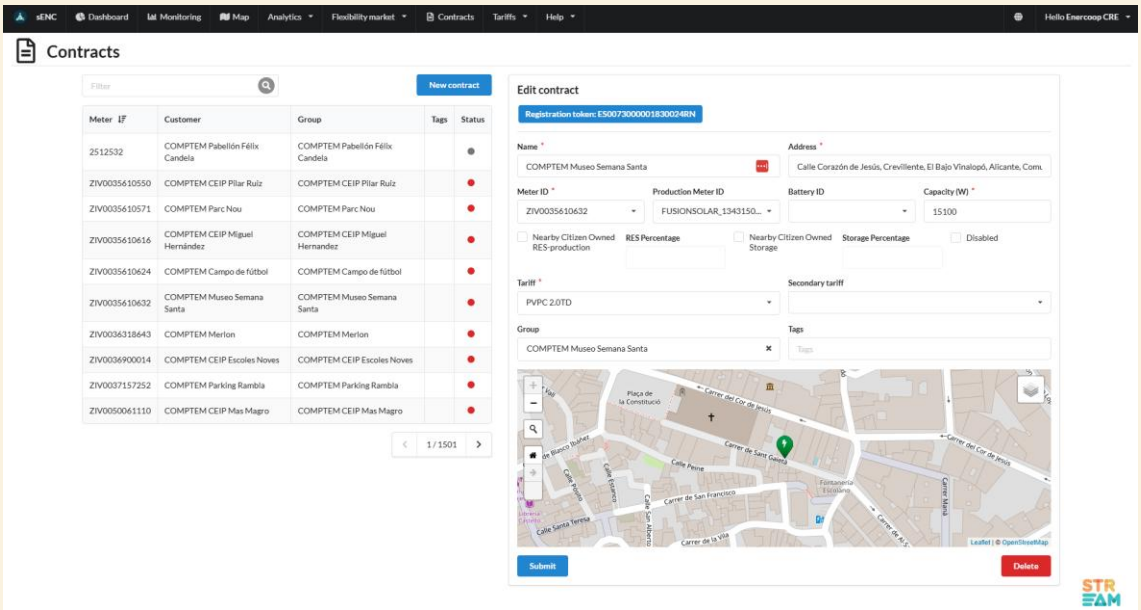


Figure 173: Contracts information of EnC member linked to a collective self-consumption generator in sENC

For each hour, sENC takes the forecasted generation and consumption of the group and calculates the expected balance for each user: which ones will cover their consumption with their allocated generation and have surplus to sell in the market, and which ones will need additional generation

from the market to complement their allocation. The results for the next hour are stored in sENC's long-term database.

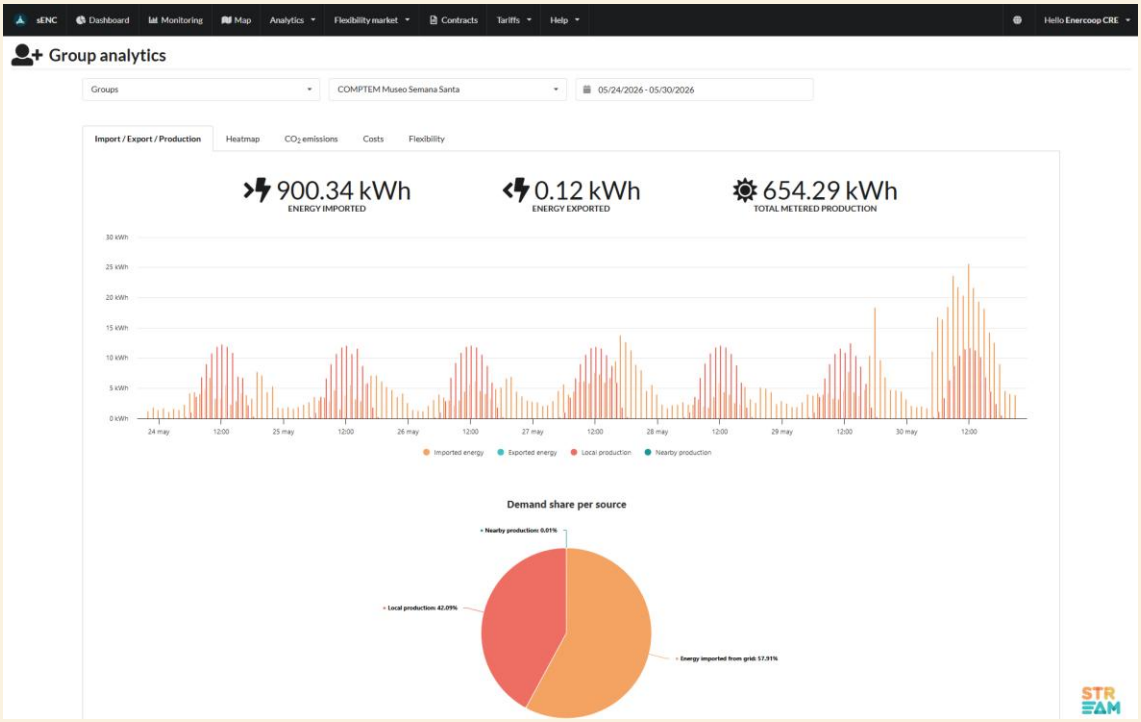


Figure 174: Group analytics (generation and consumption forecasts) of the collective self-consumption installation

After these results are ready, the sMART connector for sENC is called to create the sell (asks) and buy (bids) orders for the next hour. The reference price for each bid is the mid-point of the energy price and the feed-in tariff. Figure 175 shows the P2P open sessions in sMART that are visualized in sENC. Since the P2P market is a continuous market, the sessions are automatically open when an order is sent to sMART.

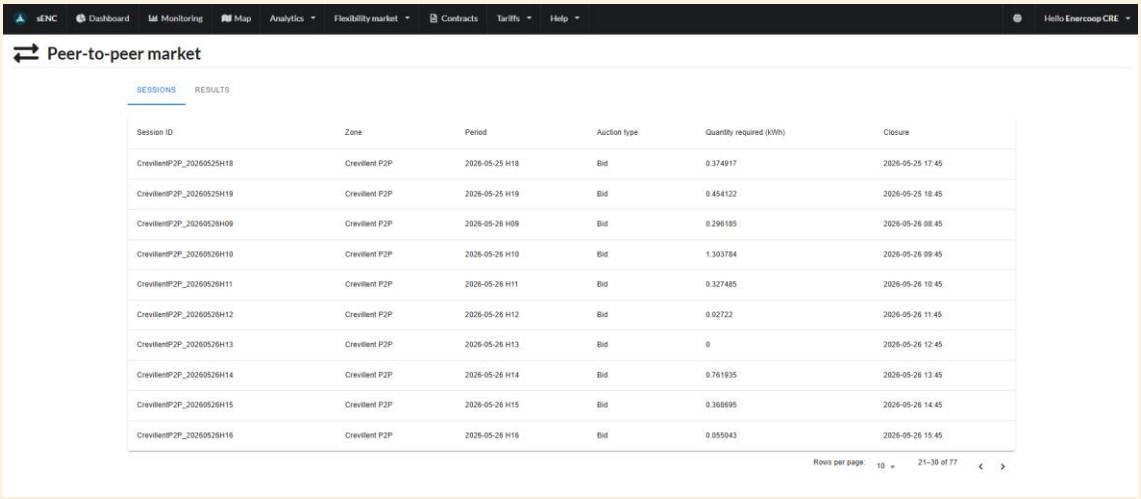


Figure 175: P2P market sessions open in sMART visualized in sENC

Figure 176 shows the orders prepared in sENC for the session open for the day 25/05/2026 H18, with the bids (left side) sent for the participants of the collective self-consumption installation with more consumption than allocated generation, and the asks (right side) for the participants with more allocated generation than consumption for that specific hour. As previously stated, these orders are sent to sMART through the connector, where the bids and asks are matched. Figure 177 displays the order book in sMART of the bids sent by sENC.

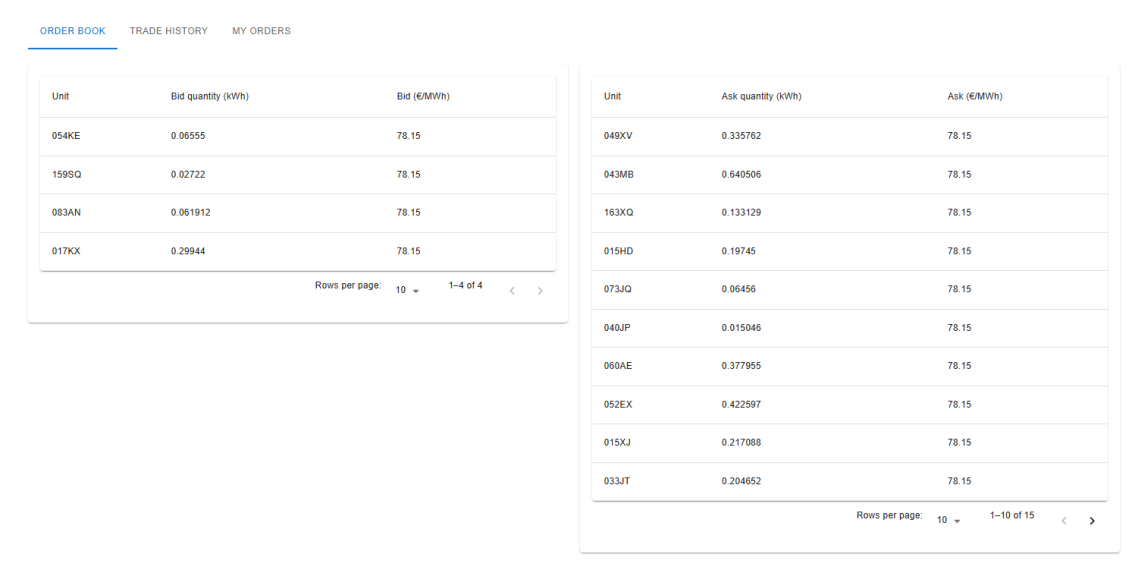


Figure 176: Order book for a market session visualized in sENC with the bids (buying offers) and asks (selling offers) sent to sMART

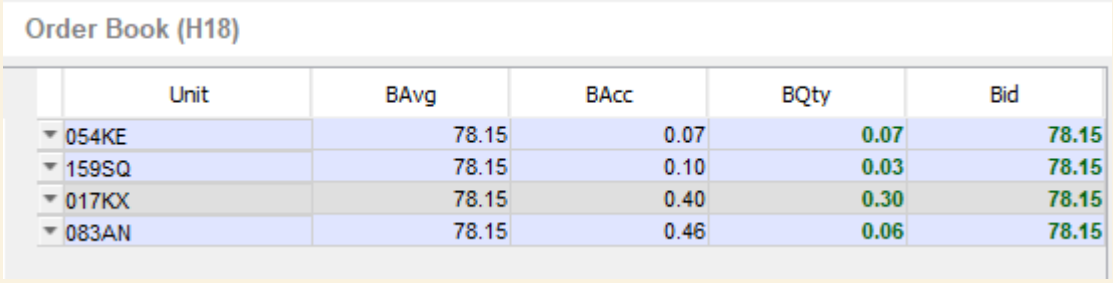


Figure 177: Order book visualized in sMART for the bids sent through sENC

Due to the continuous nature of the P2P market, as soon as an ask is sent with a price lower or equal than the more competitive bid, the orders are matched. In this case, since the prices were similar as they followed the same strategy, all the orders were matched. This is reflected in Figure 178

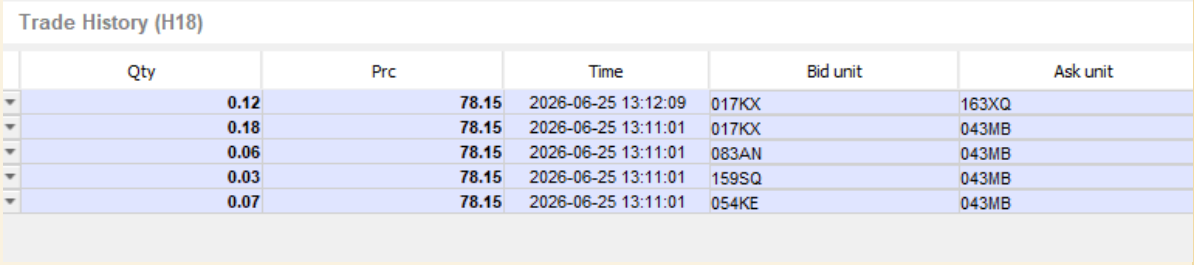


Figure 178: Trade history in sMART once all the orders are sent by sENC

The results of the market are stored in sENC for subsequent analysis, as shown in Figure 179.

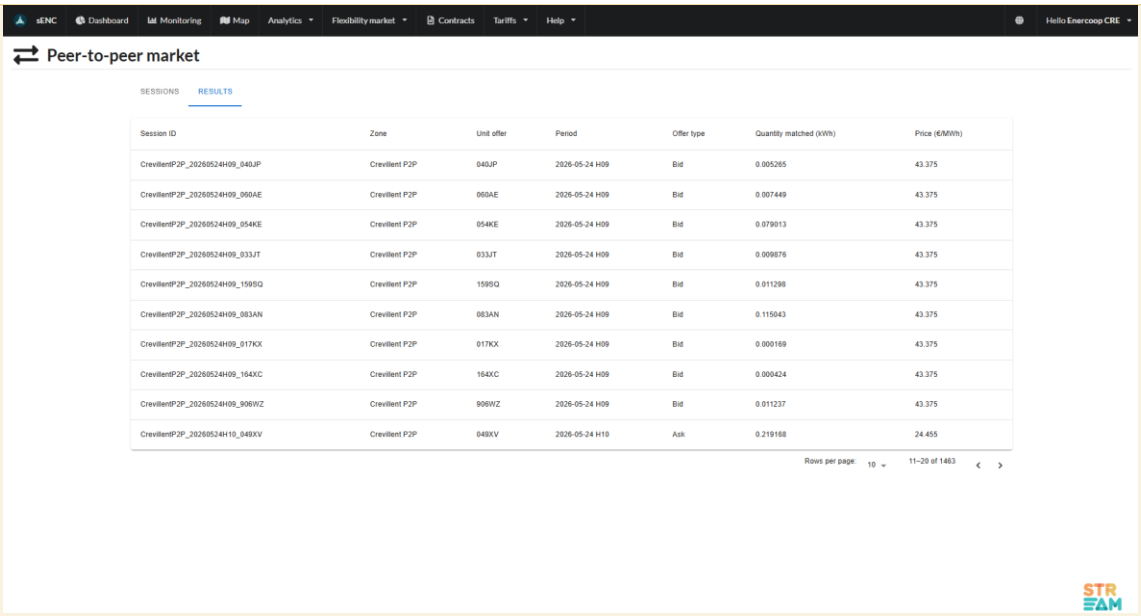


Figure 179: Results of the P2P sessions retrieved from sMART and stored in sENC

Qualitative analysis of the results

The results of the experiment for the whole week show the following outcomes for a single installation and one week:

- **100% of bids were matched.** This is the result of not having restrictions on bid/ask price (the same is used for both). In a real scenario, the prices selected for selling and buying should be wisely selected to maximize the energy traded.
- **A total of 58.13 kWh was traded**. This PV generation that would have gone to the grid was re-used internally in the EnC. With this result for a single week (77 market sessions), the potential for a scenario where the P2P schema is applied to other collective self-consumption installations and running continuously is very promising.
- **Revenue for users selling their surplus amounted to 2.45 EUR,** which is 1.92 EUR (4.5 times) more than what the feed-in tariff would have provided (0.54 EUR). This reflects that during peak solar hours, the feed-in tariff is very low or even negative, making P2P significantly more attractive to sellers.
- **Users buying from P2P saved 1.92 EUR** with regards to their energy tariff—they paid 2.45 EUR instead of 4.37 EUR with the considered energy tariff.
- This experiment was run as proof of concept for a P2P market inside the EnC. Its translation into a real-life scenario would need to consider several aspects that were assumed here, such as the aforementioned price of the trades and the mechanism to decide the submission of the orders to the market as, sMART being a continuous market in this case, it will match the bids as they arrive, so an unthought submission mechanism could favour some EnC users instead of others.

Experiment number	**ES-UC.07.01**
Name of the experiment	Overall coordination of the EnC assets operation for minimum electricity cost
Timeframe	June 2026 (M45)

Targets	The target of this test case is to coordinate the energy consumption, generation and storage of the EnC assets to minimise the energy cost of the community members, obtaining numerical values of the economic welfare improvement of the users.
Actors	• ENER as Energy Community Manager • ETRA as technology provider
STREAM products	sENC
Assets & systems	• Energy Community battery • Energy community members flexibility assets • AMI • EV chargers
Description of the experiment	Through sENC, the energy consumption patterns of the assets of the EnC and their energy tariff costs can be analysed. This analysis together with the energy consumption, production and flexibility forecasts can lead to the optimisation of the electricity cost of the EnC by managing the flexibility assets of the pilot, extracting advanced analytics in terms of their energy behaviour and managing the flexible community owned assets in a way that minimizes the energy cost for the community members. Energy community managers are thus able to receive insights from the decision support system on the assets operation and to simulate scenarios to achieve lower prices for the community, enhancing members' welfare. This functionality is subject to the emergence of a requirement from the DSO for a flexibility market session due to the detection of a congestion, which takes precedence over the optimization of the energy community. This casuistic is explored as a scenario. **Pre-condition/triggering event:** • sENC delivers AI-powered reports on energy behaviour of the Community. • The assets of the energy community are integrated in sFLEX. **Steps:** 1. sENC stores the historical data and monitors RT data of the devices of the community members. The tool analyses the user's behaviour. 2. sENC analyses the hourly prices of the community assets to obtain the prices profile, essential for the cost optimization. 3. With all the data of the assets and obtained from the analytics, the tool generates several scenarios in order to obtain the optimal one. This report is provided to the EnC manager. 4. Taking into account the report, the EnC manager takes the correspondent actions, scheduling the activation and/or deactivation of the community's flexibility assets through sFLEX in order to optimize the community's energy cost. **Post-condition:** • The Energy Community Manager is capable of designing and applying information and data-based action to optimize the EnC's energy cost through sENC.

Exception paths and scenarios of the experiment	**Flexibility Market session upon a DSO requirement** 5a. DSO's flexibility requirements meant to tackle grid issues have more priority than EnC's energy costs. Therefore, the resulting schedule of this Test Case can be modified if there is a flexibility request from the DSO.
Datasets required for the experiment	• Active and reactive power of PV + community battery installation – Historical • Community battery SOC • Generation from EnC collective self-consumption installations • Community battery setpoint • Prosumers' consumption and generation – Historical • Domestic batteries SOC • Active and reactive energy of EV chargers • EVs SOC • Weather data • Prosumer's energy tariffs • Wholesale market price • Consumption, generation and flexibility forecasts
Field data to be gathered	• Community battery setpoint
Related KPIs	KPI ES.06

Results of the Experiment

The economical optimization of the EnC is approached differently depending on the nature of the elements managed. It combines the user profiling of the flexible assets and the energy performance-based clustering of the rest of the members of the EnC (as explained in sections 4.1.4 and 4.2 of D3.3 [2]).

The optimization of flexible assets such as domestic batteries is done with the same algorithm used for the community battery. The optimal setpoint of the storage system is calculated based on the forecasted demand and production of each installation and the price of the energy, with a two-fold objective: maximizing self-consumption and minimising the energy cost. This approach is followed for all batteries integrated in sENC, which, as a general rule, charge in cheaper hours and discharge when prices are high:



Figure 180: Optimization of flexible assets

For the rest of the EnC, no actuation can be performed to optimise the energy price, so a different approach is followed. sENC analyses the consumption baseline of the members in order to group them into clusters with similar behaviour, so that the EnC manager is able to design tailored tariffs and/or reach deals for those sets of users that have flexible daytime consumption (Time-of-Use tariffs) or flat consumption (flat-rate tariffs).

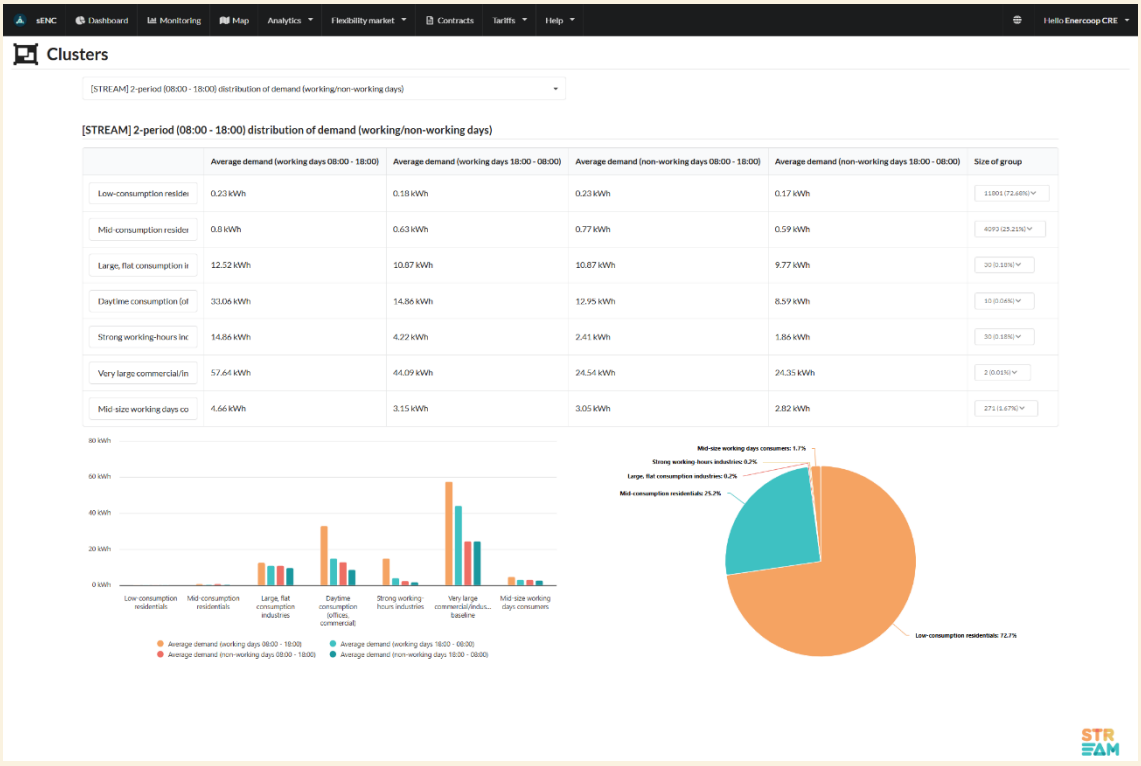


Figure 181: Clustering of EnC members

Details about the different clusters are provided in Table 44:

Table 44: Clusters details

Cluster	Members	Label	Reasoning
0	11801	Low-consumption residential	Very low total (~0.8 kWh/h), nearly flat across all periods — no behavioral signal. Typical small household, always-on baseline.
1	1	Anomaly / outlier	~119000 kWh/h total with inverted nwd pattern (more at night on weekends). Single meter, almost certainly industrial substation or data error. Needs investigation.
2	4093	Medium-consumption residential	~2.8 kWh/h, same flat profile as cluster 0 just at 3× the level. Larger households or small residential consumers.
3	30	Large baseline industry / always-on services	~44 kWh/h, very flat across all periods (wd/nwd 1.13, p1/p2 ~1.1). Continuous process — could be water treatment, telecom, cold storage.
4	10	Office / commercial daytime	~69 kWh/h total but strong daytime peak on working days (wd p1/p2 ratio 2.22, wd/nwd 2.22). Classic office building — high during business hours, low at night and weekends.
5	30	Strong working-hours industry	~23 kWh/h but extreme working-day daytime concentration (wd p1/p2 ratio 3.52, wd/nwd ratio 4.46). Factory or workshop operating only on weekday business hours.
6	2	Very large commercial / industrial baseline	~151 kWh/h, moderate working-day peak (wd/nwd 2.08). Large facility — shopping centre, hospital, or campus. Only 2 meters so likely two specific sites.
7	271	Mid-size working-day consumers	~14 kWh/h with moderate daytime working-day bias (wd p1/p2 1.48, wd/nwd 1.33). Small-to-medium businesses or commercial premises with partial weekend activity.

The most interesting clusters for demand-side management are 4 (pure office profile) and 5 (pure working-hours industry), both have very predictable flexibility windows. Cluster 1 should be flagged for data review before any further analysis.

Qualitative analysis of the results

The experiment combines different services in order to cover specific aspects of the EnC portfolio. The optimization of storage systems has been tested in previous Test Cases with the incorporation of market signals; this Test Case demonstrates its use for everyday cost optimization. In the case of the clustering of users, it is not *per se* a cost-saving functionality, but a decision support tool for the EnC manager to take actions to reduce the cost of both the users and the EnC overall.

8.3 ITALIAN PILOT SITE

Experiment number	**IT-UC.01.01**
Name of the experiment	Accuracy assessment of grid reconstruction
Timeframe	March – June 2026 (M42-M45)

Targets	This experiment aims to evaluate the accuracy of the MV grid model reconstruction using smart meter data collected at the MV/LV substation level.
Actors	• ASM as DSO • COMS as technology provider
STREAM products	sGRID, sDATA
Assets & systems	• MV/LV substations • MV consumer • Power quality analysers
Description of the experiment	The main objective is to collect power quality analyzer data at the MV/LV substation level and consumers directly connected to the MV level and to use advanced data analytics and optimization techniques to reconstruct the MV grid model (impedance matrix). The experiment will evaluate the accuracy and effectiveness of the reconstruction process. **Pre-condition/triggering event:** The MV/LV substations are equipped with smart meters that are capable of collecting and transmitting relevant data. **Steps:** 1. The smart meter data from all MV/LV substations in a selected feeder is collected by sDATA. This data contains information about voltages and power. 2. The collected data is preprocessed to remove noise, handle missing values, and prepare it for analysis. 3. Processed data from sDATA is pulled by the sGRID 4. Advanced data analytics and optimization algorithms are applied to reconstruct the MV grid model and create an impedance matrix of the grid. The voltage of the substation and the powers of the MV/LV transformers are used to calculate the voltage drops across the cables, which are then compared with the measured voltage drops. 5. The optimization algorithm determines the impedance matrix by minimizing the difference between measured and calculated voltage drops. 6. The reconstructed grid model is validated against known grid parameters provided by the DSO. The difference between the line impedances provided by the DSO and the calculated values is compared with the percentage error (PE). **Post-condition:** The reconstructed impedance matrix of the medium voltage grid is created and validated using known parameters of the grid.
Datasets required for the experiment	• Voltages of transformers and substation • Power flows on transformers • Line parameters
Field data to be gathered	• Grid impedance matrix
Related KPIs	KPI IT.07

Results of the Experiment

The experiment demonstrates the implementation of the MV grid reconstruction service for the selected Italian pilot feeder. The aim is to reconstruct an equivalent impedance matrix of the feeder and to assess whether the reconstructed model can reproduce the voltage-drop behaviour of the grid under various loading conditions. Owing to limitations in the available field data, the reconstruction was carried out using simulation-supported input data. The main obstacles were missing tap changer information for MV/LV transformers and uncertainty about the exact location of some MV-connected loads. As unknown tap changer positions directly affect voltage levels, the voltage profiles across the feeder could not be reliably compared using field measurements alone. To address this, power flow simulations were used to obtain a consistent set of voltage and power profiles for testing the reconstruction methodology.

The reconstruction was performed using voltage and power profiles for one reference node and five downstream load points. For each timestamp, the voltage droppage between the reference node and each load point was calculated as:

$$\Delta U_k(t) = U_{ref}(t) - U_k(t)$$

where $U_{ref}(t)$ is the phase-to-ground voltage at the reference node, and $U_k(t)$ is the phase-to-ground voltage at load point. The current at each load point was estimated from the corresponding power and voltage value as:

$$I_k(t) = \frac{P_k(t)}{3\,U_k(t)}$$

where $I_k(t)$ is the estimated line current at load point k and timestamp t, $P_k(t)$ is three-phase power and $U_k(t)$ is the corresponding phase-ground voltage. For each timestamp, the individual voltage drops and currents are collected into vectors:

$$\Delta \boldsymbol{U}(t) = \begin{bmatrix} \Delta U_1(t) \\ \Delta U_2(t) \\ \vdots \\ \Delta U_N(t) \end{bmatrix}, \qquad \boldsymbol{I}(t) = \begin{bmatrix} I_1(t) \\ I_2(t) \\ \vdots \\ I_N(t) \end{bmatrix}$$

where N is the number of analysed downstream load points. The reconstruction is based on the assumption that the voltage-drop vector can be approximated from the current vector and the equivalent impedance matrix:

$$\Delta \boldsymbol{U}(t) \approx \boldsymbol{Z} * \boldsymbol{I}(t)$$

where $\boldsymbol{Z}$ is the equivalent impedance matrix to be reconstructed. Each timestamp provides one relationship between the current vector and the voltage-drop vector. However, the objective is not to obtain a separate matrix for each timestamp; rather, it is to find a single common matrix $\boldsymbol{Z}$ that best explains the voltage-drop behaviour across all selected operating points. In theory, if sufficiently diverse and consistent operating points are used, the optimisation should converge towards the feeder impedance matrix that represents the analysed grid section. Before running the optimisation, representative operating points were selected from the available dataset. Instead of using all timestamps directly, power profiles were clustered to identify diverse loading situations. This prevents the reconstruction from being dominated by repeated or very similar operating states and improves the information content of the optimisation dataset. The impedance matrix was reconstructed through numerical optimisation. The decision variables are the unknown elements of matrix $\boldsymbol{Z}$. As the matrix is assumed to be symmetric, only the upper triangular part of the matrix is optimised, while the lower triangular part is mirrored.

$$Z_{a,b} = Z_{b,a}$$

where a and b denote the row and column indices of the impedance matrix. For each candidate matrix $\boldsymbol{Z}$, the calculated voltage-drop vector is obtained as:

$$\Delta \boldsymbol{U}_{calc}(t) = \boldsymbol{Z} * \boldsymbol{I}(t)$$

The optimisation then minimises the difference between the input voltage drops and the calculated voltage drops over all selected timestamps:

$$\min_{Z} \sum_{t} \sum_{k=1}^{N} \left(\Delta U_k(t) - \Delta U_{calc,k}(t)\right)^2 * w_k(t)$$

where $\Delta U_k(t)$ is the input voltage drop at load point k, $\Delta U_{calc,k}(t)$ is the calculated voltage drop for the same load point using the candidate matrix $\boldsymbol{Z}$ and $w_k(t)$ is a loading-based weighting factor. In the implementation, operating points with higher loading have stronger influence on the final reconstruction result. The purpose of the optimisation is to ensure that the impedance matrix converges to a single set of values that consistently reproduces the feeder voltage drops under various loading conditions. Individual timestamps may indicate slightly different impedance values due to numerical effects, modelling assumptions or data uncertainty. The optimisation addresses this by identifying the matrix that minimises the total weighted voltage-drop error across the selected dataset. It also incorporates basic physical consistency checks, prohibiting negative impedance values. This prevents unrealistic matrix structures and ensures a physically meaningful reconstruction. The optimisation was performed using the Powell method implemented in Python, and the reconstructed matrix was then compared with the reference matrix derived from known feeder line parameters. The percentage error of each matrix element was calculated as:

$$\varepsilon_{a,b} = \left| \frac{Z_{a,b}^{true} - Z_{a,b}^{rec}}{Z_{a,b}^{true}} \right| * 100\%$$

where $Z_{a,b}^{true}$ is particular reference matrix element and $Z_{a,b}^{rec}$ is the corresponding reconstructed matrix element. The comparison between the reference (left) and reconstructed (right) matrices is shown in Figure 182.

Z_true - NumPy object array

	0	1	2	3	4
0	0.074351	0.074351	0.074351	0.074351	0.074351
1	0.074351	0.166146	0.166146	0.166146	0.166146
2	0.074351	0.166146	0.244896	0.244896	0.244896
3	0.074351	0.166146	0.244896	0.377393	0.377393
4	0.074351	0.166146	0.244896	0.377393	0.893197

Z_rec - NumPy object array

	0	1	2	3	4
0	0.0690419	0.0704272	0.0759461	0.0735247	0.0759055
1	0.0704272	0.187939	0.158103	0.171408	0.160449
2	0.0759461	0.158103	0.247823	0.243108	0.244845
3	0.0735247	0.171408	0.243108	0.378508	0.375252
4	0.0759055	0.160449	0.244845	0.375252	0.902202

Figure 182: Comparison between the reference (left) and reconstructed (right) matrices

The reconstructed matrix achieved a maximum percentage error of 13.12% and an average percentage error of 2.78% compared with the reference matrix. The results show that the reconstructed matrix follows the structure of the reference matrix. Most matrix elements are close to the corresponding reference values, while the largest deviations are limited to individual elements. The low average error indicates that the reconstructed matrix provides a good approximation of the reference feeder model.

To support the interpretation of the reconstructed matrix, it is useful to clarify what the matrix elements represent physically. The impedance matrix Z reflects the cumulative impedance between the reference node and each analysed load point, as well as the feeder sections that are shared by different load currents. For example, consider a simplified radial feeder with three load points as shown in Figure 183Figure 183. Load points L_1 and L_2 are located on the same branch, with L_2 positioned behind L_1. Load point L_3 is located on a second branch. The feeder contains one common upstream section L_0.

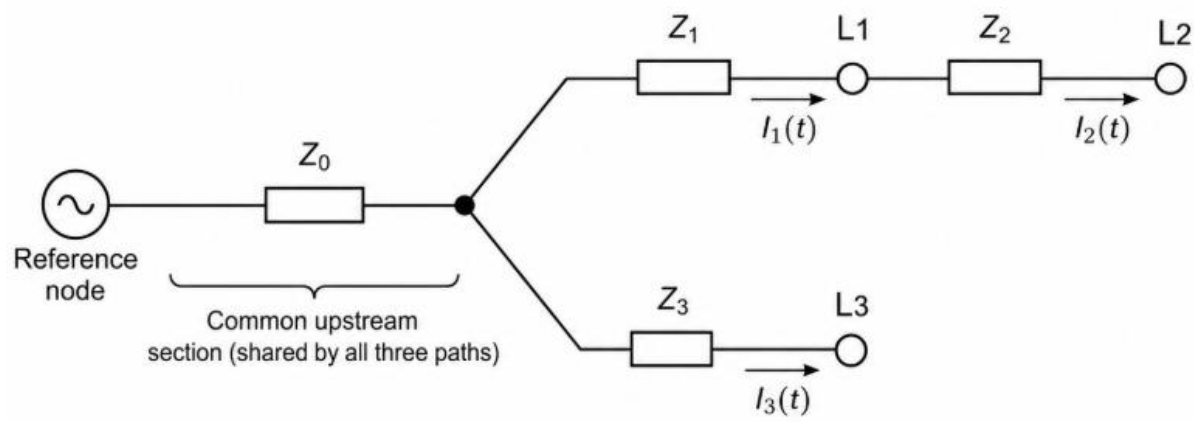


Figure 183: Simplified radial feeder example scheme

In this case, the voltage-drop relationship can be represented as:

$$\begin{bmatrix}\Delta U_1(t)\\ \Delta U_2(t)\\ \Delta U_3(t)\end{bmatrix} = \begin{bmatrix}Z_0+Z_1 & Z_0+Z_1 & Z_0\\ Z_0+Z_1 & Z_0+Z_1+Z_2 & Z_0\\ Z_0 & Z_0 & Z_0+Z_3\end{bmatrix}\begin{bmatrix}I_1(t)\\ I_2(t)\\ I_3(t)\end{bmatrix}$$

In this example, Z_0 is shared by all three loads, because all load currents flow through the common upstream feeder section. Load points L_1 and L_2 also share section Z_1, because they are located on the same branch. Load point L_2 has an additional cumulative impedance Z_2, because it is located further downstream behind L_1. Load point L_3 is located on a separate branch and therefore shares only the common upstream section Z_0 with $L_1$and L_2, while its own branch impedance is represented by Z_3. This example illustrates why the reconstructed matrix contains both diagonal and off-diagonal elements. The diagonal elements represent the cumulative impedance path from the reference node to each load point. The off-diagonal elements represent the impedance sections shared by the current paths of two different load points. Therefore, the reconstructed matrix does not only describe the individual distance of each load point from the reference node, but also the electrical coupling between load points caused by shared feeder sections.

Qualitative analysis of the results

The test case is assessed as partially passed. The reconstruction service was implemented, the optimisation converged successfully, and the reconstructed matrix achieved a low average error compared with the reference matrix. However, the validation was performed using simulation-supported data rather than solely field measurements. For this reason, the result should be interpreted as a controlled validation of the methodology. The achieved accuracy may be more favourable than what could be expected in a fully field-based validation, where additional uncertainties such as tap changer positions, measurement noise, time alignment and uncertain load locations would be present.

Experiment number	**IT-UC.02.01**
Name of the experiment	Accuracy assessment of transformer loading forecast
Timeframe	May – June 2026 (M44-M45)

Targets	The aim of this experiment is to assess the accuracy of transformer loading forecasts generated for the Italian pilot site. The original objective of the test case was to evaluate the correct day-ahead detection of transformer congestion. However, the analysis of historical transformer loading data showed that no actual congestion events were observed on the analysed transformers during the available observation period. For this reason, the scope of the experiment was refined. Instead of evaluating the detection of congestion events, the experiment focuses on the correctness of the forecasted transformer loading. This remains directly relevant for congestion management, because accurate loading forecasts are a prerequisite for identifying future congestion risks and for triggering flexibility activation through sMART when transformers begin operating closer to their operational thresholds.
Actors	• ASM as DSO • COMS as technology provider
STREAM products	sGRID, sDATA, sMART
Assets & systems	• MV/LV transformers
Description of the experiment	This experiment focuses on the forecasting of loading on MV/LV transformers in the Italian pilot site. Transformer loading forecasts represent an important input for congestion management, as they allow the DSO and the aggregator to identify periods in which the transformer may operate close to or above its operational threshold. The experiment is linked to the use of sGRID as the STREAM tool responsible for forecasting grid conditions. The forecasted transformer loading is later used as an input for flexibility activation, where sENC determines whether flexible assets can be scheduled to reduce the expected loading, and sMART supports the flexibility request and market interaction process. **Pre-condition/triggering event:** the P (active power), Q (reactive power), I (current) and U (voltage) values of the MV/LV transformers of the DSO are continuously monitored. **Steps:** 1. The sDATA tool collects historical measurements of MV/LV transformers. The data is cleaned and processed to handle missing values, outliers or anomalies in the recorded values. The cleaned data is then pulled from sDATA to sGRID. 2. Retrieve and align weather data with the transformer loading time series. 3. Generate time-based, lag-based and weather-based model features. 4. Train an XGBoost model for each transformer. 5. Forecast transformer loading. 6. Compare forecasted and actual loading profiles and calculate forecast accuracy metrics **Post-condition:** The experiment provides forecasted transformer loading profiles and corresponding forecast accuracy metrics for the analysed transformers and lines. The results indicate how well the model reproduces

	the actual transformer loading behaviour and whether the forecast is suitable as a basis for future congestion risk assessment.
Datasets required for the experiment	• Exported and imported energy through transformer • Currents of transformer • Technical parameters of transformer • Historic weather data
Field data to be gathered	• Congestion forecast data
Related KPIs	KPI IT.05

Results of the Experiment

The experiment used historical transformer measurement data obtained through the sDATA platform and weather data from the Open-Meteo app. For each analysed transformer and line, the loading profile time series was used as the target variable for the forecasting model.

During data preparation, missing values were handled according to the availability of the remaining phase measurements. Where one phase power value was missing and the other two phases were available, the missing phase was reconstructed using the average of the available phase powers. If only one phase was available, the corresponding timestamp was excluded from the modelling dataset.

The forecasting model was developed separately for each analysed transformer line. An XGBoost regression model was used to forecast estimated transformer loading. The model used a combination of historical loading features, calendar-based features, and weather-related explanatory variables. The selected input features included hour of the day, month, day of the week, weekend indicator, previous-day loading, previous-week loading, outdoor temperature, and direct solar radiation. The experiment was implemented as a monthly rolling backtest. For each forecasted week, the model was trained using all historical data available before the start of that week. Compared with the initial implementation, where only the immediately preceding month was used for training, the refined approach used a broader historical dataset. To ensure the model still reflected the most recent operating behaviour, recency-based sample weighting was applied during training. More recent observations received higher weights, while older observations remained included in the training set with gradually lower influence.

The historical loading analysis showed that no actual congestion events were observed on the analysed transformers during the available observation period. For this reason, the experiment could not meaningfully evaluate congestion classification indicators such as correctly detected congestion events, missed events, or false alarms as was previously envisioned in D2.2. Consequently, the scope of the evaluation was refined. Instead of assessing the correct detection of congestion events, the experiment focused on the accuracy of the forecasted transformer loading. This remains directly relevant for congestion management, as reliable loading forecasts are a necessary prerequisite for future congestion prediction and flexibility activation.

The forecasted loading profile was compared with the actual measured loading profile for each analysed transformer and forecast month. Forecasts were first generated for individual transformer lines and then aggregated to transformer level by summing the forecasted and measured loading of all analysed lines. The final evaluation was therefore performed using one forecasted and one actual loading profile per transformer.

The evaluation covered the entire analysed forecast period using two relative forecast accuracy metrics: Mean Absolute Percentage Error (MAPE) and Weighted Mean Absolute Percentage Error (WMAPE). MAPE assessed the average relative error across individual time intervals, while

WMAPE measured the total absolute forecasting error relative to the total actual transformer loading.

For reporting purposes, representative example is provided below. The figure shows the transformer-level forecast for MBT 7 during the most recent week of May 2026. This period was selected to illustrate the behaviour of the forecasting model in the latest available part of the analysed dataset. The figure is not intended to replace the full monthly evaluation, but to provide a clear visual example of the relationship between forecasted and actual loading.

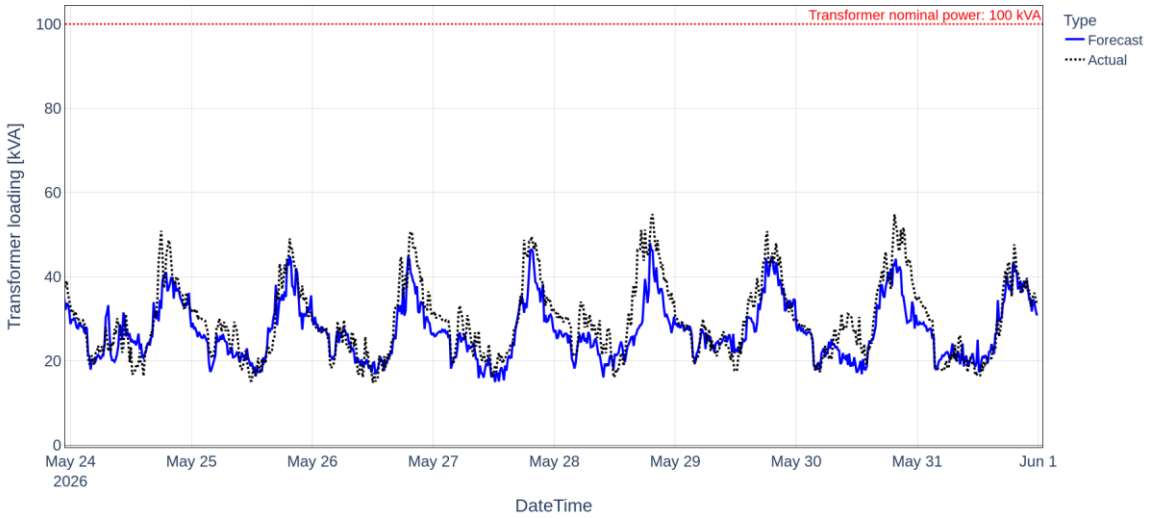


Figure 184: Forecasted and actual transformer loading for MBT 7

The figure shows that the forecast follows the general shape of the actual loading profile and captures the recurring daily loading pattern. Both forecasted and actual loading remain well below the transformer nominal power of 100 kVA, confirming that no congestion occurred during the displayed period. Some deviations are observed around short-term peaks and rapid changes in loading. In these intervals, the forecast may slightly underpredict or overpredict the actual transformer loading. This is expected, as sudden short-term variations may result from operational behaviour not fully represented in the available input features. Nevertheless, the forecast reproduces the main temporal structure of the loading profile and provides a useful basis for operational planning. For the displayed week, the forecast achieved a MAPE of 12.23% and a WMAPE of 12.80%. These values indicate that the model reproduced the main transformer loading pattern with a reasonable level of accuracy during the selected period. The weekly result is also consistent with the monthly performance for May 2026, where the forecast achieved a MAPE of 11.68% and a WMAPE of 11.19%. Across the analysed forecast months (July 2025 – May 2026), WMAPE ranged from 11.19% to 19.63%, while MAPE ranged from 11.68% to 22.88%. The best performance was achieved in May 2026, while the weakest was observed in April 2026. This indicates that forecast quality varied between months, but the model generally reproduced the main loading behaviour of the transformer.

Qualitative analysis of the results

The results show that the forecasting approach captures the main temporal behaviour of the analysed transformer loading. The model follows the recurring daily pattern and provides a reasonable estimate of expected loading under normal operating conditions. Deviations are mainly visible around short-term peaks and rapid changes in load, where the forecast may slightly smooth the measured profile. This is expected, as such variations can depend on operational or user-driven behaviour that is not fully represented in the available input features.

As no actual congestion events were observed in the available historical data, the test case could not be evaluated as a congestion detection task. The focus was therefore shifted to the accuracy

of the transformer-level loading forecast. This remains relevant, as loading forecast accuracy is the necessary first step before reliable congestion prediction and flexibility activation can be assessed.

It should also be noted that while transformer loading forecasting was one of the use cases considered in the Italian pilot, it was not the main focus of the pilot demonstration. As a standalone function, load forecasting is a well-established topic and is not the most innovative element of the project. In addition, comparison with state-of-the-art approaches is difficult, because forecast accuracy strongly depends on the analysed asset, measurement quality, available input data, seasonality and the selected forecast period. The monthly results also show that performance can significantly vary between months even for the same transformer.

The main value of this test case is therefore its role as an enabling component within the wider STREAM flexibility management workflow. A more accurate transformer loading forecast can improve the input provided to other use cases, especially the optimisation of flexible assets and the preparation of flexibility requests. If future forecasts indicate that a transformer is expected to operate close to or above its threshold, this information can support the scheduling logic in sENC and the activation process through sMART.

The results also show that loading forecasts can be useful even when no congestion is present. Under normal operating conditions, they provide information on expected transformer utilisation and help establish the basis for future congestion assessment. If future pilot data include higher loading levels or actual congestion events, the same forecasting framework could be extended with event-based validation indicators, such as correctly predicted threshold exceedances, missed congestion intervals and false alarms.

Experiment number	**IT-UC.03.01**
Name of the experiment	Registering a new charging station onto the flexibility platform
Timeframe	October – December 2024 (M25-M27)
Targets	This experiment aims to evaluate the process of registering a new charging station onto the flexibility platform, which integrates a marketplace structure between CPO and DSO.
Actors	ASM as DSO, EMOT as charging point operator
STREAM products	sMART
Assets & systems	Marketplace platform, registered consumers and assets
Description of the experiment	The main objective is to validate the registration process of a new asset on the flexibility platform and ensure its seamless integration into the marketplace. This experiment will focus on ensuring that the asset can actively participate in bidding on the marketplace. **Pre-condition/triggering event:** The flexibility platform is operational and ready to accept new consumer registrations. **Steps:** 1. The CPO initiates the registration process on the flexibility platform, providing necessary identity information (station ID, location, maximum power, charging capabilities)

	2. The DSO reviews the information provided to verify the authenticity and compatibility of asset with grid limitations. 3. After successful verification, the platform creates an asset profile for the charging station, granting it access to the marketplace and enabling participation in flexibility trading. 4. The platform confirms the successful registration of the asset. 5. The consumer's profile is fully integrated into the marketplace, where they can participate in trading activities. The platform monitors initial interactions to ensure proper functionality and responsiveness to DSO signals for flexibility needs. **Post-condition:** A new consumer is successfully registered and integrated into the flexibility platform, with a verified profile that allows them to participate in the marketplace.
Datasets required for the experiment	• Charging station data
Field data to be gathered	• Charging station registration on flexibility platforms
Related KPIs	KPI IT.06
Results of the Experiment	
The experiment successfully demonstrated the registration and integration of EV charging stations into the flexibility platform during the final demonstration phase. The implemented workflow validated the capability of the platform to onboard new charging assets provided by the CPO and make them available for future participation in flexibility services and marketplace interactions. The registration process was completed through the following operational steps: • The charging station data, including station identifier, location, charging capabilities and maximum charging power, were submitted through the platform interface by the CPO. • The DSO verified the submitted technical and operational information to ensure compatibility with grid requirements and platform constraints. • After successful validation, the charging stations were registered within the flexibility platform and associated with dedicated asset profiles. • The registered assets became visible within the platform dashboard together with their operational information and monitoring data.	

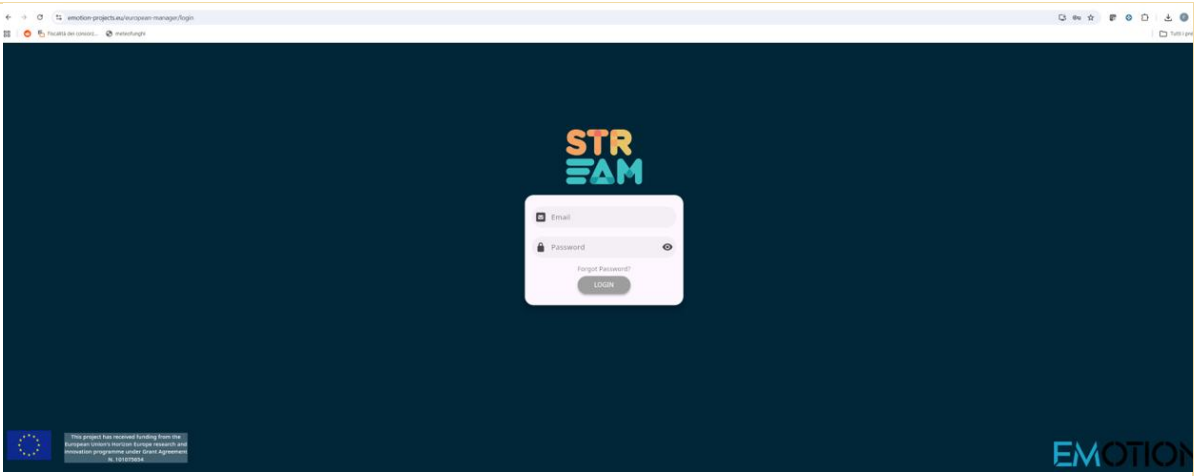


Figure 185: Flexibility platform login

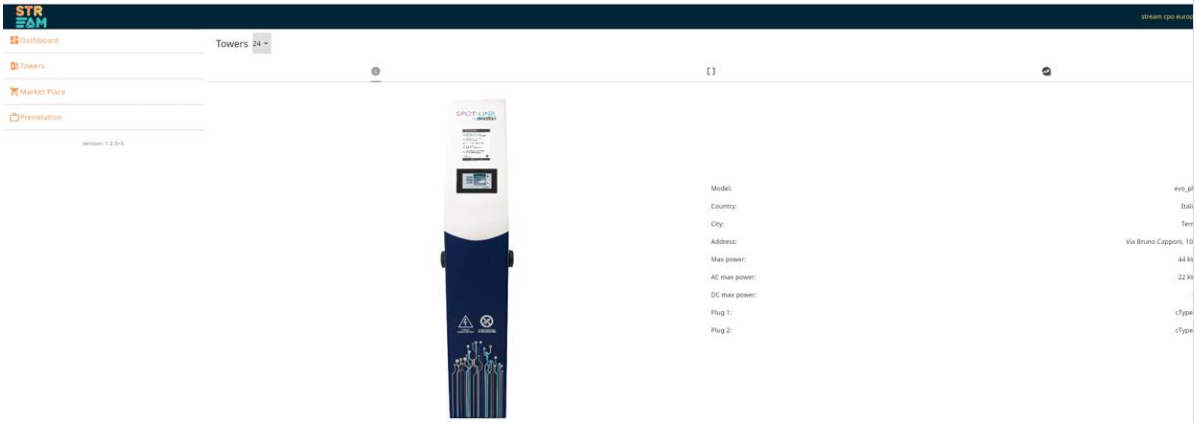


Figure 186: Registered charging station overview

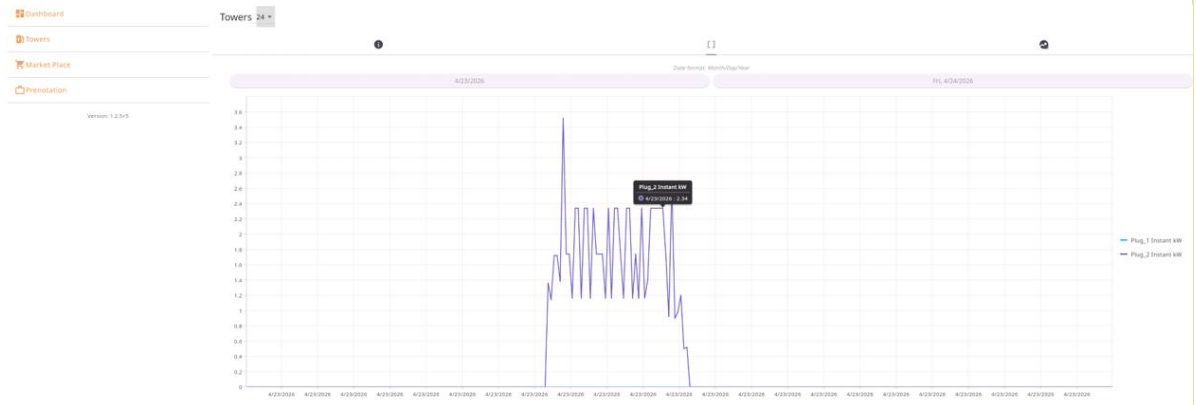


Figure 187:Charging station historical data



Figure 188: Charging station real-time data

The screenshots collected during the demonstration confirm the successful onboarding process and the correct integration of the charging stations into the flexibility platform environment. The platform visualisation includes:

- Successful registration confirmation of the charging stations;
- Asset identification and technical parameters;
- Historical charging and consumption data;
- Real-time operational measurements and monitoring values.

The demonstration also confirmed that the platform is capable of managing both static asset information and dynamic operational data associated with the charging stations. Historical and real-time measurements were correctly displayed within the monitoring interface, demonstrating the readiness of the assets for future participation in flexibility-related services. The experiment therefore verified the correct operation of the registration workflow and confirmed that newly onboarded charging stations can be integrated into the marketplace structure connecting the CPO and the DSO. The successful registration of the assets represents a necessary prerequisite for subsequent flexibility activation, bidding and validation use cases within the STREAM framework. The experiment also contributed to KPI_05 (Number of registered flexibility providers), as the successful onboarding of EV charging stations increased the number of assets and flexibility providers available within the sMART marketplace environment. The test case confirmed that the platform can support the registration and integration workflow required for expanding the portfolio of flexibility participants connected to the marketplace ecosystem.

Qualitative analysis of the results

The results confirm that the flexibility platform can successfully support the onboarding and management of EV charging infrastructure within the local flexibility ecosystem. The registration workflow proved to be functional and sufficiently structured to allow the integration of charging assets while ensuring verification by the DSO. The experiment also demonstrated the importance of combining asset registration with operational monitoring capabilities. The availability of both historical and real-time data increases transparency and supports the future validation of flexibility services. From the perspective of market participation, the successful creation of asset profiles represents the first operational step required before charging stations can participate in flexibility requests, bidding processes and congestion management services. The test case additionally confirmed the interoperability between the CPO and DSO roles within the STREAM framework and validated the capability of the platform to maintain a centralised representation of registered flexibility assets.

Experiment number	IT-UC.03.02
Name of the experiment	Flexibility mobilization
Timeframe	January – March 2025 (M28-M30)
Targets	The aim of this test case is to enable Charging Point Operators (CPO) to respond to grid congestion requests by using their electric vehicle fleets for flexibility. By coordinating flexibility through a marketplace, the CPO can bid on flexibility requests triggered by the DSO during times of congestion, helping to maintain grid stability.
Actors	• EMOT (CPO) as both flexibility provider and aggregator, owning and operating the EV fleet • ASM (DSO) as the authority signalling congestion and requesting flexibility • COMS as technology provider
STREAM products	sMART, sGRID
Assets & systems	• EV charging stations • Smart meters
Description of the experiment	This experiment allows the CPO to act as one of the marketplace participants and bid on flexibility requests made by the DSO when grid congestion is expected. CPO, which has control over its fleet of EVs and charging stations, responds to these flexibility requests by adjusting the charging behaviour of EVs via the marketplace to avoid congestion. **Pre-condition/triggering event:** the marketplace is developed and ready for submitting the flexibility requests and bids **Steps:** 1. sGRID informs DSO of upcoming congestion event 2. The DSO sends a flexibility request through sMART marketplace. 3. Flexibility bidding: CPOs receive the flexibility request, assess their available flexibility based on EV charging schedules and submit bids specifying the amount and timing of flexibility they can provide 4. Bid selection and activation: The DSO evaluates the bids and accepts the most suitable offers. The accepted CPO adjusts its charging plans or curtails demand according to the agreed flexibility scheme. 5. Monitoring: The provision of flexibility is monitored to ensure compliance and to assess the impact on grid congestion. **Post-condition:** Grid congestion is alleviated as the DSO successfully mobilizes flexibility through the CPOs' response on the marketplace.
Datasets required for the experiment	• Energy production by renewable energy sources provided by ASM smart meters • Energy consumption by energy loads in the electric grid provided by ASM smart meters

	• Congestion forecast data provided by sGRID • Electric vehicle state of charge data • Charging station energy data
Field data to be gathered	• Energy flexibility provision data
Related KPIs	KPI IT.02

Results of the Experiment

The experiment successfully demonstrated the mobilisation of EV charging flexibility through the sMART marketplace during the final demonstration phase. The test case validated the interaction between the DSO and the CPO for congestion management purposes and confirmed the capability of the platform to support flexibility requests, bid submission, flexibility activation and operational monitoring. During the demonstration, forecasted congestion events identified by sGRID triggered the generation of flexibility requests by the DSO through the sMART marketplace. The flexibility requests specified the required flexibility volume and the activation time window associated with the expected congestion period. The CPO received the flexibility requests through the marketplace interface and evaluated the available flexibility potential based on the charging schedules and operational status of the connected EV charging stations. Based on this assessment, the CPO submitted flexibility bids indicating the amount of load reduction or charging rescheduling that could be provided during the requested period. The DSO evaluated the submitted bids and selected the flexibility offer considered most suitable for mitigating the forecasted congestion event. Following bid acceptance, the CPO adjusted the charging behaviour of the EV charging stations according to the agreed flexibility activation scheme. This included temporary charging power reduction and charging schedule shifting during the congestion window.

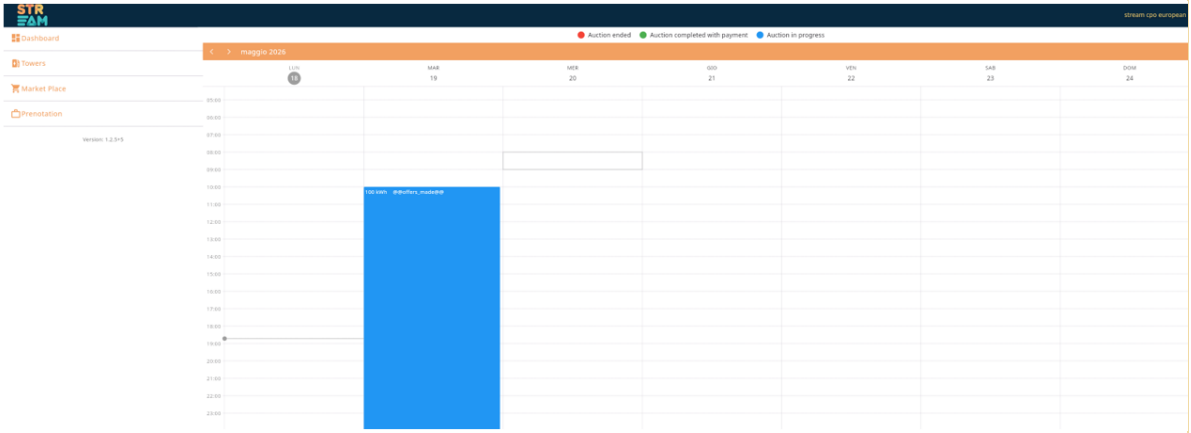


Figure 189: DSO energy flexibility request in marketplace

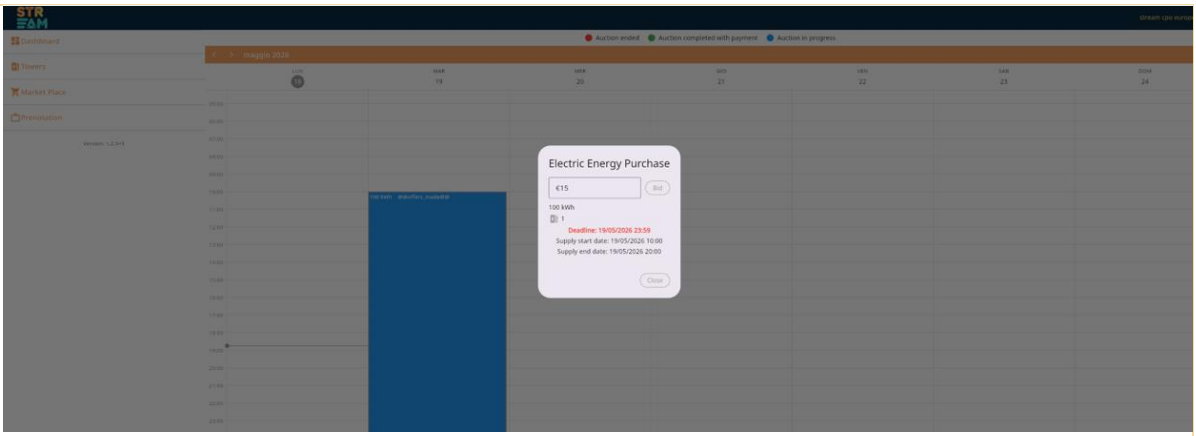


Figure 190: CPO energy flexibility offer in the marketplace

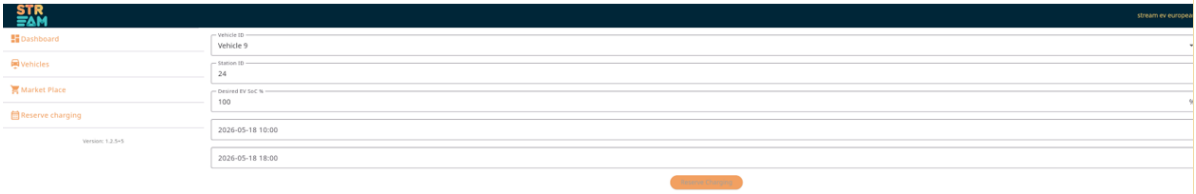


Figure 191: Charging schedule registration

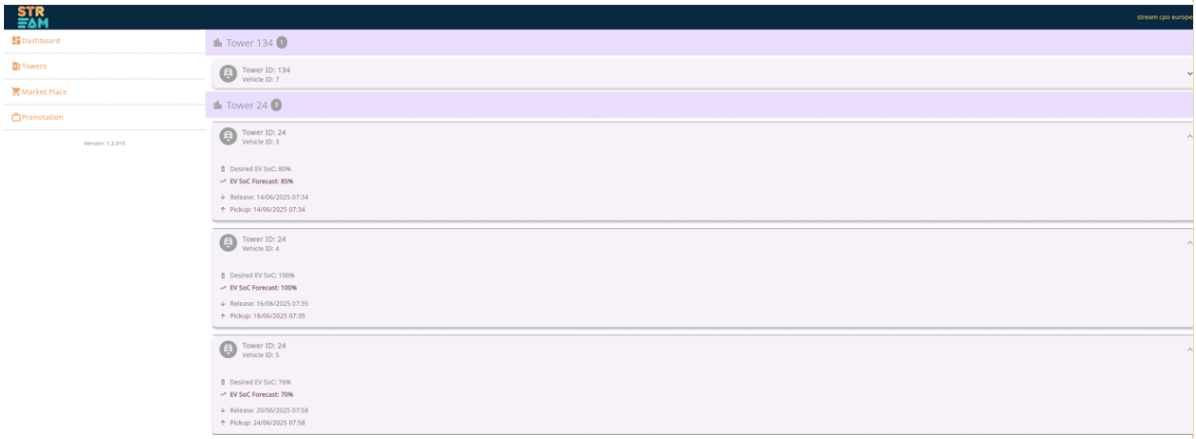


Figure 192: Charging schedule overview



Figure 193: Charging session real-time monitoring

The screenshots collected during the demonstration confirm the successful execution of the flexibility mobilisation workflow and demonstrate the following platform functionalities:

- visualisation of flexibility requests issued by the DSO;
- submission and management of flexibility bids by the CPO;
- activation of flexibility services through charging schedule registration;
- real-time monitoring of flexibility provision.

The experiment confirmed that EV charging infrastructure can provide controllable demand-side flexibility services capable of supporting local congestion management objectives. The monitored operational data showed that charging demand could be shifted away from congestion periods while maintaining charging service continuity. The demonstration also validated the interoperability between sGRID and sMART within the STREAM framework. sGRID provided the congestion forecast information required to initiate the flexibility process, while sMART enabled the market-based interaction between the DSO and the flexibility provider. The experiment therefore demonstrated the feasibility of using EV charging stations as active flexibility resources within a local flexibility marketplace and confirmed the capability of the STREAM ecosystem to support congestion-oriented flexibility mobilisation workflows. The experiment contributed to KPI_02 (Response to flexibility request) by demonstrating the successful activation of flexibility services following a DSO flexibility request. The test case confirmed that flexibility requests issued through the marketplace can be answered by the CPO and operationally implemented through EV charging schedule adaptation.

Qualitative analysis of the results

The results confirm that EV charging infrastructure can act as an effective flexibility resource for local congestion management when coordinated through a marketplace-based mechanism. The experiment demonstrated the complete operational workflow linking congestion forecasting, flexibility requests, bid submission, flexibility activation and operational monitoring. The test case also highlighted the importance of interoperability between forecasting tools and marketplace services within the STREAM architecture. The integration between sGRID and sMART enabled congestion events identified at grid level to be translated into operational flexibility actions performed by the CPO. From the perspective of the flexibility provider, the experiment confirmed that EV charging schedules can be adapted in response to grid needs without fully interrupting charging services. This demonstrates the suitability of EV charging infrastructure for demand-side flexibility applications, particularly in scenarios where charging sessions can tolerate moderate temporal adjustments. The experiment additionally confirmed the role of the marketplace as a coordination mechanism between DSOs and flexibility providers. The ability to issue requests, submit bids and activate flexibility through a common platform supports transparent and scalable flexibility management processes. Overall, the test case demonstrated the practical feasibility of congestion-oriented flexibility mobilisation using EV charging stations and validated the STREAM workflow for market-based flexibility activation within the Italian pilot.

Experiment number	**IT-UC.04.01**
Name of the experiment	Digital twin-based estimation of water pump baseline operation and flexibility potential
Timeframe	M43-M45
Targets	The goal of this experiment is to develop and validate a digital twin of the water pumping station in the Italian pilot and to use it for estimating the expected baseline operation of the pumps. The baseline represents how the

	pumps are expected to operate in the next-day horizon if no optimisation or flexibility action is applied. The experiment also estimates the technical flexibility potential of the pumping station by analysing how long pump operation could be interrupted at selected reservoir level thresholds while maintaining the reservoir level above the minimum operational limit. The output of the experiment is the digital twin model, which calculates the baseline pump operation and provides the basis for comparison with the optimised schedule generated later in sENC.
Actors	• COMS as technology provider
STREAM products	sFLEX, sENC, sDATA
Assets & systems	• Water pumping station • Water reservoir
Description of the experiment	This experiment focuses on modelling the water pumping station as a digital twin within sFLEX. The digital twin represents the physical and operational behaviour of the reservoir and pumps and is used to calculate the expected baseline pump operation for the next-day horizon. The reservoir level is the main state variable in the model. Water consumption decreases the reservoir volume, while pump activation increases it. The pumps are not continuously adjustable; each pump operates in binary mode, meaning tThe baseline pump operation is calculated according to the normal water-level-based operating logic of the pumping station. As the reservoir level decreases, the number of active pumps increases. The digital twin simulates the reservoir level at 15-minute resolution and determines the number of active pumps tIn addition to calculating the baseline, the experiment also assesses the technical flexibility potential at selected reservoir level thresholds. For each threshold scenario, the pumps that would normally be active are assumed to be temporarily switched off, and the model estimates how long this interruption could be sustained before the reservoir reaches the minimum operational level. This flexibility estimation is not an optimisation result; it is a technical assessment of the physical interruption potential of the pumping station. **Pre-condition/triggering event:** Historical and operational data from the water pumping station are available, including pump status, reservoir level and water consumption or derived outflow. Static technical parameters of the pumping station are also available, including reservoir surface area, minimum and maximum reservoir levels, number of pumps, pump nominal power and pump flow rate. The pumping station operates within defined reservoir level constraints, and maintaining water supply has priority over any flexibility action. **Steps:** 1. Collect historical operational data for the water pumping station, including pump status, reservoir level and water consumption data. 2. Collect static technical parameters of the pumping station, including reservoir surface area, minimum and maximum reservoir levels, number of pumps, pump nominal power and pump flow rate.

	3. Implement the water-level-based pump operating logic in the sFLEX digital twin. 4. Simulate the evolution of reservoir volume and reservoir level over the next-day horizon. 5. At each 15-minute interval, determine the number of active pumps based on the simulated reservoir level and the normal pump operating logic. 6. Translate the resulting pump activation profile into a baseline electricity consumption profile of the pumping station. 7. Estimate the threshold-based flexibility potential by calculating how long pump operation could be interrupted at selected reservoir level thresholds before reaching the minimum reservoir level. 8. Provide the digital twin baseline and technical flexibility information as input for comparison with the optimised pump schedule generated in sENC. **Post-condition:** The sFLEX digital twin of the water pumping station is developed and used to calculate the expected baseline pump operation. The output includes the expected number of active pumps at each 15-minute interval, the expected reservoir level evolution and the baseline electricity consumption profile. In addition, the digital twin provides a threshold-based estimate of the technical interruption potential of the pumping station. This baseline serves as the reference case for the sENC optimisation test case, where the optimised pump schedule is compared against the expected operation without optimisation.
Datasets required for the experiment	• Pump operation status • Reservoir water level • Water consumption / derived outflow • Pump technical parameters • Reservoir technical parameters • Historical operational data
Field data to be gathered	• Baseline pump operation profile • Reservoir level profile • Baseline electricity consumption profile • Estimated water demand / outflow • Threshold-based interruption potential • Shiftable energy under conservative and average consumption assumptions
Related KPIs	KPI IT.04
Results of the Experiment	
The experiment resulted in the development and application of a digital twin of the water pumping station in sFLEX. The digital twin represents the reservoir and pumps as a discrete-time physical model with a 15-minute simulation step. The main purpose of the model is to calculate the expected baseline operation of the pumps for the next-day horizon, assuming that no optimisation or flexibility action is applied. This baseline represents the expected pump operation under the current water-level-based operating logic of the pumping station.	

The technical parameters used are summarised below.

Table 45: Technical parameters of the pumping station

Parameter	Value	Comment
Number of pumps	10	Pumps operate in binary On/Off mdoe
Nominal power per pump	$30\ kW$	
Maximum pumping power	$300\ kW$	
Pump flow rate	$13\frac{l}{s}$	Water inflow per pump
Time resolution	$15\ min$	Aligned with granularity of other tools
Reservoir surface area	$800\ m^2$	
Minimum reservoir level	$2.0\ m$	
Maximum reservoir level	$3.4\ m$	
Operational water range	$1.4\ m$	$3.4\ m - 2\ m$
Usable operational storage volume	$1120\ m^3$	$800\ m^2 * 1.4\ m$

The day-ahead water demand used in the simulation is obtained from historical water consumption data. Since water consumption follows a repetitive daily pattern within the same month, the current implementation derives the expected day-ahead demand profile from the average historical 15-minute water consumption profile for the corresponding month. In practice, historical water consumption values are grouped by time of day and averaged, resulting in a representative 24-hour demand profile with 15-minute resolution. This profile is then used as the expected water outflow $D(t)$ in the next-day simulation.

The day-ahead demand profile is integrated into the reservoir propagation model as the outflow from the reservoir. At each 15-minute time step, the model subtracts the expected water demand from the current reservoir volume and adds the water inflow produced by the active pumps. The reservoir volume is updated as follows:

$$V(t+1) = V(t) - D(t) + P(t)$$

where $V(t)$ is the reservoir volume at time step t, $D(t)$ is the water demand or outflow during the 15-minute interval, and $P(t)$ is the inflow of pumped water volume during the same interval. The reservoir level is calculated from the reservoir volume using the reservoir surface area:

$$h(t) = V(t)/A$$

where $h(t)$ is the current height of the water and A is the surface area of reservoir; in our case $800\ m^2$. The pump inflow for the next time step is inferred from the current reservoir level. This means that at each time step, the digital twin first evaluates the current reservoir level $h(t)$ and then determines how many pumps should be active according to the current water-level-based operating logic. The resulting number of active pumps defines the pumped inflow $P(t)$ for that interval.

The operating logic implemented in the digital twin is shown below.

Table 46: Operating logic of the digital twin

Water level range	Number of active pumps

3.1 – 3.4 m	5
2.9 – 3.1 m	6
2.7 – 2.9 m	7
2.5 – 2.7 m	8
2.0 – 2.5 m	9
< 2.0 m	10

The pumped volume is calculated from the number of active pumps

$$P(t) = n(t) * 11.7\ m^3$$

where $n(t)$ is the number of active pumps at the timestep t. The value $11.7m^3$ represents the approximate volume pumped by one pump during 15-minute interval and is derived from the pump flow rate:

$$13\frac{l}{s} * 900\ s\frac{1}{1000} = 11.7m^3$$

The sequence of calculation in each 15-minute interval is therefore:

1. The current reservoir volume $V(t)$ is converted into the current reservoir level h(t).
2. The number of active pumps n(t) is selected based on the reservoir level threshold.
3. The pump inflow $P(t)$ is calculated from the number of active pumps.
4. The expected water demand $D(t)$ is taken from the day-ahead demand profile.
5. The reservoir volume for the next time step $V(t+1)$ is calculated.
6. The resulting reservoir level is propagated to the next interval.

This approach ensures that the baseline pump operation is not fixed in advance, but dynamically derived from the simulated evolution of the reservoir level. If the reservoir level decreases, more pumps are activated in the next simulation steps. If the reservoir level increases, fewer pumps are required. The pumps are binary assets and cannot be partially adjusted. Each pump can only be switched on or off. Since each pump has a nominal power of 30 kW, the electricity consumption for one per 15-minute interval is:

$$30\ kW * 0.25\ h = 7.5\ kWh.$$

and the baseline electricity consumption for the entire pumping station is calculated as:

$$W(t) = n(t) * 7.5\ kWh$$

The resulting propagation model includes the expected number of active pumps, the expected reservoir level and the water demand for each 15-minute interval of the next-day horizon as show in Figure below. This later serves as the main input and the baseline for comparing expected normal schedule of water pump operation with the optimised schedule.

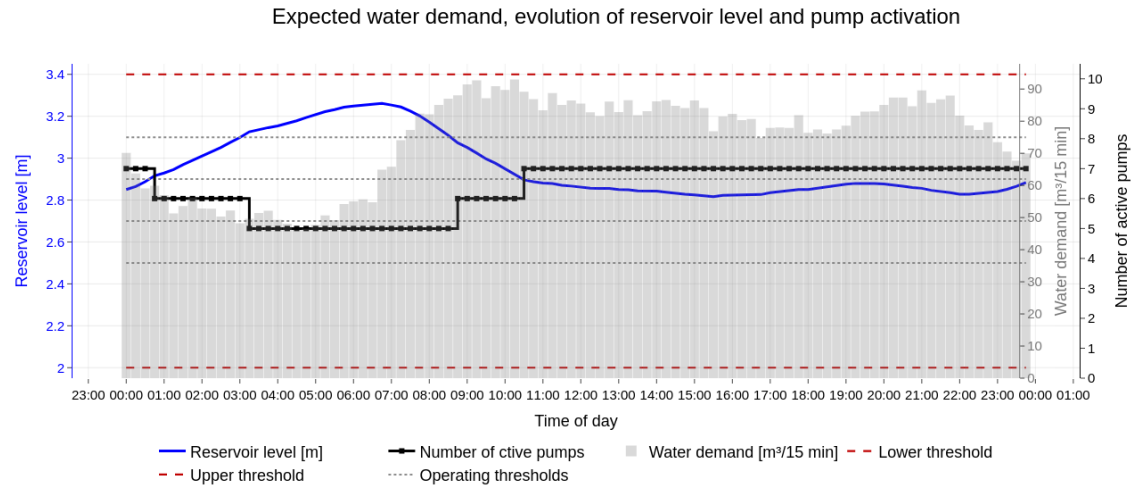


Figure 194: Expected water demand, evolution of reservoir level and pump activation

In addition to calculating the baseline operation, the digital twin was used to estimate the technical interruption potential of the pumping station at selected reservoir level thresholds. This was done to determine how long the pumps (normally active at each threshold) could theoretically be switched off before the reservoir reaches the minimum operational level of 2.0 m.

For each threshold scenario, the storage margin above the minimum allowable water level was calculated as:

$$Storage\ margin\ [m^3] = (scenario\ lower\ water\ level - minimum\ water\ level) * A$$

For example, for the scenario with a lower level of 3.1 m:

$$(3.1\ m - 2.0\ m) * 800\ m^2 = 880\ m^3$$

The available power that could be interrupted was then calculated as:

$$Power\ flexibility\ [kW] = number\ of\ pumps\ normally\ active * 30\ kW$$

For example, at 3.1 m, five pumps are normally active:

$$5 * 30\ kW = 150\ kW$$

Two water consumption assumption scenarios were used in the calculation. The first was a conservative worst-case historical depletion scenario. Based on the historical data, the worst observed average 15-minute water depletion was approximately $0.15\frac{m^3}{s}$. Converted to one 15-minute interval, this equals:

$$0.15\frac{m^3}{s} * 900\ s = 135\ m^3$$

Given the reservoir surface area of $800\ m^2$ this corresponds to a reservoir level decrease of:

$$\frac{135\ m^3}{800\ m^2} = 0.16875\ m$$

Therefore, under the conservative stress-test condition, the reservoir level decreases by approximately 17 cm per 15-minute interval. However, such high water demand represents an outlier rather than a regular operating condition. In the recorded data, this level of depletion was observed only a few times and did not persist for more than a single 15-minute interval. It was therefore not used as a normal operating assumption, but rather as a very conservative estimate for testing the lower bound of the technical interruption potential.

For a more realistic estimate, a second scenario considered the average 15-minute water consumption in the most recent month. During the test case evaluation, the first twelve days of available data in May of 2026, shown in Figure X, were used to observe the relationship between water level, inflow and estimated water consumption.

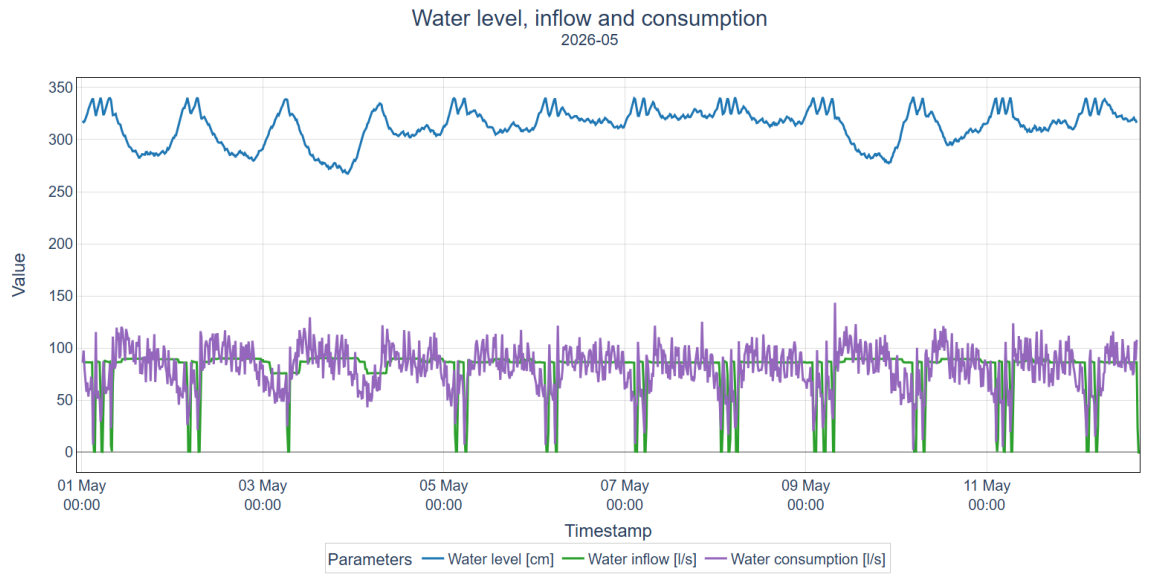


Figure 195: Water level, inflow and consumption

Based on this period, the average 15-minute water consumption was approximately 82 m^3. This value was used as a representative consumption assumption for normal operating conditions.

From there the number of available full 15-minute interruption intervals was calculated as:

$$N_{intervals} = floor\left(\frac{storage\ margin}{average\ water\ consumption}\right)$$

Intervals were rounded down to consider only full intervals and therefore keep the estimate conservative. Finally, the shiftable energy was calculated by multiplying the available power flexibility by the interruption duration:

$$W_{shiftable}\ [kWh] = power\ flexibility\ [kW] * N_{intervals} * 0.25\ h$$

The scenario-based results are shown in the table below.

Table 47: Scenario-based results

Scenario	Initial water level	Pumps normally active	Power flexibility	Storage margin above 2.0 m	Duration – worst case	Shiftable energy – worst case	Duration – average consumption	Shiftable energy – average consumption
1	3.1 m	5	150 kW	880 m³	90 min	225 kWh	150 min	375 kWh
2	2.9 m	6	180 kW	720 m³	75 min	225 kWh	120 min	360 kWh
3	2.7 m	7	210 kW	560 m³	60 min	210 kWh	90 min	315 kWh
4	2.5 m	9	270 kW	400 m³	30 min	135 kWh	60 min	270 kWh

The results show that the technical interruption potential is strongly dependent on the reservoir level. At higher reservoir levels, the available storage margin is larger, which allows pump operation to be interrupted for a longer period. On the other hand at lower reservoir levels, more pumps are normally active and the available power flexibility is higher, however the interruption duration is shorter because the reservoir is closer to the minimum allowable level.

For example, at 3.1 m, five pumps are normally active, corresponding to 150 kW of interruptible pumping power. Under the conservative worst-case depletion scenario, this interruption can be sustained for 90 minutes, resulting in 225 kWh of shiftable energy. Under the average

consumption scenario, the same interruption can be sustained for 150 minutes, resulting in 375 kWh of shiftable energy.

At 2.5 m, nine pumps are normally active, corresponding to 270 kW of interruptible pumping power. However, because the reservoir is much closer to the minimum level, the available interruption duration is significantly shorter. Under the worst-case scenario, the interruption can be sustained for only 30 minutes, resulting in 135 kWh of shiftable energy. Under average consumption conditions, the interruption duration increases to 60 minutes, corresponding to 270 kWh of shiftable energy.

This confirms that the flexibility potential of the pumping station cannot be expressed as a single fixed power value. Although the maximum installed pumping power is 300 kW, the technically available flexibility depends on the reservoir level, the number of pumps active under normal operation, water demand and the minimum water level constraint. The digital twin therefore provides a state-dependent representation of the pumping station, which is required for calculating the baseline operation and for later comparison with the optimised schedule generated in sENC.

Qualitative analysis of the results

The results confirm that the developed digital twin provides a technically grounded baseline for the water pumping station. This baseline is not an externally imposed schedule, but is calculated from the physical and operational behaviour of the water system and represents the expected day-ahead operation of water pumps left to their current operational logic, assuming no action is taken regarding flexibility provision or optimisation.

The experiment also confirms that, although the water pumping station is not a flexible device in the conventional sense, it can still indirectly represent a relevant flexibility asset because its electricity consumption can be shifted in time through the use of water reservoir storage. The reservoir acts as a buffer between water consumption and pump electricity consumption, allowing the timing of pump operation to be partly decoupled from the timing of water demand.

Compared with residential HVAC flexibility, which is also considered in the pilot, water pump flexibility has greater capability, is more deterministic, and is easier to verify. Furthermore, while HVAC flexibility depends on user behaviour, comfort constraints and voluntary response, water pump flexibility only needs to respect operational constraints regarding the water level.

The binary nature of the particular pumps in the pilot is important for implementation. As the pumps cannot be partially adjusted, flexibility is always provided in discrete 30 kW steps. This must be considered in the related sENC optimisation test case, because the optimised schedule can only switch pumps on or off and cannot continuously modulate their power.

The threshold-based results also show that available flexibility is state-dependent. A fixed flexibility value would be misleading because the available power and duration change according to the reservoir level. On one hand, a lower reservoir level may result in more active pumps and therefore higher instantaneous power flexibility, but shorter duration. On the other hand, a higher reservoir level may allow a longer interruption, but fewer pumps are normally active.

From the perspective of the overall STREAM workflow, this test case provides the baseline reference needed for the sENC optimisation test case. sFLEX calculates how the pumps would operate without optimisation. sENC then uses this baseline and compares it with an optimised pump schedule according to the selected objective, i.e. either price-based optimisation, self-consumption maximisation or congestion mitigation.

Experiment number	**IT-UC.05.01**

Name of the experiment	Estimation of HVAC energy consumption and flexibility potential based on temperature correlation
Timeframe	March – April 2026 (M42-M43)
Targets	The goal of this experiment is to estimate daily energy consumption for HVAC purposes in residential apartments by analyzing the correlation between temperature and energy consumption, and to determine the potential for flexibility by determining how much of HVAC-related energy consumption could be shifted or reduced based on temperature thresholds.
Actors	• COMS as technology provider
STREAM products	sFLEX, sENC, sDATA
Assets & systems	• Smart meters
Description of the experiment	This experiment is designed to estimate how much energy is consumed for HVAC purposes in residential apartments by analyzing the energy consumption data and its correlation with daily average temperatures. The assumption is that if the temperature is within a "comfortable range", no HVAC systems are required and any consumption above or below this range can be attributed to heating or cooling. **Pre-condition/triggering event:** The daily energy consumption data from smart meters in residential apartments is anonymized and available for analysis. Historical temperature data is also available for the area in which the apartments are located. **Steps:** 1. Collect daily energy consumption data from smart meters installed in residential apartments over a period of time in sDATA. Collect the corresponding temperature data for the same period from a reliable weather data source. 2. Define the base temperature range where no HVAC is normally required (e.g. between 18°C and 23°C). This range represents "comfortable" conditions where it is assumed that energy consumption is not associated with the use of HVAC. 3. For each apartment, estimate how much of the total daily energy consumption is used for HVAC based on the temperature-based correlation. 4. Calculate potential flexibility based on the assumption that a portion of the HVAC load could be adjusted without compromising comfort (e.g., pre-heating or pre-cooling apartments, or adjusting temperature set points during peak hours). 5. Aggregate the results of HVAC energy consumption and flexibility potential across all apartments and share them with sENC. **Post-condition:** The potential flexibility of HVAC-related residential consumption is estimated at apartment level and aggregated at community level. The output includes apartment-specific comfort ranges, baseline consumption values, estimated heating- and cooling-related consumption, apartment HVAC profile classification, and an aggregated temperature-

	dependent flexibility curve. This aggregated curve represents the output of sFLEX and provides an input to sENC for further aggregator-level flexibility management.
Datasets required for the experiment	• Energy consumption • Historical outdoor temperature data
Field data to be gathered	• Flexibility potential
Related KPIs	KPI IT.03

Results of the Experiment

The experiment used anonymised electricity consumption data from smart meters installed in residential apartments, along with corresponding historical outdoor temperature data for the same geographical area and period. The aim was to estimate the proportion of electricity consumption attributable to HVAC operation and to assess the associated flexibility potential that could be aggregated and utilised by sENC.

The initial analysis confirmed that a fixed comfort temperature range cannot be applied uniformly to all apartments. The temperature range in which electricity consumption remains low and stable varies between apartments, as expected due to differences in user behaviour, thermal comfort preferences, apartment characteristics, installed HVAC equipment, insulation quality and occupancy patterns. Therefore, the detailed analysis used apartment-specific comfort ranges, with baseline consumption determined from the temperature interval or group of intervals with the lowest and most stable electricity consumption.

For each apartment, the average hourly consumption was calculated in 2°C outdoor temperature intervals. The baseline consumption was determined from the apartment-specific temperature interval or group of intervals where consumption remained stable and did not show a clear temperature-sensitive increase. Consumption above this baseline during colder or warmer intervals was interpreted as estimated HVAC-related consumption. Colder intervals with increased consumption were interpreted as heating-related, while warmer intervals with increased consumption were interpreted as cooling-related. If no meaningful deviation from the baseline was observed, the apartment was classified as temperature-insensitive, indicating that no detectable HVAC-related flexibility could be identified from the available smart meter data.

The classification used an interval-based deviation approach. For each apartment, a baseline mean was calculated from the selected stable consumption intervals. A deviation threshold was then defined using the baseline mean, the variability of the baseline and a minimum absolute deviation criterion. Heating or cooling behaviour was identified only when adjacent temperature intervals showed a meaningful positive deviation above the baseline. This approach reduces the risk of falsely assigning HVAC flexibility to apartments with relatively constant electricity consumption profiles.

The automated classification was applied to the full analysed smart meter range from SM50 to SM99, corresponding to 50 smart meters in total. Out of these, 41 meters provided sufficient data quality for the HVAC-related flexibility assessment, while 9 meters were excluded due to missing, incomplete or invalid measurements.

Table 48: Meters automated classification

Category	Number of meters	Description

Total analysed smart meters	50	Full analysed smart meter range from SM50 to SM99
Valid meters	41	Meters with sufficient data quality for HVAC-related classification
Invalid meters	9	Meters excluded from aggregation due to missing, incomplete or unusable data
No detectable HVAC-related behaviour	12	No meaningful temperature-sensitive increase in electricity consumption was detected
Heating-related only	6	Increased consumption was detected only in colder temperature intervals
Cooling-related only	7	Increased consumption was detected only in warmer temperature intervals
Heating- and cooling-related	16	Increased consumption was detected in both colder and warmer temperature intervals

For each valid meter, the method assigned one of the following categories: no detectable HVAC-related behaviour, heating-related behaviour, cooling-related behaviour, or combined heating- and cooling-related behaviour. The results show that 29 out of 41 valid meters exhibited some form of temperature-dependent electricity consumption. This indicates that a significant proportion of the analysed residential portfolio contains detectable HVAC-related consumption patterns. At the same time, 12 valid meters were classified as temperature-insensitive. For these apartments, no meaningful increase in electricity consumption was detected in colder or warmer outdoor temperature intervals. These meters were therefore not treated as relevant contributors to HVAC-related flexibility aggregation.

Four representative smart meters were selected to illustrate the main types of temperature-dependent consumption behaviour observed in the dataset. These profiles show that residential HVAC flexibility varies across apartments and that different apartments may contribute to flexibility under different temperature conditions.

SM67 represents an apartment with no clear HVAC-related consumption profile. The average hourly consumption remains relatively stable across the analysed temperature intervals, with no significant increase during either colder or warmer outdoor conditions. This indicates that, based on the available smart meter data, no relevant HVAC-related flexibility potential can be identified for this apartment.

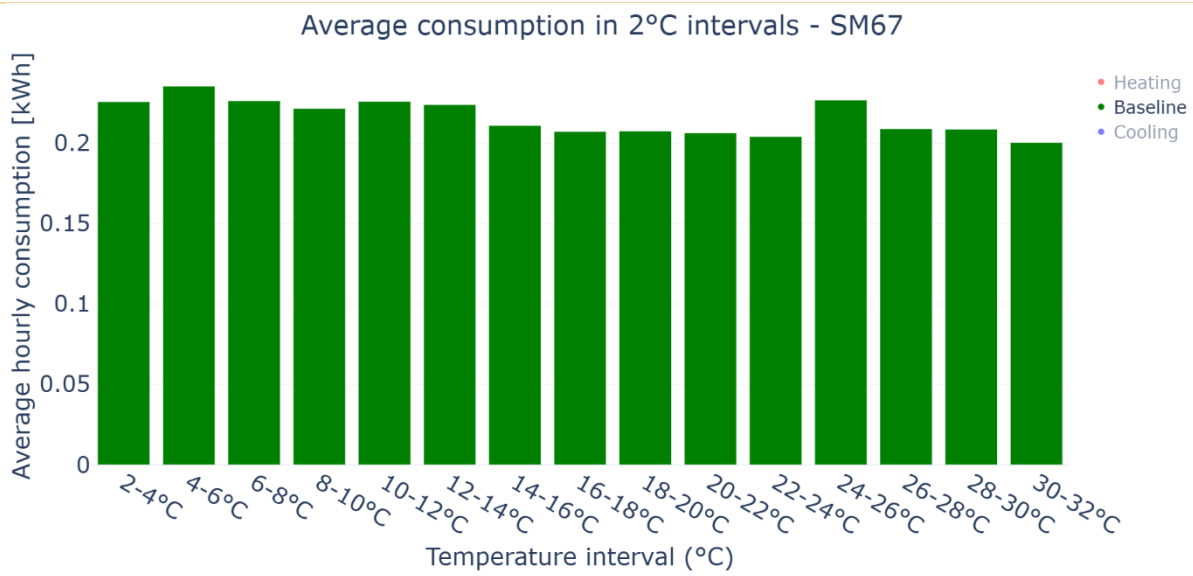


Figure 196: Average consumption in 2º intervals – SM67

SM64 represents a cooling-dominated profile. The average hourly consumption remains relatively stable during lower and moderate temperature intervals, while a clear increase is observed when the outdoor temperature exceeds the apartment-specific comfort range. This pattern indicates cooling-related electricity consumption and suggests that cooling flexibility may be available during high-temperature periods.

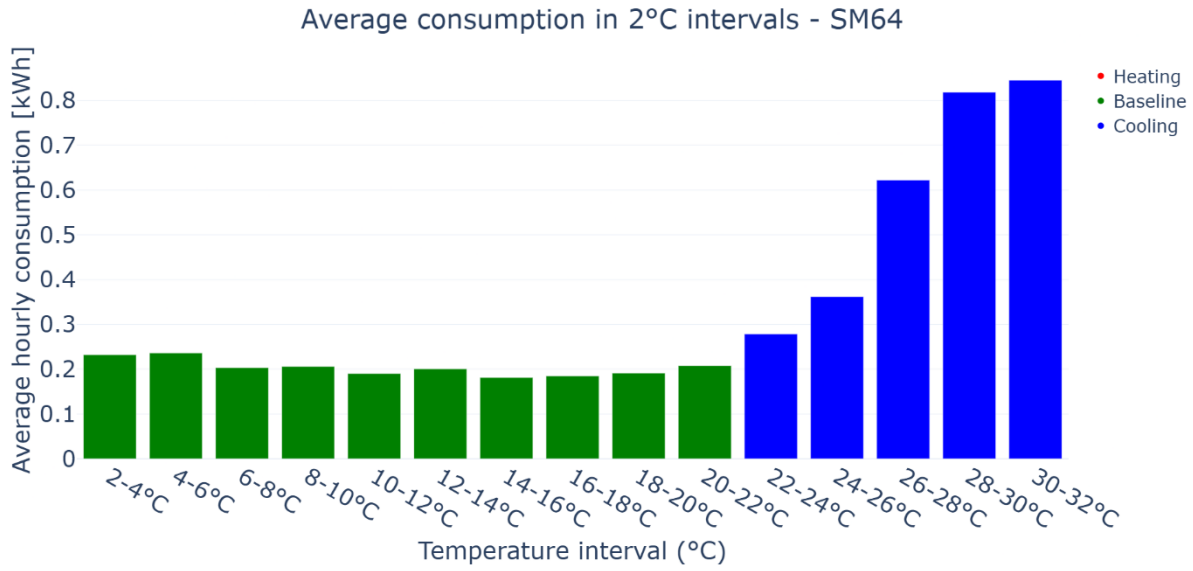


Figure 197: Average consumption in 2ºC intervals - SM64

SM69 represents a heating-dominated profile. The average hourly consumption is highest in the lowest temperature intervals and gradually decreases as the outdoor temperature approaches the comfort range. No relevant increase is observed at higher temperatures, which suggests that the temperature-sensitive part of consumption is mainly related to heating.

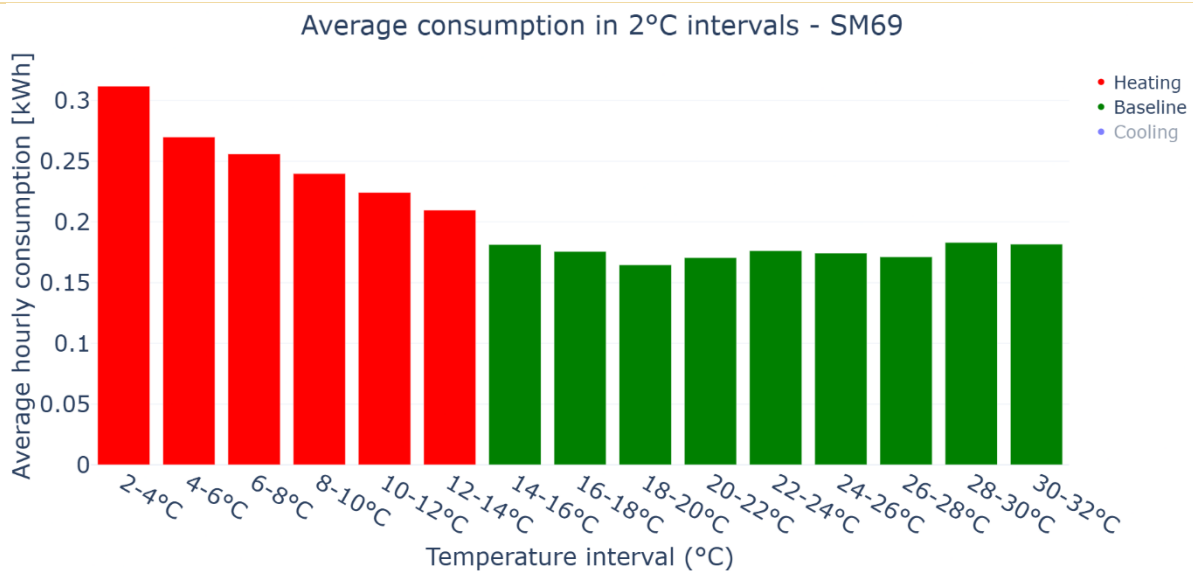


Figure 198: Average consumption in 2ºC intervals - SM69

SM92 represents a combined heating and cooling profile. The average hourly consumption is elevated during colder temperature intervals and also increases significantly during warmer intervals, while the lowest consumption is observed within the comfort range. This is the clearest example of an apartment where both heating and cooling contribute to electricity consumption and where flexibility potential may exist on both sides of the temperature range.

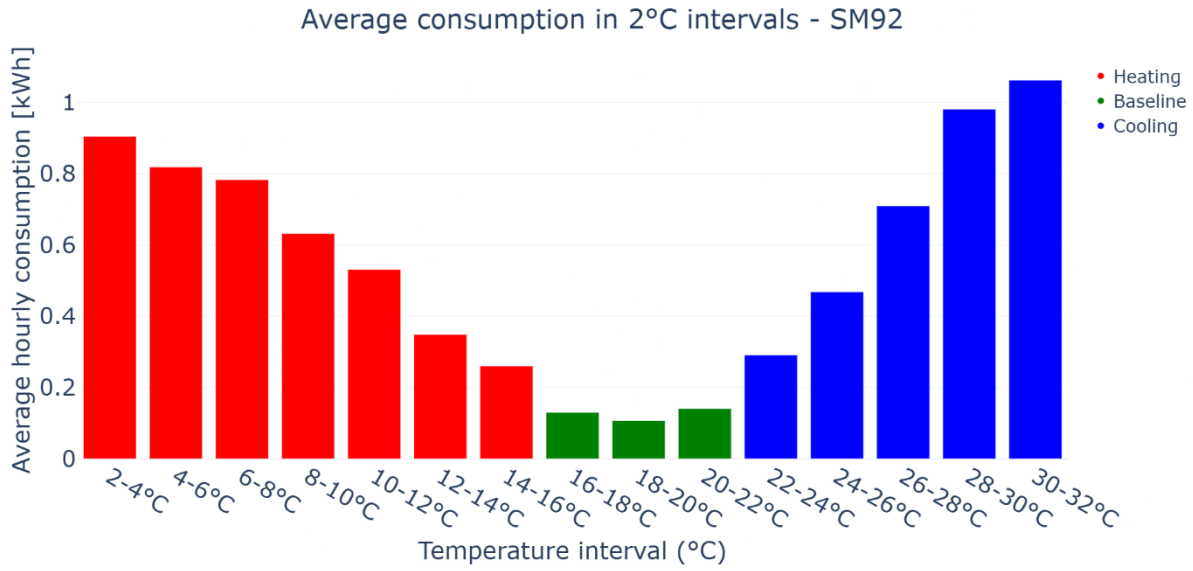


Figure 199: Average consumption in 2ºC intervals - SM92

In addition to the apartment-level analysis, the estimated flexibility potential was aggregated at community level. The aggregation step summed deviations from baseline across all relevant apartments for each 2°C temperature interval. This aggregated temperature-dependent flexibility curve represents the main output of sFLEX for the residential HVAC disaggregation use case. It provides sENC with an upper-bound estimate of the residential HVAC flexibility that may be available under specific temperature conditions. This format is suitable for aggregator-level operation because sENC requires aggregated flexibility information rather than individual apartment-level consumption profiles. To avoid overestimating the flexibility potential, the aggregation included an additional physical plausibility constraint. Heating flexibility was counted only in temperature intervals up to 16°C, while cooling flexibility was counted only in temperature

intervals from 20°C upward. This ensured that heating was not aggregated in unrealistically warm outdoor conditions and that cooling was not aggregated in temperature intervals where cooling operation would be unlikely. In the aggregated results, heating-related flexibility is represented separately from cooling-related flexibility.

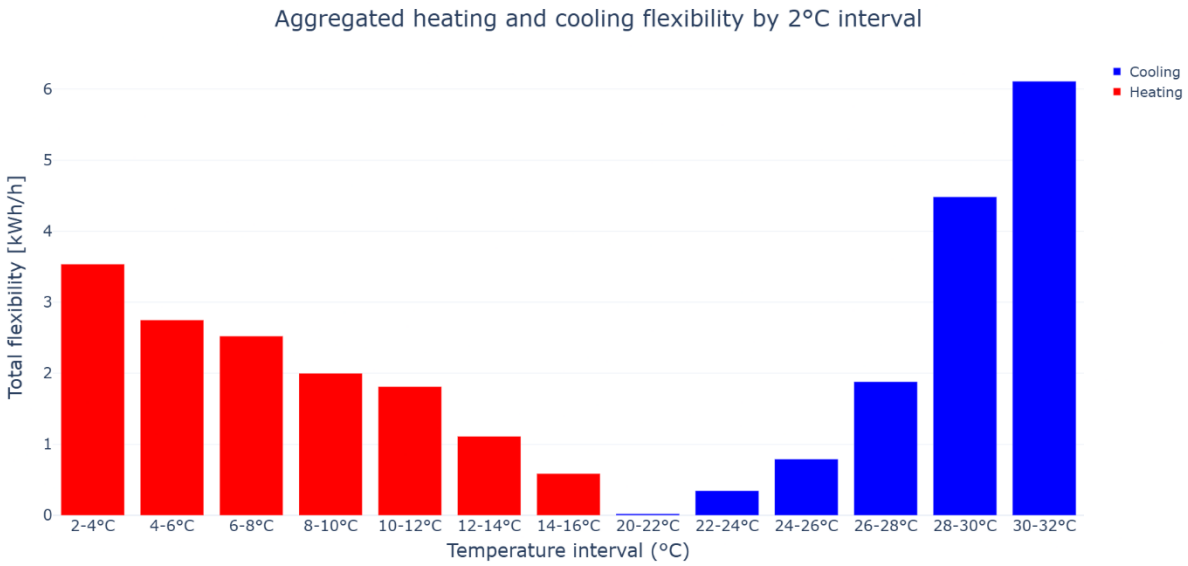


Figure 200: Aggregated heating and cooling flexibility by 2ºC interval

The values are not yet scaled by an end-user response factor. Therefore, they represent the gross detectable HVAC-related flexibility potential, not the realistically activatable flexibility that would be available after considering user participation, acceptance of SMS incentives, comfort limitations or actual response.

The results of the experiment indicate that smart meter data combined with outdoor temperature data can be used to estimate HVAC-related consumption patterns at apartment level and to aggregate the corresponding flexibility potential across a group of residential users. The outputs of this analysis provide an indication on which apartments may offer heating-related, cooling-related or combined HVAC flexibility and can therefore support sENC in preparing aggregated flexibility estimates for different outdoor temperature conditions.

Qualitative analysis of the results

The results confirm that residential HVAC-related consumption varies significantly between apartments. The analysed meters revealed several distinct profiles: some apartments exhibited no detectable temperature-sensitive behaviour, while others displayed heating-related, cooling-related, or combined heating and cooling patterns. This demonstrates that residential HVAC flexibility cannot be reliably estimated using a single generic profile or a fixed comfort temperature range for all apartments.

The use of apartment-specific baseline ranges was therefore essential. The temperature interval in which consumption remains stable varies between apartments, most likely due to variations in user preferences, thermal comfort expectations, building characteristics, apartment orientation, insulation quality, occupancy behaviour, the type of heating or cooling equipment used, etc. By identifying the baseline separately for each apartment, the method avoids attributing flexibility potential to meters where no clear HVAC-related signal is present.

The test case also highlights the importance of apartment-level metering. If the entire building was monitored only through a single common meter, individual apartment-level differences would be obscured within the total building load. This would make it much more difficult to distinguish HVAC-related consumption from general household consumption, occupancy effects,

and appliance use. Apartment-level monitoring therefore provides a crucial basis for identifying which end users are relevant candidates for HVAC flexibility aggregation.

At portfolio level, the aggregation results provide a system-level estimate of available heating- and cooling-related flexibility across the analysed meters. The aggregation method sums the positive deviation from each apartment's baseline consumption in relevant temperature intervals, while applying physical plausibility constraints: heating flexibility is counted only in colder intervals, and cooling flexibility only in warmer intervals. This reduces the risk of overestimating flexibility in temperature ranges where HVAC operation is unlikely.

It is important to note that the estimated flexibility potential of individual apartments remains relatively limited. This is expected, as a single apartment typically represents a small controllable or influenceable load. The practical value of this flexibility therefore depends on aggregation across a sufficiently large number of end users. From the perspective of sENC, this confirms the importance of the aggregator role: only a sufficiently large and well-characterised portfolio can provide a flexibility volume that is meaningful for local flexibility market participation.

From the STREAM integration perspective, the test case confirms the role of sFLEX as a flexibility estimation layer between raw data collection and aggregator-level optimisation. The tool does not activate flexibility directly and does not generate market bids. Instead, it converts historical smart meter and temperature data into a structured flexibility representation that can be used by sENC. This is particularly important for residential HVAC loads, where direct control is not available and user response is voluntary. The aggregated flexibility curve therefore provides sENC with a realistic operational envelope, while still recognising that actual activation depends on user participation and comfort constraints.

Experiment number	**IT-UC.06.01**
Name of the experiment	Optimisation of available flexibility based on selected objective function
Timeframe	April — June 2026(M43-M45)
Targets	The aim of this experiment is to demonstrate how sENC, acting as an aggregator-level optimisation tool, utilises the flexibility information estimated by sFLEX and grid forecasts provided by sGRID to optimise the operation of flexible assets. The experiment focuses primarily on the optimisation of the water pumping station, which represents the most controllable and verifiable flexible asset in the Italian pilot. The objective is to generate a day-ahead pump schedule that respects the operational constraints of the water system while addressing one selected optimisation objective function. Three optimisations are considered: • minimisation of electricity cost based on day-ahead market prices; • maximisation of local renewable energy self-consumption; • mitigation of forecasted transformer congestion.
Actors	• ASM as DSO and water operator • COMS as technology provider
STREAM products	sENC, sFLEX, sGRID, sMART
Assets & systems	• Water pumping station

	• Residential HVAC flexibility portfolio • Local PV generation • MV/LV transformers • Electricity market price data
Description of the experiment	This experiment focuses on the use of sENC as an aggregator-level optimisation tool. While sFLEX estimates the available flexibility potential and provides the water pumping station digital twin, sENC uses this information to determine how the available flexibility should be allocated according to a selected operational objective. The main controllable asset in this experiment is the water pumping station. The pumping station is suitable for optimisation because its operation can be shifted in time by using the water reservoir as storage, while still maintaining the reservoir level within defined operational limits. The baseline operation of the pumps is provided by the sFLEX digital twin and represents how the pumps would operate under the default water-level-based control logic without optimisation. The optimisation is performed on a day-ahead horizon with 15-minute resolution. At each time interval, sENC decides how many pumps should be active. The resulting schedule is then compared with the baseline operation to determine when electricity consumption has been shifted, reduced, or increased. Residential HVAC flexibility can also be considered by sENC as an aggregated flexibility envelope. However, unlike water pumps, residential HVAC flexibility is not directly controllable. It depends on voluntary user response to SMS notifications or incentives and is therefore treated as less deterministic. For this reason, the water pumping station is prioritised in the optimisation, while residential flexibility can be used as an additional support resource where relevant. **Pre-condition/triggering event:** The sFLEX digital twin of the water pumping station is available and has generated the baseline day-ahead pump operation profile. Day-ahead electricity market prices are available from ENTSO-E. Transformer loading forecasts and local PV generation forecasts are available from sGRID. The current reservoir level is available from operational monitoring and is used as the initial condition for the optimisation. **Steps:** 1. Collect the inputs required by sENC, including baseline pump operation by sFLEX, water demand, pump parameters and initial reservoir level. 2. Execute the selected optimisation mode to adjust pump operation against the selected objective. 3. Generate the adjusted day-ahead pump schedule while respecting reservoir limits, water demand, maximum pump capacity and discrete pump operation. 4. Compare the adjusted schedule with the sFLEX baseline schedule to quantify the flexibility effect. **Post-condition:** sENC generates a feasible day-ahead operating schedule for the water pumping station according to the selected objective function. The schedule respects the technical and operational constraints of the water

	system and can be compared against the baseline pump operation calculated by sFLEX.
Datasets required for the experiment	• Baseline pump operation profile from sFLEX • Expected water demand / outflow profile • Pump technical parameters • Reservoir technical parameters • Day-ahead electricity market prices • Local PV generation forecast from sGRID • Transformer loading forecast from sGRID • Flexibility requests from sMART, where applicable
Field data to be gathered	• Optimised pump schedule • Baseline pump schedule • Electricity cost before and after optimisation • Local PV self-consumption before and after optimisation • Transformer loading before and after optimisation
Related KPIs	KPI IT.04

Results of the Experiment

The experiment demonstrates the use of sENC as an aggregator-level optimisation tool for managing flexibility within the Italian pilot. The main input to the optimisation is the baseline pump operation profile calculated by the sFLEX digital twin. This baseline represents the expected operation of the water pumping station under its default water-level-based control logic and provides the reference case against which optimised schedules are compared.

Price-based optimisation

The first optimisation scenario focuses on minimising the electricity cost of water pump operation. In this scenario, sENC uses day-ahead electricity prices as the main optimisation signal. The objective is to shift pump operation away from expensive electricity price intervals, while still respecting the operational constraints of the water reservoir.

The optimisation was performed on 14th May 2026, using Terni electricity price data retrieved from the ENTSO-E platform. The price data was converted from EUR/MWh to EUR/kWh and aligned with the 15-minute optimisation horizon used by the other STREAM tools. The results were obtained using a Python-based optimisation workflow. The technical model of the water pumping station follows the parameters and reservoir propagation logic already presented in the water pump digital twin test case. Therefore, the present test case does not repeat the full digital twin formulation, but focuses on how the baseline model is used by sENC to generate an optimised pump schedule.

The optimisation minimises the total electricity cost of pumping over the day-ahead horizon. The objective function can be expressed as:

$$\min \sum_{t=1}^{T} c_t * n_t * 30\ kW * 0.25\ h$$

where c_t is the electricity price in interval t expressed in €/kWh and n_t is the number of active pumps in that interval. The decision variable of the optimisation is therefore the number of active pumps in each 15-minute interval. The optimiser determines when pumps should be activated to minimise electricity cost, while maintaining the reservoir level between the predefined minimum and maximum operational limits. In addition, the final reservoir level in optimisation mode is constrained to be the same as in baseline mode:

$$V_T^{opt} = V_T^{base}$$

This constraint ensures that the optimisation does not achieve artificial cost savings by ending the day with a lower reservoir level than would be expected under normal baseline operation. This also ensures that the same total amount of water is pumped in both scenarios over the analysed horizon. Therefore, the comparison between baseline and optimised operation is fair: the optimisation does not reduce the water service provided, but only changes the timing of pump operation.

The main constraints applied in the optimisation are therefore:

$$V_{min} \leq V_t^{opt} \leq V_{max}$$
$$0 \leq n_t \leq n_{max}$$
$$V_T^{opt} = V_T^{base}$$

where V_t^{opt} is the reservoir volume in interval t under the optimised schedule, V_{min} and V_{max} are the minimum and maximum allowed reservoir volumes, n_t is the number of active pumps in interval t, n_{max} is the maximum number of available pumps, V_T^{opt} is the final reservoir volume in optimisation mode, and V_T^{base} is the final reservoir volume in baseline mode.

Based on the described optimisation formulation, sENC generates a schedule for the next day and compares it with the baseline schedule calculated using the default water-level-based control logic. The operational behaviour of the optimised and baseline schedules for 15 May is shown in the figure below.

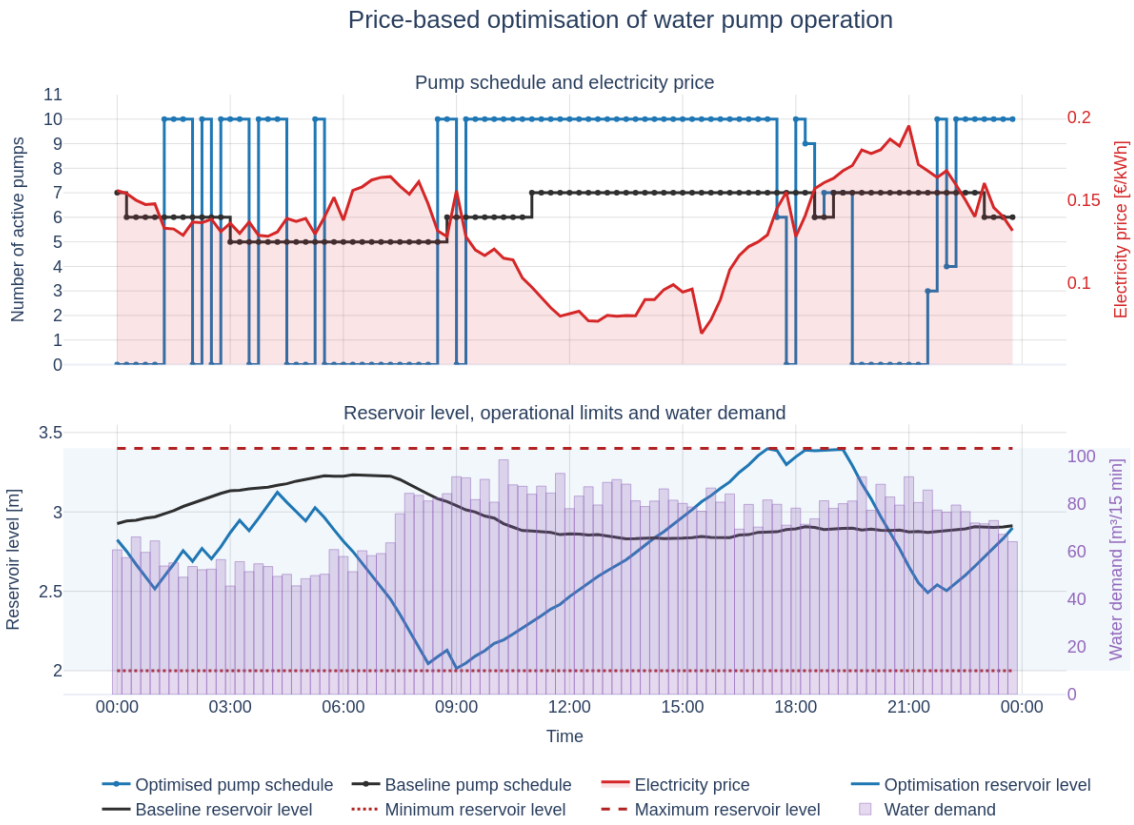


Figure 201: Operational behaviour of the optimised and baseline schedules for 15 May

In the upper part of the figure, the electricity price signal (red line) is shown, and the optimised pump schedule (blue line) is compared with the baseline pump operation (black line). The lower subplot displays the water demand (purple bars), while the corresponding water reservoir level is shown with a blue line for optimised operation and a black line for baseline operation.

The results show that the optimisation follows the electricity price signal, but only within the physical limits of the water system. The optimised schedule does not simply minimise the number of active pumps in all expensive periods. Instead, it uses the available reservoir volume more actively than the baseline operation in order to shift pumping to more favourable price intervals. This is visible in the periods where the optimised pump schedule drops to zero. During these intervals, the optimiser temporarily switches the pumps off and allows the reservoir level to decrease. Water demand continues to be supplied from the stored water volume, while electricity consumption for pumping is postponed. In this way, the reservoir acts as a flexibility buffer that partly decouples the timing of water consumption from the timing of electricity consumption. Compared with the baseline operation, the optimised schedule allows the reservoir level to move across a wider part of the available operating range. The baseline logic keeps the reservoir level more tightly linked to predefined water-level thresholds and activates pumps according to the current level. In contrast, the optimised schedule uses the storage capacity of the reservoir more strategically. It allows the level to decrease when electricity prices are high and restores the level when prices are lower or when future expensive periods are expected. This confirms that the economic benefit is achieved by using the reservoir volume as operational storage.

The figure also shows that pump operation cannot be shifted freely. When the reservoir level approaches the lower operational threshold, the optimiser must activate pumps even if electricity prices are not favourable. At this point, the water system constraint becomes dominant, because maintaining the reservoir above the minimum level has priority over cost minimisation. This explains why the optimised schedule still includes pumping during some less favourable price intervals. Similarly, the optimiser sometimes activates a high number of pumps before or after expensive periods. This does not indicate inefficient operation, but rather a deliberate scheduling decision. By increasing pump operation in selected intervals, the optimiser restores the reservoir level or creates sufficient storage margin to avoid pumping later when electricity prices are higher. The schedule therefore reflects both immediate price conditions and the expected evolution of reservoir level over the remaining optimisation horizon.

The optimised reservoir trajectory confirms that the available storage range is used more intensively than in the baseline case. The reservoir approaches the lower threshold during parts of the day and later reaches the upper part of the operating range. This wider use of the reservoir volume is the key mechanism that enables cost reduction. At the same time, the reservoir level remains within the defined minimum and maximum limits throughout the analysed period, confirming that the optimised schedule is technically feasible and does not compromise water system operation.

Water demand further explains the timing of pump activation. During intervals with higher water demand, the reservoir level decreases more quickly, which reduces the possibility of postponing pump operation. During intervals with lower water demand, or when the reservoir level is already high, the optimiser has more flexibility to keep pumps switched off and wait for more favourable electricity prices. The resulting schedule is therefore both price-driven and constraint-driven: it minimises electricity cost where possible, but always within the operational boundaries of the reservoir.

The economic effect of the price-based optimisation is shown in the cumulative cost comparison below.

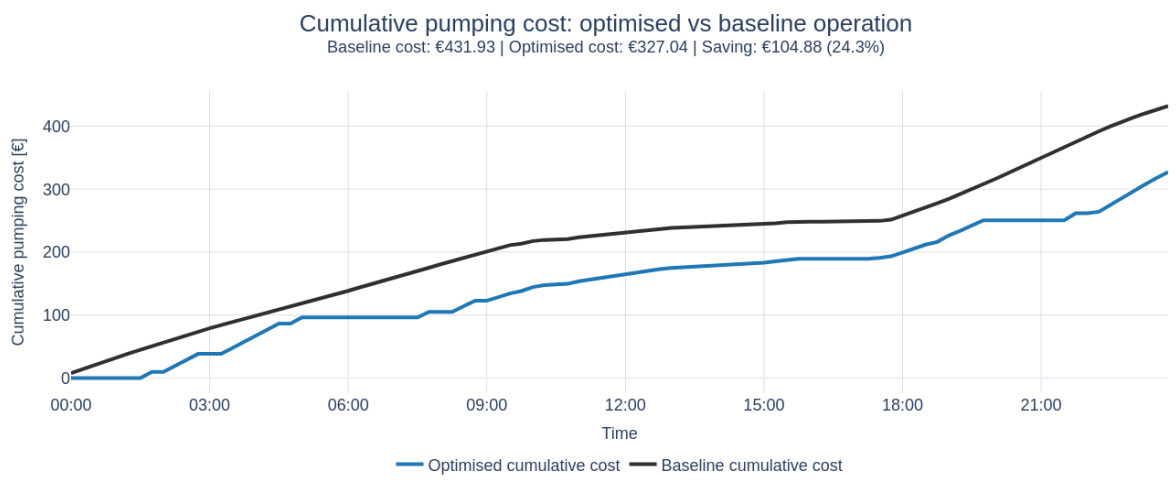


Figure 202: Economic effect of the price-based optimisation

The figure compares the cumulative pumping cost of the baseline operation and the optimised schedule over the analysed day. The baseline cost increases more steadily, as pump operation follows the default water-level-based logic without considering electricity prices. In contrast, the optimised cost curve increases more slowly during intervals where sENC postpones or reduces pumping and uses the reservoir buffer instead. By the end of the analysed day, the optimised schedule results in a total pumping cost of 327.04€, compared with 431.93€ for the baseline operation. This corresponds to a saving of 104.88€, or 24.3%.

Local renewable self-consumption optimisation

The self-consumption optimisation scenario aims to increase the use of locally produced renewable electricity for water pump operation. In this scenario, sENC uses the forecasted PV production profile as the main scheduling signal and adjusts the baseline pump operation so that a larger share of pumping occurs during periods with available PV generation.

As there is no PV generation installed directly at the water pumping station in the pilot, the PV production profile was derived from another transformer located on the same MV feeder. For this test case, the PV profile was upscaled by a factor of five. This scaling was introduced to create a self-consumption scenario in which the available PV power is of the same order of magnitude as the pumping station capacity. In the original profile, the available pump flexibility would be sufficient to absorb the PV production without requiring significant schedule adaptation. After upscaling, there are also intervals where PV production exceeds the nominal power of all available pumps. This makes the scenario more suitable for testing the scheduling logic, as the algorithm must not only increase pump operation during PV production intervals, but also create sufficient reservoir headroom in advance. The pre-draining step therefore becomes relevant: without reducing pump operation before the PV production period, the reservoir could reach the upper limit too early and prevent further PV-based pumping.

The self-consumption scheduling logic is implemented in four main steps. First, a baseline pump schedule is calculated using the default water-level-based control logic. This baseline represents the expected pump operation without self-consumption optimisation and is used as the reference schedule.

Second, the algorithm identifies the PV surplus relative to the baseline pump operation. The scheduled pump power is calculated from the number of active pumps in the baseline schedule and the nominal power of one pump. The available PV surplus is then calculated as the positive difference between PV production and scheduled pump power. This identifies intervals where additional pumping could potentially be supplied by local PV generation.

Third, a pre-draining step is applied before the PV surplus period. The purpose of this step is to create additional reservoir headroom before PV production becomes available. Without this step, the reservoir may already be too full during PV production periods, which would limit the possibility of increasing pump operation and absorbing local PV generation. Pre-draining is only allowed in intervals with no PV production, so the algorithm does not reduce pumping during periods where renewable electricity is already available. In addition, the pre-draining reduction is accepted only if the simulated reservoir level remains above the minimum operational limit before the PV surplus period.

Fourth, during PV production intervals, the algorithm increases pump operation where additional PV energy is available and where reservoir headroom allows it. The number of additional pumps is based on the available PV power after accounting for the scheduled pump operation. If the remaining PV power is lower than the full nominal power of one pump, the algorithm may still activate one additional pump, provided that reservoir headroom is available. This allows residual PV production to be absorbed instead of left unused, while the uncovered part of the pump consumption is supplied from the grid. This rule is useful because pumps operate in discrete 30 kW steps and cannot be partially activated.

The resulting PV-aware schedule is checked against the maximum reservoir level to avoid overflow. If the additional pumping would raise the reservoir above the allowed maximum level, the number of active pumps is reduced accordingly. After the last PV surplus interval, the schedule returns to the default water-level-based logic, starting from the reservoir level reached by the PV-aware operation.

The operational effect of the self-consumption optimisation is shown in the figure below. The upper subplot compares PV production with the baseline pump power and the PV-aware pump power, while the lower subplot shows the corresponding reservoir level trajectories, operational limits and water demand.

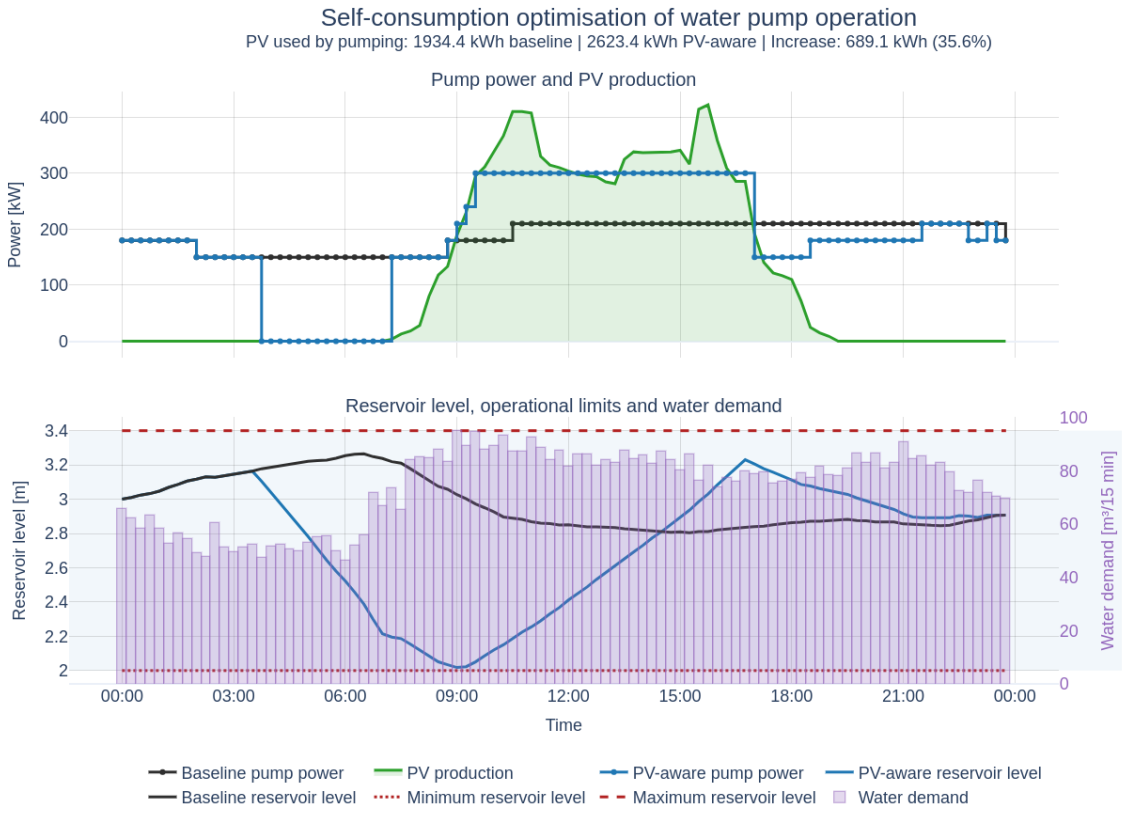


Figure 203: Operational effect of the self-consumption optimisation

The figure shows that the PV-aware schedule shifts a substantial part of pump operation into the period with high PV production. During the main PV generation window, the PV-aware pump power increases to the full installed pumping capacity (300 kW; all the pumps turned on), while the baseline schedule remains lower and follows the default water-level-based operation. This confirms that the algorithm actively increases pump operation when local renewable production is available.

Another key feature of the result is the pre-emptying of the reservoir before the PV production period. In the morning, the PV-aware schedule reduces pump operation compared with the baseline and allows the reservoir level to decrease almost to the minimum allowable threshold. This is a deliberate scheduling action: by creating additional reservoir headroom before the PV generation peak, the algorithm enables more water to be pumped later using locally produced PV electricity.

The lower subplot confirms that this pre-emptying remains technically feasible. The reservoir level approaches the lower operational limit, but it does not violate it. This shows that the algorithm uses almost the full available storage range of the reservoir, while still respecting the minimum water level constraint. On the other hand, during the PV production period, the reservoir level increases as additional pumps are activated. This illustrates the second part of the scheduling strategy: once PV production is available, the previously created reservoir headroom is used to absorb more locally produced renewable electricity compared to baseline pump operation. In this way, the reservoir acts as temporary storage that enables the conversion of PV generation into shifted pumping activity.

The figure also shows that after the PV surplus period, around 19:00, the pump operation returns to the default water-level-based logic. From that point onward, the PV-aware and baseline schedules gradually converge. By the end of the analysed day, the reservoir level in the PV-aware schedule is almost the same as in the baseline case. This is important because it confirms that the optimisation does not simply end the day with a higher or lower reservoir state, but mainly changes the timing of pump operation during the day.

The resulting increase in local PV use is significant. In the baseline case, pumping uses 1.93 MWh of PV energy, while the PV-aware schedule increases this to 2.62 MWh. This corresponds to an additional 689 kWh, or a 35.6% increase in PV energy used for pumping. The result confirms that the pre-emptying and PV-aware activation logic can substantially improve local renewable self-consumption while maintaining reservoir constraints.

Congestion management optimization

The third optimisation scenario addresses congestion management. In this scenario, sENC uses the day-ahead transformer loading forecast as the primary operational signal and adjusts the pump schedule when the forecasted transformer load exceeds the defined congestion threshold. Unlike the price-based and self-consumption scenarios, this optimisation mode is directly relevant for future participation in a flexibility marketplace, as it can be linked to a congestion request issued by the DSO through sMART.

The purpose of the congestion management logic is to follow the baseline water pump schedule under normal conditions, but to reduce pump operation during forecasted congestion intervals where technically feasible. As pumps represent a controllable load in discrete 30 kW steps, reducing the number of active pumps directly decreases transformer loading in the affected interval. The reservoir serves as the operational buffer, allowing pumping to be shifted away from congested periods without compromising water supply.

The congestion-aware scheduling workflow comprises three main steps. First, the baseline pump schedule is calculated using the default water-level-based control logic, similar as in the other two optimisations. Second, sENC applies a pre-fill logic before forecasted congestion periods. If congestion is expected within the selected look-ahead window, the algorithm may increase pump operation before the congestion period, provided this does not push the transformer load above

the congestion threshold or exceed the maximum reservoir level. The purpose of this pre-fill step is to increase the reservoir level before congestion occurs, so that pump operation can be reduced later during the constrained interval. Third, during congestion intervals, the algorithm estimates the amount by which the forecasted transformer loading exceeds the congestion threshold. This excess loading is translated into the number of pumps that should be turned off:

$$n_{off,t} = \left\lceil \frac{P_{load,t} - P_{thr}}{P_{pump}} \right\rceil$$

where $P_{load,t}$ is the forecasted transformer load in interval t, P_{thr} is the congestion threshold, and P_{pump} is the nominal power of one pump, equal to 30 kW. The number of pumps turned off is limited by the number that would otherwise be active in the baseline schedule. The reduction is accepted only if the resulting reservoir level remains above the minimum operational limit. This ensures that congestion mitigation does not compromise water system operation.

The effective transformer loading after the flexibility action is calculated by comparing the congestion-aware pump schedule with the baseline schedule:

$$P_{eff,t} = P_{load,t} + (n_{act,t} - n_{base,t}) \cdot P_{pump}$$

where $n_{act,t}$ is the number of active pumps in the congestion-aware schedule and $n_{base,t}$ is the number of active pumps in the baseline schedule. If fewer pumps are operated than in the baseline, the effective load is reduced. If additional pumps are operated during pre-fill periods, the effective load is increased, but only where this remains below the congestion threshold. The operational result of the congestion management optimisation is shown in the figure below.

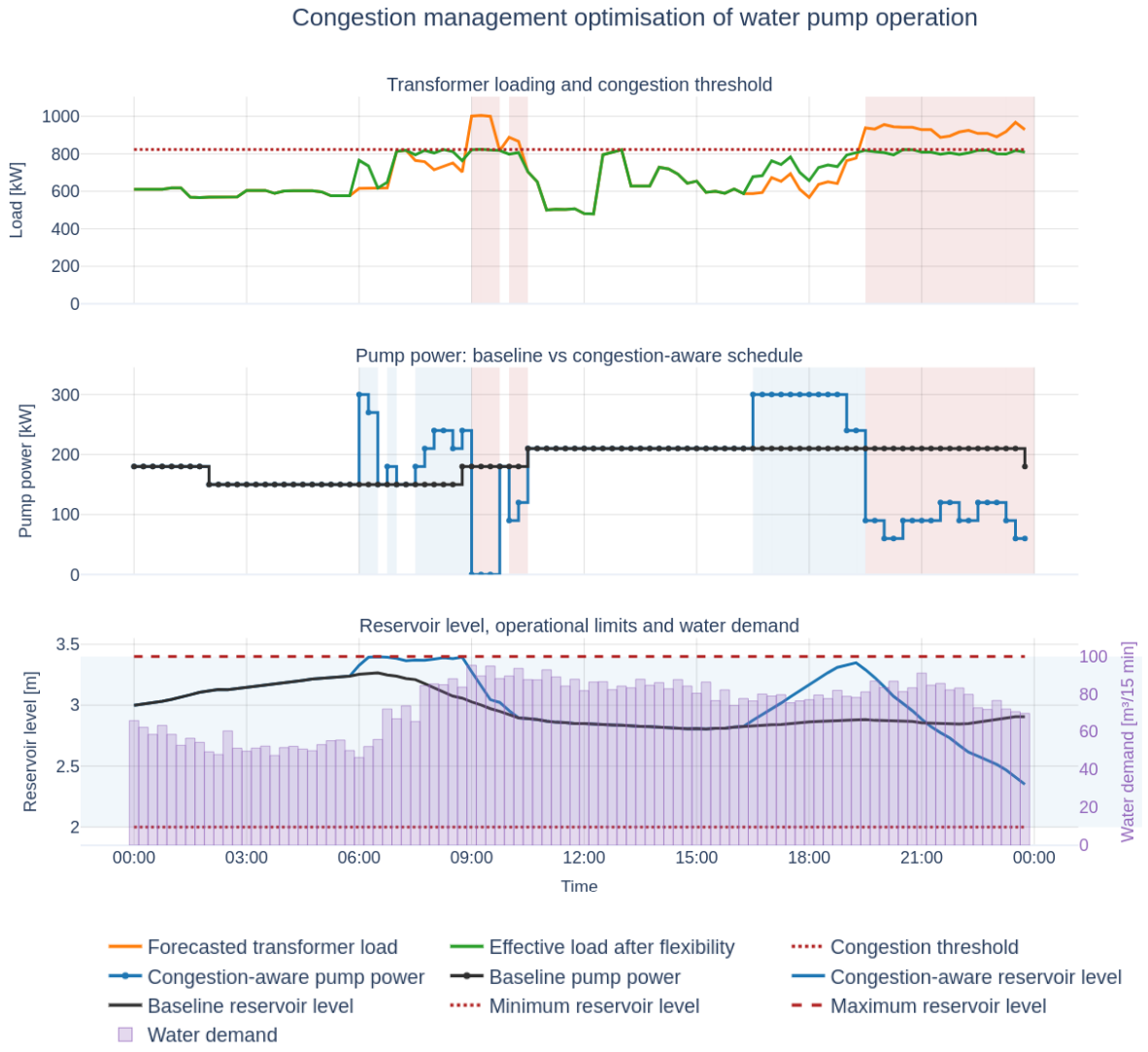


Figure 204: Operational result of the congestion management optimisation

The upper subplot displays the forecasted transformer loading, the congestion threshold, and the effective load after implementing the congestion-aware pump schedule. The shaded red areas indicate intervals where the original forecasted transformer load exceeds the congestion threshold. In these intervals, the congestion-aware schedule reduces pump operation where possible, lowering the effective transformer loading to below or closer to the threshold.

The middle subplot illustrates how the pump schedule is adjusted. Before the congestion period, the congestion-aware schedule increases pump power compared with the baseline schedule. This pre-filling action (shaded blue areas) raises the reservoir level in advance, enabling reduced pumping during the upcoming congestion interval. During the congestion intervals, the congestion-aware schedule substantially reduces pump power compared with the baseline. This flexibility action would be relevant for a potential market-based congestion management service.

The lower subplot confirms that the schedule remains technically feasible. The congestion-aware reservoir level rises during pre-fill periods and decreases during congestion periods when pumping is reduced. The reservoir remains within the minimum and maximum operational limits throughout the analysed horizon. This demonstrates that congestion mitigation is achieved without violating water system constraints.

However, the result should not be interpreted as a guarantee that all congestion events can always be fully resolved by water pump flexibility. In the analysed scenario, full congestion mitigation was possible because the required load reduction could be achieved by reducing the operation of pumps that were already active, and because the reservoir provided sufficient buffer to maintain water system operation during the reduction period. In practice, this will not always be the case. The requested congestion reduction may exceed the power of the pumps operating at that time. For example, if the congestion exceeds the threshold by 200 kW, but only five pumps are active, the immediately available pump reduction is limited to 150 kW. Similarly, a congestion event may last longer than the available reservoir buffer, even if the reservoir has been fully pre-filled before the event. In such a case, pumps would eventually need to restart to maintain the minimum reservoir level, even if the congestion period is still ongoing. The pre-fill step also has practical limits. It is only useful when additional pumping can be scheduled before the congestion interval without creating a new congestion problem in the pre-fill period. If the transformer is already close to the congestion threshold before the event, increasing pump operation in advance may not be possible. In that case, the available flexibility during the congestion interval would depend only on the current reservoir level and the pumps already scheduled to operate.

Supervised real-life activation of water pump flexibility

The optimisation scenarios presented above show how the water pumping station can be scheduled to shift electricity consumption according to a selected objective function. To complement these optimisation-based results with an operational demonstration, a supervised real-life flexibility activation was carried out at the water pumping station on 11 June 2026.

Figure 205 shows the result of this activation. The upper panel compares the measured reservoir level with the actual and expected number of active pumps, while the lower panel shows the monitored on/off states of the individual pumps. The expected number of active pumps was determined from the automatic reservoir-level logic, while the actual operation was reconstructed from measured pump activation states at 1-minute resolution. This comparison makes it possible to identify when the pumping station followed its normal automatic logic and when the operator intentionally deviated from it to emulate a flexibility activation.

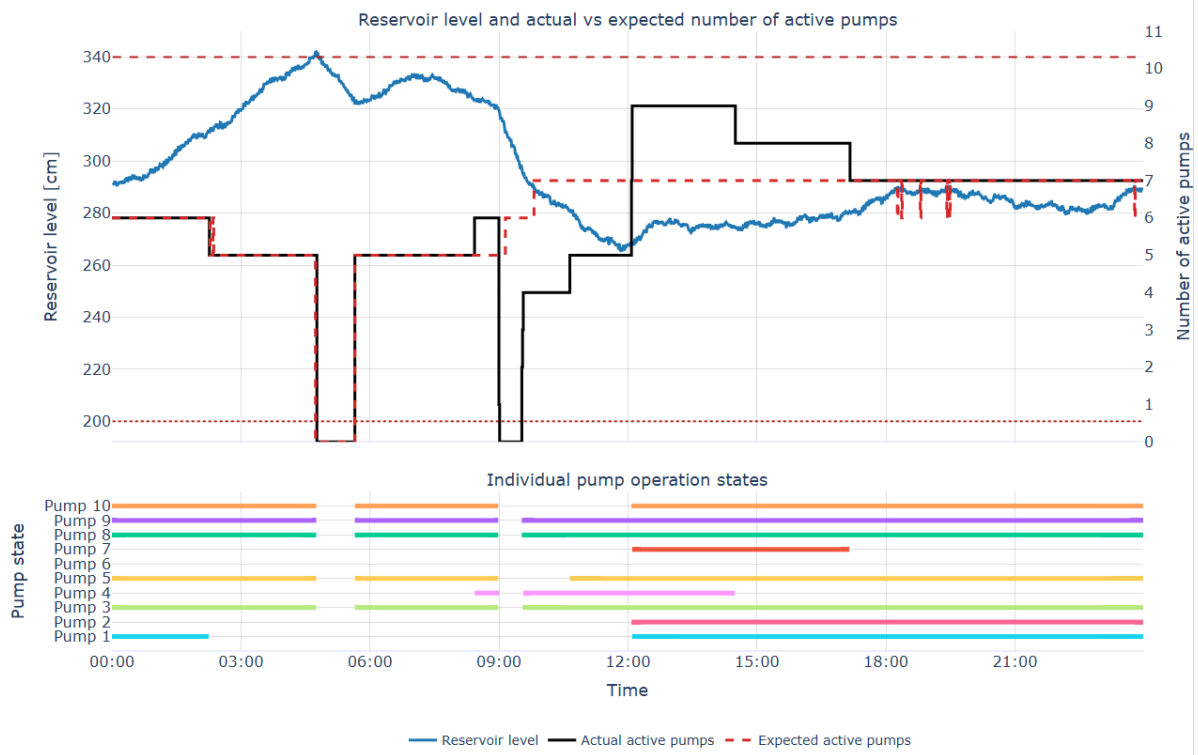


Figure 205: Water pump flexibility activation on 11 June 2026

At 08:26, the operator took manual control of the pumping station. Initially, one additional pump was activated compared with the automatic reservoir-level logic, resulting in 17 kWh of additional pumping energy. At 09:00, all pumps were switched off for approximately 34 minutes. After this interruption, the pumps were gradually restarted, but initially fewer pumps were active than required by the automatic logic. Over the curtailment and reduced-pumping phase from 09:00 to 12:03, this resulted in roughly 270 kWh of curtailed pumping energy. At 12:03, all available pumps at that time (nine pumps) were switched on, and from 12:03 to 17:10 the station operated with more pumps than required by the automatic logic. This recovery phase resulted in about 220 kWh of increased pumping energy. At 17:10, automatic pump control was resumed.

The energy impact of the intervention was calculated by comparing the actual number of active pumps with the expected number of active pumps from the automatic reservoir-level logic. Using a nominal power of 30 kW per pump, the difference in active pumps was multiplied by the 1-minute time step. The experiment therefore showed clear load-shifting behaviour: electricity consumption was reduced in the morning and partially recovered later in the day. This result demonstrates that the water pumping station can provide real operational flexibility through controlled modification of pump operation, with the reservoir acting as a buffer between water demand and electricity consumption.

After 18:00, a few short deviations between the expected and actual number of active pumps can still be observed. These are not considered part of the supervised flexibility activation, since automatic pump control had already resumed at 17:10. They occur when the reservoir level briefly crosses a control threshold at which one pump would be expected to switch off, but the exceedance lasts for less than one minute and therefore does not lead to a visible change in the actual field operation.

Qualitative analysis of the results

The test case shows that water pump flexibility is particularly suitable for optimisation because it is controllable, measurable and physically constrained in a predictable way. The reservoir provides

operational storage, allowing electricity consumption to be shifted without interrupting the water supply. This makes the water pumping station more reliable as a flexibility asset than residential HVAC loads, where activation depends on user behaviour and voluntary response.

The experiment also confirms that the same flexible asset can support different objectives depending on the operational context. In normal portfolio management, the aggregator may optimise the pumps to reduce energy costs or increase local renewable self-consumption. In congestion management, the same asset can be used to reduce load during a specific grid constraint window. However, these objectives may conflict with each other. For example, the lowest electricity price period may not coincide with the period of highest local PV generation or the period outside a congestion event. Therefore, only one objective function is activated at a time.

From a market participation perspective, the congestion management mode is the most relevant. In this scenario, sENC allows the aggregator to assess whether the requested flexibility can be delivered before submitting an offer in sMART. This is important because the aggregator must know whether the flexibility is technically feasible and what the operational cost is aThe test case also highlights that flexibility from the water pumping station is not unlimited. Even though the installed pump capacity is significant, the available flexibility depends on the reservoir level, expected water demand, operational constraints and the timing of the requested flexibility. sENC is therefore needed to convert the estimated flexibility potential into a feasible schedule.

Lastly, this test case experiment presents a supervised real-life activation of water pump flexibility. With additional manual activation experiments of this type, the operator can further verify the behaviour of the pumping station under controlled flexibility actions and build confidence in the proposed scheduling logic. As confidence increases and the operational safeguards are further validated, the optimised schedules generated by sENC could in the future be implemented more directly and potentially automated in practice.

Experiment number	**IT-UC.07.01**
Name of the experiment	Validation and remuneration of CPO flexibility
Timeframe	March – May 2025 (M30-M32)
Targets	The purpose of this test case is to ensure that the flexibility provided by the CPO is accurately validated and remunerated based on actual performance during periods of grid congestion.
Actors	• EMOT as CPO • ASM as DSO • COMS as technology provider
STREAM products	sMART
Assets & systems	• EV charging stations • CPO platform with real-time monitoring and validation tool
Description of the experiment	This experiment focuses on validating and compensating the CPO for the flexibility actually provided during grid congestion. When the CPO receives a flexibility request due to a forecasted congestion, it modifies EV charging schedules to either reduce or shift load as needed. The CPO flexibility platform monitors and

	checks the flexibility provided in real time and ensures that the flexibility provided matches the requested amount and schedule. **Pre-condition/triggering event:** Flexibility bid of CPO has been selected and accepted by DSO **Steps:** 1. The CPO changes the charging patterns of its EV stations and adjusts the load according to the flexibility agreement with the DSO. 2. The flexibility platform continuously monitors the charging stations to verify that the required flexibility is provided according to the DSO's specifications. 3. At the end of the flexibility period, the platform prepares a validation report detailing the exact amount of flexibility provided by the CPO and confirming compliance with the requested parameters. 4. The platform calculates remuneration for the CPO based on the verified flexibility provided. The DSO processes the payment as compensation for the CPO's demand response contribution. **Post-condition:** The flexibility provided by the CPO is validated and remunerated by the DSO, ensuring that the CPO is accurately remunerated based on real-time performance
Datasets required for the experiment	• Electric vehicle state of charge data provided by EMOT smart meters (OBDs) • Charging station energy data provided by EMOT smart meters • Energy flexibility provision data provided by EMOT smart meters
Field data to be gathered	• CPO remuneration amount (in token)
Related KPIs	KPI IT.02
Results of the Experiment	
The experiment successfully demonstrated the validation and remuneration workflow for flexibility services provided by the CPO within the sMART platform during the final demonstration phase. The test case verified that the flexibility delivered by EV charging stations during congestion events can be monitored, validated and remunerated based on the actual measured performance. During the demonstration, the CPO responded to flexibility requests issued in response to forecasted grid congestion conditions by modifying the charging behaviour of connected EV charging stations. The charging load was reduced or shifted according to the agreed flexibility schedule and operational requirements defined by the DSO. The validation process was continuously supported through the monitoring capabilities of the sMART platform. Real-time operational data from the charging stations and associated smart metering infrastructure were collected and analysed to verify compliance with the requested flexibility activation period and target flexibility volumes.	

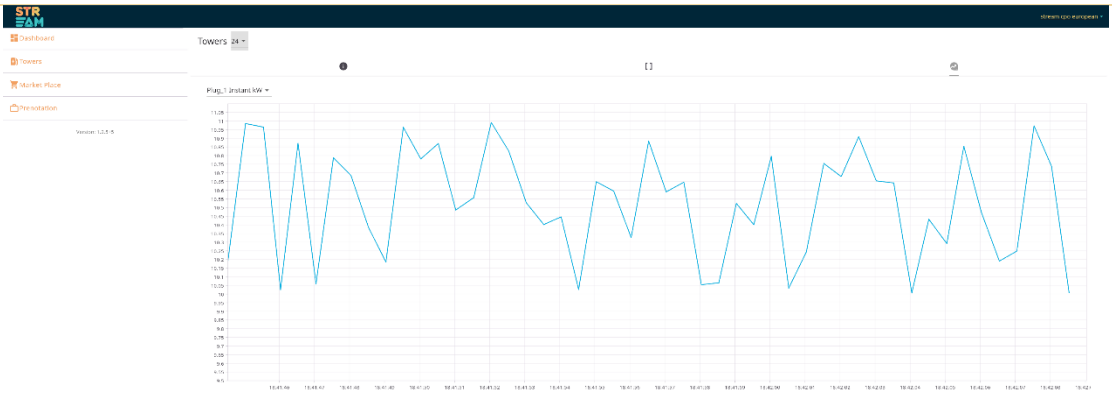


Figure 206: Charging session real-time monitoring

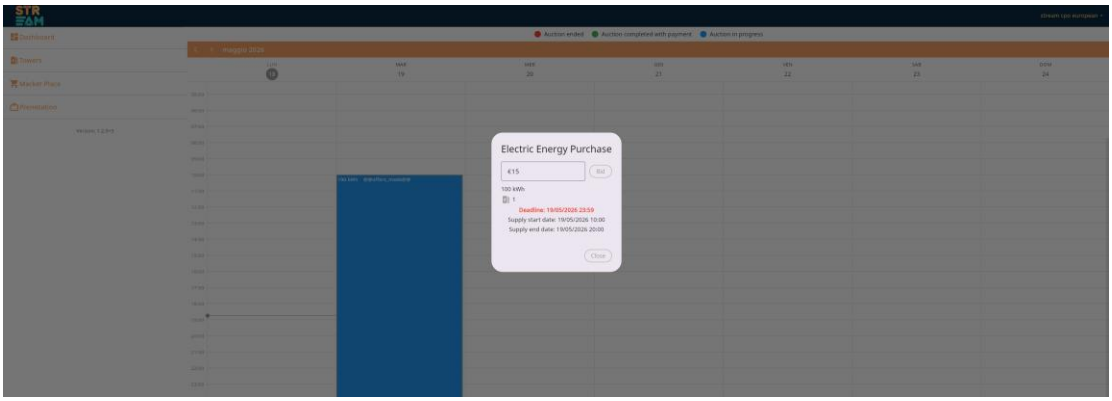


Figure 207: CPO compensation request for flexibility service delivering


```
{
    "id": 7,
    "from": "0xd0FF252d0B4924E7Ee1E1eb76B898c4ef6288201",
    "deadline": "2025-03-05 14:13:00",
    "extra": [
        10,
        1741180200,
        1741183980,
        3,
        19
    ],
    "state": "open",
    "offers": [],
    "decision": [],
    "decided": null
},
{
    "id": 1,
    "from": "0xd0FF252d0B4924E7Ee1E1eb76B898c4ef6288201",
    "deadline": "2025-04-24 15:24:54",
    "extra": [
        20,
        1748100294,
        1748100299,
        18,
        5
    ],
    "state": "decided",
    "offers": [
        1
    ],
    "decision": [
        1
    ],
    "decided": "2025-02-24 16:29:09",
    "payed": true
},
{
    "id": 3,
    "from": "0xd0FF252d0B4924E7Ee1E1eb76B898c4ef6288201",
    "deadline": "2025-04-24 15:25:00",
    "extra": [
        20,
        1748100294,
```


Figure 208: Backend workflow for flexibility service validation and remuneration

The collected screenshots confirm the successful execution of the validation workflow and demonstrate the following functionalities of the platform:

- real-time tracking of charging sessions and energy consumption;
- generation of validation reports confirming the flexibility provided;

- remuneration values associated with validated flexibility services.

The experiment demonstrated that the platform can correctly associate operational charging data with flexibility activation events and validate whether the agreed flexibility service has been delivered. The validation report generated at the end of the flexibility period included the measured flexibility contribution and confirmed compliance with the requested operational parameters. The remuneration workflow was also successfully demonstrated. Based on the validated flexibility provision, the platform calculated the corresponding compensation for the CPO according to the predefined remuneration mechanism. Specifically, the remuneration mechanism was based on marketplace bids submitted by the CPO, where the flexibility provider specified the requested compensation for delivering the flexibility service. Following service activation, the final remuneration was calculated according to the accepted bid and the amount of validated flexibility effectively delivered during the activation period. This confirmed the capability of the sMART platform to support not only flexibility activation and monitoring, but also the post-event settlement and compensation process required for flexibility market participation. The experiment therefore validated the end-to-end process linking flexibility activation, operational monitoring, service validation and remuneration of EV charging flexibility services within the STREAM framework. Although the primary objective of the experiment was the validation and remuneration of delivered flexibility, the successful execution of the workflow also supports KPI_05 by demonstrating the operational readiness of registered flexibility providers to participate in marketplace-based flexibility services.

Qualitative analysis of the results

The results confirm that the sMART platform can successfully support the validation and remuneration workflow for EV charging flexibility services. The experiment demonstrated that charging stations operated by the CPO can participate in flexibility events and that their contribution can be verified using measured operational data collected in real time. The test case also confirmed the importance of continuous monitoring and transparent validation procedures for flexibility markets. The ability to compare requested flexibility against actual delivered flexibility is essential for ensuring trust between the DSO and flexibility providers and for enabling fair remuneration mechanisms. From an operational perspective, the experiment showed that EV charging infrastructure can provide measurable and verifiable demand-side flexibility through the adjustment of charging schedules. The platform successfully linked flexibility activation requests with charging station monitoring and post-event validation procedures. The remuneration functionality additionally demonstrated the readiness of the platform to support practical market-oriented flexibility services. By validating the delivered flexibility and associating it with a compensation mechanism, the experiment confirmed the feasibility of integrating EV charging flexibility into future local flexibility market processes within the STREAM ecosystem.

Experiment number	sDATA-UC.01.02
Name of the experiment	Data provider to data user data exchange in the Italian pilot
Timeframe	April 2026 (M43)
Targets	The goal of this test case is to verify the accurate transmission of data from the data source to the data user via the sDATA exchange platform. The experiment aims to ensure that all requested data is fully included and correctly structured. The results will demonstrate whether the data exchange is complete

	and accurate, with no data loss, and will assess the quality of the transmitted data.
Actors	• ASM as data provider, • COMS as data user, • IND as technology provider
STREAM products	sDATA, sGRID, sFLEX
Assets & systems	• ASM database • sDATA APIs for data exchange • sGRID and sFLEX logic for data acquisition
Description of the experiment	One of the main functionalities of the sDATA platform is a secure and efficient data exchange between data providers, such as DSO and data users, such as sGRID tool. This test will assess whether the data transfer between the data source and data user is reliable. This test will include testing the grid topology data and historical timeseries measurement data. Both datasets will be tested and analysed in depth to confirm that the data transformation and exchange process within the sDATA platform is correct, and to confirm that no data is lost in the process. The test will be repeated multiple times to show that data is successfully exchanged at a sufficiently high rate. **Pre-condition/triggering event**: Historical timeseries measurement data and are saved at the data provider, ASM (DSO). This data is available for retrieval by sDATA. **Steps:** 1. sDATA requests historical data from the DSO through the database connection. 2. Authentication and authorization processes are performed on the requester to grant data access. 3. The data retrieved is transformed to fit the data model and then saved to the sDATA database. 4. sGRID or sFLEX requests historical timeseries measurement data from sDATA through implemented and operational sDATA API. 5. Authentication and authorization processes are being performed on the requester to grant data access. 6. The data is sent as the response of the sGRID's/sFLEX's request. 7. The data received by sGRID/sFLEX is checked and tested. **Post-condition**: sGRID/sFELX receives all the data that is needed for further analyses and processes.
Datasets required for the experiment	• Historical timeseries measurement data.
Field data to be gathered	• Historical timeseries measurement data. • Count of successful and unsuccessful API responses

Related KPIs	KPI sDATA.01

Results of the Experiment

- Roles of Actors: The experiment successfully demonstrated the end-to-end data flow with clearly defined roles. ASM acted as the data provider, making historical timeseries measurement data available via a database connection. IND (technology provider) ensured the sDATA platform successfully extracted, transformed, and stored this data. Finally, COMS (data user) utilized the sGRID/sFLEX logic to request and retrieve this data via sDATA APIs.
- Data Ingestion and Transformation: sDATA successfully initiated requests to the ASM (DSO) database. The historical timeseries measurement data was retrieved, properly transformed to fit the internal sDATA model, and securely saved to the sDATA database. Authentication and authorization protocols were verified at this stage.



Figure 209: Data request log

- Examples of Exchanged Data (Workflow): The data provision workflow was validated when sGRID/sFLEX (COMS) requested the data.

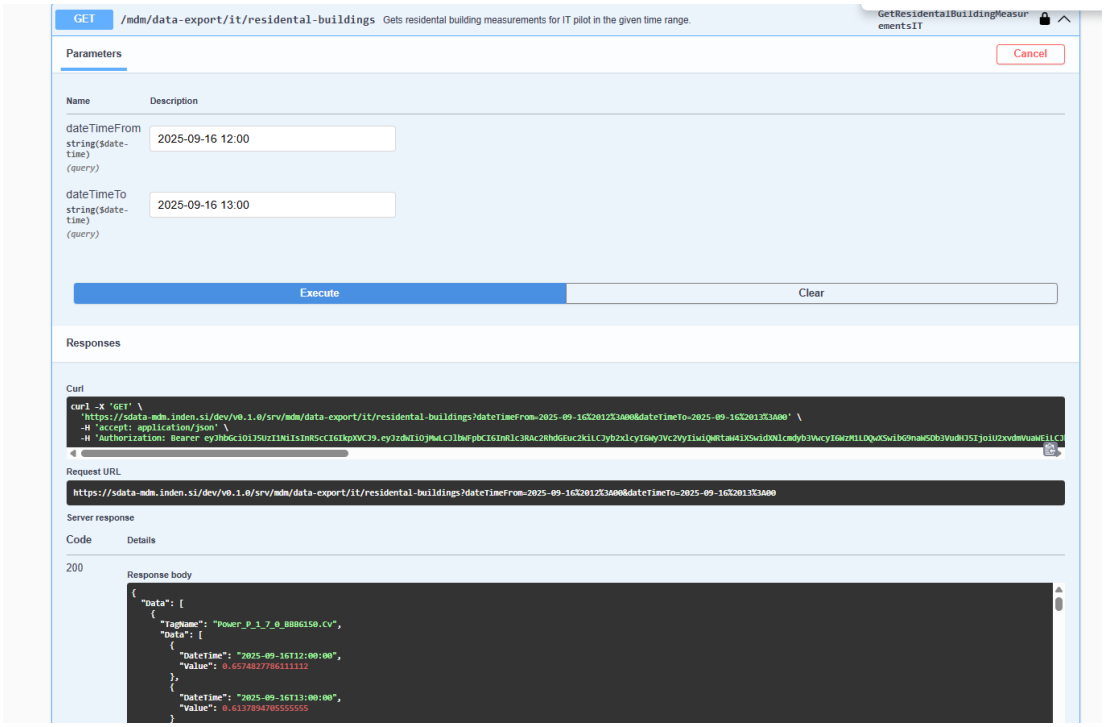


Figure 210: End-to-end data transformation and exchange process

- Data Completeness and Accuracy: An in-depth comparative analysis between the source data (ASM database) and the destination data (received by sGRID/sFLEX)

confirmed a 100% data match. No data loss, duplication, or corruption occurred during the transformation and exchange processes.

- Quantitative Performance Metrics:
  - API Response Success Rate: The system actively gathered and counted API responses. Out of 4100 requests made during the test period, 28 encountered errors (99,3% success rate), meeting the KPI targets.
  - Latency and Data Volume: The sDATA platform handled high-frequency requests, processing data transformations with an average latency of 350 ms per payload without data loss.
- Exception Paths Testing: Exception scenarios were tested to guarantee platform resilience:
  - Provider DB Unavailability: Simulated downtime of the ASM database resulted in sDATA appropriately logging a connection timeout and queueing the ingestion task for an automatic retry, without crashing.
  - Invalid Authentication: Requests made by sGRID/sFLEX with expired or invalid API tokens were correctly rejected with a 401 Unauthorized HTTP status code.
  - Data Format Mismatch: A simulated injection of improperly formatted data from the provider was caught by sDATA's transformation logic, which safely skipped the corrupted record and logged an error while processing the rest of the batch.

Qualitative analysis of the results

- Reliability and Robustness: The end-to-end data exchange process proved to be highly reliable. The platform's ability to consistently handle database connections, data extraction, transformation, and API provisioning demonstrates a mature and stable architecture. The high success rate of API responses under repeated testing builds confidence in its operational readiness.
- Interoperability: The test confirms excellent interoperability between the data provider's legacy database (ASM) and the modern API-driven data users (sGRID/sFLEX operated by COMS). sDATA successfully acted as the central interoperability hub, normalizing the data formats seamlessly.
- System Performance: The transformation processes introduced negligible overhead. The platform managed high-frequency data exchange requests efficiently, proving its capacity to handle the historical measurement data required by advanced forecasting tools like sGRID.
- Observed Limitations and Minor Issues: A minor limitation was observed when requesting large periods of historical data (month or more). This resulted in a prolonged response time. To mitigate this in future iterations, a pagination mechanism or a hard limit on the date-range per request is recommended for the sDATA API.
- Conclusion: The experiment successfully validates the core functionality of the sDATA platform for the Italian pilot. It confirms that the requirements for KPI sDATA.01 are met, proving that sDATA provides a secure, complete, and accurate data exchange mechanism between ASM and COMS.

Experiment number	**sDATA-UC.02.02**

Name of the experiment	History of data access events in the Italian pilot
Timeframe	April 2026 (M43)
Targets	The objective of this test case is to verify that data access events are accurately logged in the distributed ledger. This ensures a comprehensive history log of all user access events within the sDATA platform. The history log should include essential details for investigative purposes, such as: • Username. • Timestamp. • Actions executed by the user during their session.
Actors	• COMS as data user • IND as technology provider
STREAM products	sDATA, sGRID, sFLEX
Assets & systems	• sDATA APIs for data exchange • sGRID/sFLEX logic for data acquisition
Description of the experiment	The Distributed Ledger provides capturing data during all access events, including logins and the initiation of actions. This data is systematically recorded onto a distributed ledger e.g. hyper ledger, providing a transparent and immutable record of events. The expected outcome of the test is that every data access event is properly stored in the distributed ledger, with a complete and accurate history log that includes all necessary information for future investigations. **Pre-condition/triggering event**: Users must have access credentials and permissions to log into the sDATA platform. The distributed ledger must be properly configured and integrated with the platform. Steps: 1. Test user logs into to sDATA platform (for example: Master Data Management platform). 2. Test user initiates multiple access event actions, e.g. opens specific Charging station metadata, opens his own profile page, requests time series measurement data of the specific electric meter, logs out. 3. User access events history log is acquired from the distributed ledger. 4. The history log of access events is checked. 5. The confirmation of the consistency and accuracy of the history log related to user activities. **Post-condition**: sGRID/sFLEX receives all the data that is needed for further analyses and processes.
Datasets required for the experiment	• Master Data management data

Field data to be gathered	/
Related KPIs	/

Results of the Experiment

- Roles of Actors: The experiment's execution was clearly divided between the designated actors in the Italian pilot. COMS (data user) acted as the test subject, logging into the platform and initiating various data access events to trigger the tracking system. IND (technology provider) managed the distributed ledger infrastructure, acquired the history logs via the API, and validated the integrity and accuracy of the logged data.
- Execution of User Actions: The test user (COMS) successfully logged into the sDATA Master Data Management platform. Multiple actions were deliberately initiated, such as viewing specific Charging Station metadata (e.g., EMOT assets), accessing the user profile page, requesting timeseries measurement data for specific electric meters (e.g., ASM assets), and logging out.

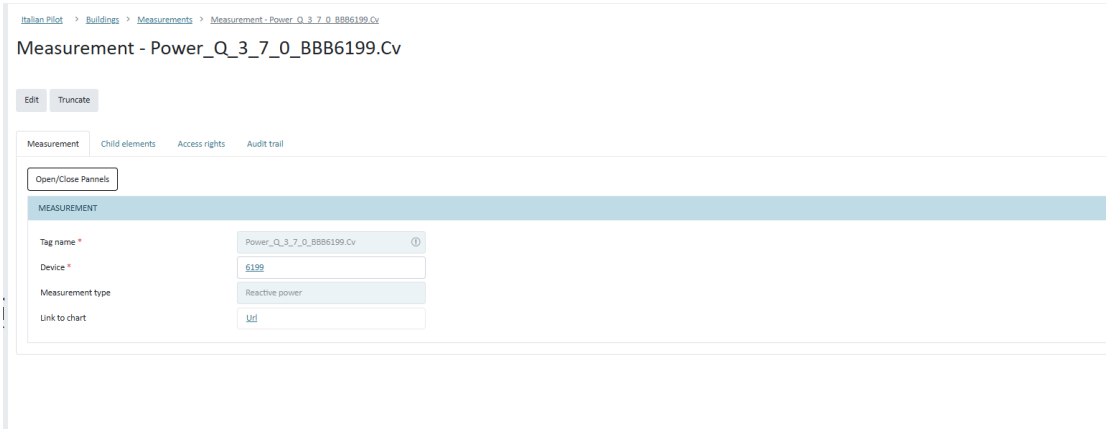
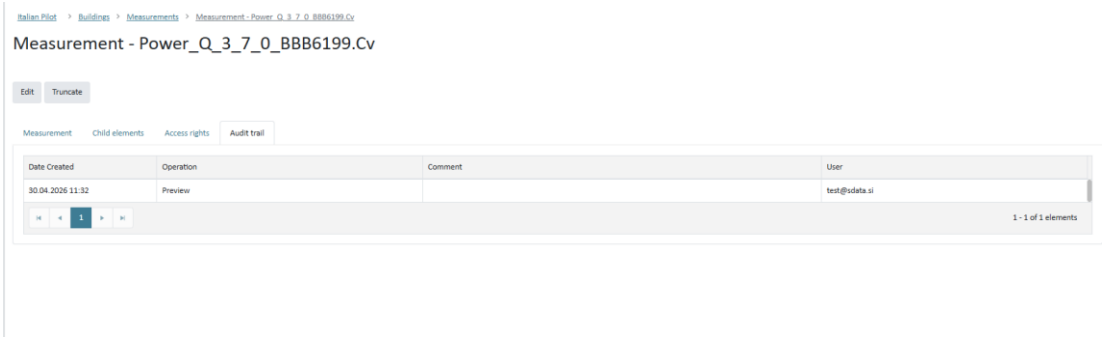


Figure 211: Measurement device metadata

- Examples of Exchanged Data (Workflow): The workflow for capturing access events was validated. Every interaction triggered a systematic record onto the distributed ledger (e.g., Hyperledger).



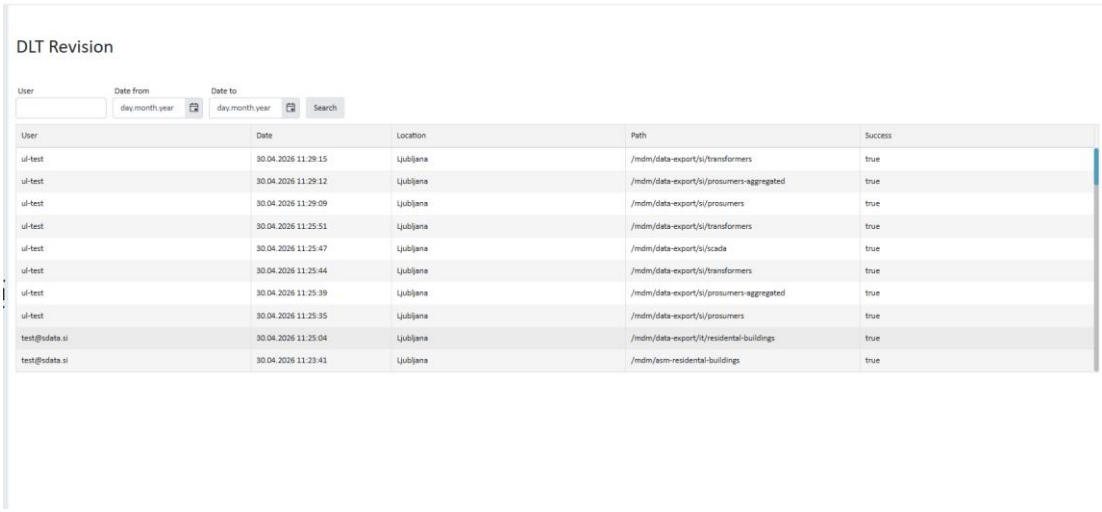


Figure 212: DLT revision record

- Log Content Verification & Accuracy: Each entry acquired from the distributed ledger was analyzed. A 100% one-to-one match was confirmed between the actions performed by COMS and the events recorded. No duplicates or missed events occurred. The logs accurately captured the Username, Timestamp, and specific Action executed.
- Quantitative Performance Metrics:
  - Throughput: The system successfully processed up to 137.23 requests per second (handling over 41,330 requests in a 5-minute window).
  - Latency: For standard payloads (10–20 records), the average latency was 88.92 ms (P95: 147.75 ms), well below the 120 ms target. For heavy payloads (100 records), average latency was 239 ms (P95: 425 ms).
  - Error Rate & Stability: The platform maintained a perfect 0% error rate under all load conditions (up to 50 concurrent Virtual Users), successfully meeting the strict < 1% error threshold.
- Exception Paths Testing: Exception scenarios were executed to test the ledger's resilience:
  - Distributed Ledger Unavailability: A scenario where the ledger service was temporarily taken offline was simulated. The sDATA platform successfully queued the access events locally and logged them sequentially once the service was restored, preventing any audit trail data loss.
  - Corrupted Log Data Attempt: Simulated malformed event payloads (e.g., null username or missing timestamp) were correctly caught by the validation layer and rejected/flagged before ledger insertion.
  - Delayed Log Confirmation: Simulated delays in the ledger's confirmation response did not freeze the main sDATA platform, proving the asynchronous design keeps the UI responsive for the data user.

Qualitative analysis of the results

- Reliability of the Logging Mechanism: The experiment demonstrates that the Distributed Ledger technology is highly reliable for capturing and immutably storing data access events within the Italian pilot. It effectively acts as a robust audit trail mechanism even under stress-test conditions.

- Transparency and Trustworthiness: The ability to retrieve a complete and unalterable history log significantly enhances the sDATA platform's transparency. This is vital for building trust among Italian pilot data providers (ASM, EMOT) and data users (COMS), ensuring all data interactions are fully traceable and verifiable for future security audits, regulatory compliance, or dispute resolutions.
- System Performance: The background process of recording events to the distributed ledger had no discernible impact on the user's experience or the overall performance of the sDATA platform.
- Observed Limitations and Minor Issues: User interface for log processing is not the most user friendly, which can be addressed in subsequent upgrades.
- Conclusion: The results confirm that the distributed ledger component is successfully integrated and fully operational. It meets the objective of providing a secure, complete, and accurate history of user access events, serving as a cornerstone of the sDATA platform's data governance in the Italian pilot.

Experiment number	**sDATA-UC.03.02**
Name of the experiment	User access rights configuration in Master Data Management Portal in the Italian pilot
Timeframe	April 2026 (M43)
Targets	The target of this test case is to ensure that the user management system within the sDATA Master Data Management (MDM) portal functions correctly and efficiently. Specifically, the test aims to validate the usability of the system, confirming that administrators and users can easily navigate and utilize the platform. Additionally, the test will verify that user access rights are accurately set and enforced, ensuring secure and controlled access to the sDATA portal based on predefined roles and permissions. This validation is crucial for maintaining the integrity and security of the platform while providing a seamless user experience.
Actors	• ASM as metadata steward, • COMS as new data user, • IND as technology porvider
STREAM products	sDATA
Assets & systems	• sDATA – Master Data Management portal
Description of the experiment	One of the main components of the sDATA platform is the Master Data Management (MDM) portal. Within this portal, the user management system and metadata records system are key components. The user management system is essential for managing user data and access rights, ensuring that access to the sDATA portal is both limited and controlled. By conducting this experiment, we aim to ensure that the sDATA portal provides a secure, efficient, and user-friendly environment for managing master data.

	Pre-condition/triggering event: Administrator must have access credentials and permissions to log into the Master data management platform. The user management system within the MDM must be developed and operational. **Steps:** 1. Administrator logs into the MDM platform and adds a new user in the User section. 2. Administrator sets the new user data and access rights. 3. New user logs into the MDM system. 4. The user attempts to access various sections of the portal that they are authorized to view, verifying that permissions are correctly applied, and that access is granted as expected. **Post-condition**: User access rights are accurately set and enforced within the MDM portal, the usage of the portal is user-friendly.
Datasets required for the experiment	• Master Data management data
Field data to be gathered	/
Related KPIs	KPI sDATA.03
Results of the Experiment	
• Roles of Actors: The experiment's execution was clearly divided among the designated actors for the Italian pilot. ASM (metadata steward) acted as the Administrator, responsible for navigating the MDM portal, creating the new user account, and configuring granular access rights. COMS (new data user) acted as the test subject, logging in to verify that the assigned permissions and restrictions were accurately enforced. IND (technology provider) monitored the backend user management system and the MDM portal's responsiveness during these configuration changes. • User Creation and Login: The administrator (ASM) successfully logged into the MDM portal and created a new user account (COMS). The new user was able to successfully log in using the provided credentials.	

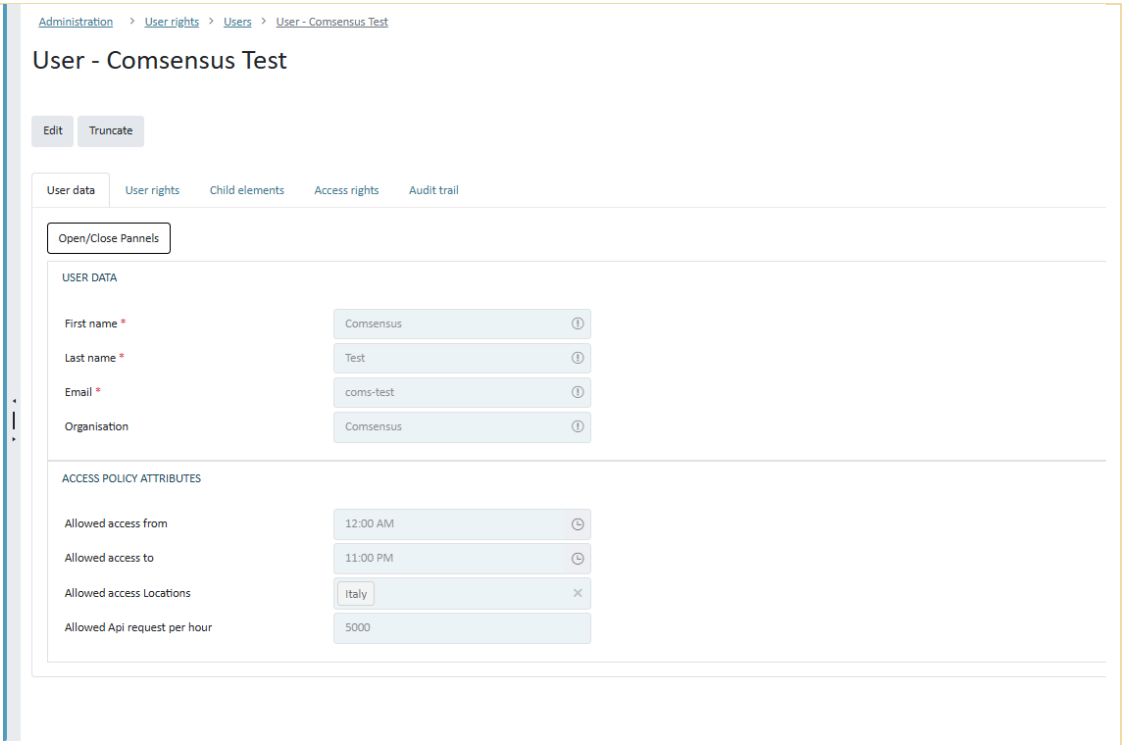


Figure 213: User data

- Examples of Exchanged Data (Workflow): The workflow for defining and saving user permissions was validated. When the Administrator saved the new user profile, the following data payload was processed:

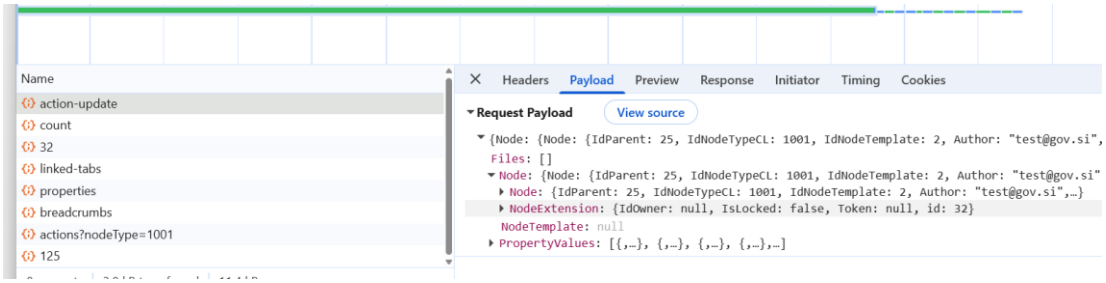


Figure 214: Payload data

- Quantitative Performance Metrics:
  - Latency: The system applied access right configurations. The API response time for saving a new user profile averaged 2500 ms.
  - Verification Speed: The latency for checking user permissions upon navigating to a new module by the test user (COMS) was measured at 420 ms, ensuring a seamless navigation experience without noticeable delays.
- Access Rights Verification (Authorized Access): The new user (COMS) successfully accessed all sections and data for which they were granted permissions. The system displayed the correct data (e.g., Italian pilot EV charging stations, measurement devices) and enabled the appropriate functionalities based on the assigned role.
- Access Rights Verification (Unauthorized Access) & Permission Level Enforcement: The new user was consistently and correctly denied access to all sections of the portal for which they had no permissions (e.g., Administration panels or Slovenian pilot data). In sections where the user had only "Viewer" rights, all "Edit," "Add," and "Delete" functionalities were successfully disabled or hidden.

- Exception Paths Testing: Exception scenarios were executed to test the system's security boundaries:
  - Unauthorized Access Attempt: Attempts by COMS to access restricted areas via direct URL manipulation resulted in a clear "Access Denied" error.
  - Duplicate User: The system correctly prevented the creation of a duplicate user based on an existing email address.
  - Active Session Revocation: The revocation of access rights by ASM during an active user session by COMS was successfully enforced on the user's very next action.
  - Incomplete User Creation: The system successfully blocked saving a profile with missing mandatory fields.

Qualitative analysis of the results

- Usability and User Experience: The user interface for managing users and access rights proved to be intuitive and user-friendly. Both the administrator (ASM) and the test user (COMS) were able to navigate the portal and perform their assigned tasks without needing additional instructions or support. The process of adding a new user and configuring their permissions is straightforward.
- System Responsiveness and Security: The platform responded instantly to all user actions, including login attempts and access requests. The enforcement of access rights was immediate and robust, with no identifiable security gaps or delays in applying permission changes. Error messages for unauthorized actions were clear and informative.
- Observed Limitations and Minor Issues: To provide a realistic assessment, a minor UI limitation was noted: when access was denied via direct URL manipulation, the system displayed a generic "Access Denied" page rather than gracefully redirecting the user back to their previous safe page or the home dashboard. Additionally, while the revocation of rights works on the user's next action, implementing a WebSocket-based instant session termination could further enhance real-time security when an administrator revokes access.
- Overall System Performance: The user management system functions as expected and meets all predefined targets for this test case. It provides a secure and efficient environment for controlling access to sensitive master data within the Italian pilot, demonstrating the maturity and reliability of the MDM portal's user management component.

8.4 FINNISH PILOT SITE

Experiment number	FI-UC.01.01
Name of the experiment	FCR-D: Using apartments' explicit flexibility for FCR-D ancillary services
Timeframe	February 2025 – June 2026 (M26-M45)
Targets	This test scenario verifies that sFLEX is able to meet the requirements to provide FCR-D services to the TSO. Only the FCR-D basic functionality is tested in this test scenario. At the time of estimating the flexible power, implicit flexibility is taken into consideration. Only one FCR-D activation per bid interval is tested in this scenario. It is part of use case FI01 and it verifies steps from 1 to 11. Note that no KPIs are calculated in this test scenario. KPIs are calculated in test scenario FI-UC.01.02.

	All what is described in this scenario shall be repeated in separate test cases for FCR-D-up and FCR-D-down.
Actors	• TSO (Fingrid) – simulated interface • Aggregator (Optiwatti) • Pilot sites (OptiWatti controller in customer's building)
STREAM products	sFLEX, sDATA
Assets & systems	• The test environment includes: sFLEX Server, sFLEX Client, sFLEX Manager, sFLEX Simulator and sFLEX Controllers. Simulated sFLEX Controllers are needed in addition of the real OptiWatti controllers related to the pilot apartments. The frequency is coming from a simulated application (the simulated frequency is needed to test all the acceptance test cases that the TSO requires) and is changed manually. The interface with the TSO is simulated. • The frequency accuracy shall be at least +/- 10 mHz.
Description of the experiment	Being part of the flexible energy market requires estimating the available flexible load, that is, the amount of load that can be cut or added in case of need. Having tens of thousands of load elements requires algorithm to perform this estimation. The combined calculation for all the apartments participating in the FCR is made available directly to the market interface. Bids shall be done every day by 18:30 and are approved on the same day by 22:00 by the TSO. Within a bid document covering the next day, there is information per service for each hour. After activating the flexibility functionality in a building, it is necessary to prove that the required flexibility has been generated and therefore it is necessary to verify and report the used flexibility to the TSO. FCR-D (Frequence Containment Reserve for Disturbances) the service prototyped in the Finnish pilot. It is activated in a short time interval of few seconds for relatively large frequency deviations in order to let slower frequency containment reserves have the time to activate, if the need still persists. This test scenario shall be repeated for the FCR-D-up and for the FCR-D-down, including all the exception paths. **Preconditions:** • sDATA is receiving periodic measurements from the apartments' OptiWatti controllers • Idle state • No bid validity interval is ongoing • Frequency is not monitored • No FCR is active **Steps:** 1. Flexible power estimation is performed by the Aggregator with the Flex Simulator component of sFLEX by taking into consideration also implicit flexibility. The value is stored in sDATA.

	2. A bid is made to the TSO by the Flex Manager component of sFLEX, including the service type, the amount of available load and the price for each hour. 3. The bid is approved by the TSO. The result is stored in sDATA. 4. The bid validity timer starts (60 minutes) to monitor the reserve allocation period. 5. The grid frequency is monitored by sFLEX and logging starts. 6. The aggregator reports the maintained reserve capacity to the TSO every minute. In the prototype, this is done internally in the sFLEX system since the interface to the TSO is simulated. 7. A frequency activation trigger is met (the frequency drops at 49.9 Hz or less (FCR-D-up) / the frequency rises at 50.1 Hz or more (FCR-D-down). 8. The FCR activation procedure starts by cutting (FCR-D-up) or adding (FCR-D-down) load proportionally to the frequency deviation. The Flex Server module of the sFLEX sends the necessary instructions to the Flex Client module. The actual activated flexible power is stored in sDATA. 9. A frequency deactivation trigger is met (the frequency is bigger than 49.9 Hz (FCR-D-up) / the frequency is less than 50.1 Hz (FCR-D-down). 10. The FCR is deactivated. This means that load is reconnected in case of FCR-D-up and cut in case of FCR-D-down. The Flex Server module of the sFLEX sends the necessary instructions to the Flex Client module. 11. KPI FI01_01 FCR activation speed and KPI FI01_02 Flexibility estimation reliability are not calculated in this test scenario. 12. The bid validity time expires. When the bid validity time elapses, procedures are followed based on whether the successive hour has an accepted bid or not, as indicated in the exception paths 12.1, 12.2, 12.3. Here the reference case is described: 13. if the successive hour has an approved bid and the frequency has been restored (and therefore the FCR has been deactivated), then a new bid validity interval shall start and the system shall keep monitoring the grid frequency. **Postconditions:** • The load has been cut/added in a linear kind of way (proportional to the frequency deviation) as defined in Fingrid specifications: after 7,5 seconds 86% of the reserve capacity shall be activated and 3.2 seconds * reserved_capacity MWs of energy has to be used, where reserved_capacity is the approved flexible load.
Exception paths and scenarios of the experiment	Notes (the paths listed below require separate test cases within the same test scenario): • SUCCESSFUL-rejected-bid. When the bid is not accepted by the TSO, the event is logged. No bid validity timer starts and no frequency monitoring takes place. The system goes to idle state. • 8.1. SUCCESSFUL-freq-restored-during-ramp-up. If the frequency is restored during the ramping up period, the FCR activation procedure shall be stopped and FCR deactivation shall start as soon as possible.

	• 12.1. SUCCESSFUL-bid-validity-expires-no-more-bids-freq-not-restored. When the bid validity time expires, if the successive hour has no bid and the frequency has not been restored, then after 15 minutes FCR deactivation procedure shall start and grid frequency monitoring shall be stopped (ramp down shall be done over a 5-minutes period).
	• 12.2. SUCCESSFUL-bid-validity-expires-no-more-bids-freq-restored. When the bid validity time expires, if the successive hour has no bid and the frequency is in normal range, then the system shall go to idle state.
	• 12.3. SUCCESSFUL-bid-validity-expires-more-bids-freq-not-restored. When the bid validity time expires, if the successive hour has an approved bid and the frequency has not been restored, then a new bid validity interval shall start and the FCR activation status shall be transferred to this new bid validity interval. Note that if the following hour has a different sold flexible capacity, the FCR activation status shall be adapted accordingly by increasing or decreasing the activated flexible power.
	• 1.1. ABNORMAL-flex-power-estimation-fails. When the estimation of the available flexible power fails, the event is logged and no bid is made. The system goes to idle state.
	• 3.2. ABNORMAL-no-answer-from-TSO. When no answer is received from the TSO (timer expiration), the event is logged. No bid validity timer starts and no frequency monitoring takes place.
	  ○ The system goes to idle state.
	  ○ In the commercial version of the feature:
	  ▪ If there is an hour bid, then the bid is handled manually (through the VAKSI system). Note: yearly bids cannot be handled through Vaksi.
	  ▪ The user interface shall be checked to see if the bids have reached the system. If the bids are nowhere to be found, Fingrid control center shall be contacted. The EDX shall be checked to see what state the message is in. If the state of the message is “received”, it has been picked up by Fingrid. If the state is, for example, “sent” or “delivered”, the error might also be on the aggregator side.
	• 3.3. ABNORMAL-error-from-TSO. When an error message is received from the TSO (for example, info missing) and there is no accepted bid for this hour, the event is logged. No bid validity timer starts and no frequency monitoring takes place.
	  ○ The error is handled based on the content of the cause code.
	  ○ The system goes to idle state.
	• 3.4. ABNORMAL-error-from-TSO-existing-bid. When an error message is received from the TSO (for example, info missing) and there is already an accepted bid for this hour, the event is logged. The existing information about the bid is used.
	• 8.2. ABNORMAL-no-answer-from-controller-FCR-act. If no answer is received from the OptiWatti controller when activating the FCR, other OptiWatti controllers are used and the event is logged. Otherwise, the scenario continues normally as defined in the reference test case of this test scenario.

	• 8.3. ABNORMAL-error-from-controller-FCR-act. If an error is received from the OptiWatti controller when activating the FCR, other OptiWatti controllers are used and the event is logged. Otherwise, the scenario continues normally as defined in the reference test case of this test scenario. • 10.1. ABNORMAL-no-answer-from-controller-FCR-deact. If no answer is received from the OptiWatti controller when deactivating the FCR, the event is logged and the TSO control center is informed (if only a few OptiWatti controllers lose the connection, there is no need to inform the TSO since the remaining OptiWatti controllers might provide enough active power). If no answer is received by the sFLEX server within 5 minutes, sFLEX server does an implicit ramp down within 5 minutes. This is a tricky case since it might have a destabilizing effect. • 10.2. ABNORMAL-error-from-controller-FCR-deact. If an error is received from the OptiWatti controller when deactivating the FCR, the event is logged and the TSO control center is informed (if only a few OptiWatti controllers lose the connection, there is no need to inform the TSO). If no answer is received by the sFLEX server within 5 minutes, sFLEX server does an implicit ramp down within 5 minutes. This is a tricky case since it might have a destabilizing effect.
Datasets required for the experiment	• FI_01 Configuration data • FI_02 Periodic measurements • FI_03 Energy spot prices • FI_04 Power consumption • FI_09 FCR group bid
Field data to be gathered	• FI_06 Baseline flex power forecast output • FI_08 Flexibility forecast output • FI_11 FCR log
Related KPIs	KPIS are calculated in FI-UC.01.02
Results of the Experiment	
FCR-D-up main test case Note: This case is tested with simulated load. Also, the Fingrid interface is simulated and the frequency is manually simulated. 1) Flexibility estimation and bid to the TSO An **estimation of** how much power will be used during the market day by each room designated for demand-response has been performed by **Flex Simulator**. Information about the clients within the Flex Group has been collected to be used an input for such simulation, including: • heater powers installed in the designated rooms • user settings, such as set temperature and selected spot price controls • weather forecast for the market day • starting room temperatures at the beginning of the simulation The output of the simulation included: • temperature forecast: how much room temperature changes between consecutive iterations • **power forecast**: how much power is used between iterations Those values have been stored into the **Measurements Database**.	

The table in Figure 215 shows the table in the database containing the **simulation results**.

The simulation, which used a sampling interval of 5 minutes, has been done to achieve an **offered flexible power** of **1 Megawatt** for each hour of **a day** for FCR-D-up. This is the minimum power in a FCR-D bid required by the TSO.

This simulation has produced almost 7 million measurements using assets from almost 12 thousand rooms.

```
alfa_measurements=> SELECT COUNT(*) FROM periodic_measurements
WHERE metric IN (30, 31) AND mtimestamp >= '2025-05-24 00:00:00+02' AND mtimestamp < '2025-05-25 00:00:00+02';
  count
---------
 6795072
(1 row)

alfa_measurements=> SELECT COUNT(DISTINCT(roomid)) FROM periodic_measurements
WHERE metric IN (30, 31) AND mtimestamp >= '2025-05-24 00:00:00+02' AND mtimestamp < '2025-05-25 00:00:00+02';
 count
-------
 11797
(1 row)

alfa_measurements=> SELECT mtimestamp, roomid, metric, mvalue AS "simulated_room_temperature" FROM periodic_measurements
WHERE metric IN (30) AND mtimestamp >= '2025-05-24 00:00:00+02' AND mtimestamp < '2025-05-25 00:00:00+02' AND mvalue >0 AND roomid = 29
ORDER BY mtimestamp
LIMIT 10;
       mtimestamp       | roomid | metric | simulated_room_temperature
------------------------+--------+--------+----------------------------
 2025-05-23 22:00:00+00 |     29 |     30 |          22.234524416828297
 2025-05-23 22:05:00+00 |     29 |     30 |          22.224716033227956
 2025-05-23 22:10:00+00 |     29 |     30 |           22.21491520423945
 2025-05-23 22:15:00+00 |     29 |     30 |          22.205121924044064
 2025-05-23 22:20:00+00 |     29 |     30 |           22.19533618682757
 2025-05-23 22:25:00+00 |     29 |     30 |           22.43662112011799
 2025-05-23 22:30:00+00 |     29 |     30 |          22.426657077623346
 2025-05-23 22:35:00+00 |     29 |     30 |          22.416700709632106
 2025-05-23 22:40:00+00 |     29 |     30 |          22.406752010233216
 2025-05-23 22:45:00+00 |     29 |     30 |          22.396810973520175
(10 rows)

alfa_measurements=> SELECT mtimestamp, roomid, metric, mvalue AS "simulated_absorbed_power" FROM periodic_measurements
WHERE metric IN (31) AND mtimestamp >= '2025-05-24 00:00:00+02' AND mtimestamp < '2025-05-25 00:00:00+02' AND mvalue >0 AND roomid = 29
ORDER BY mtimestamp
LIMIT 10;
       mtimestamp       | roomid | metric | simulated_absorbed_power
------------------------+--------+--------+--------------------------
 2025-05-23 22:20:00+00 |     29 |     31 |                   5500.0
 2025-05-24 04:35:00+00 |     29 |     31 |                   5500.0
 2025-05-24 04:40:00+00 |     29 |     31 |                   5500.0
 2025-05-24 04:45:00+00 |     29 |     31 |                   5500.0
 2025-05-24 04:50:00+00 |     29 |     31 |                   5500.0
 2025-05-24 04:55:00+00 |     29 |     31 |                   5500.0
 2025-05-24 05:00:00+00 |     29 |     31 |                   5500.0
 2025-05-24 05:05:00+00 |     29 |     31 |                   5500.0
 2025-05-24 05:35:00+00 |     29 |     31 |                   5500.0
 2025-05-24 18:25:00+00 |     29 |     31 |                   5500.0
(10 rows)
```

Figure 215: FCR-D-up - Simulation results

The Grafana dashboard in Figure 216 visualizes the data. The line in orange colour in the plot shows the simulated temperature and the bars in purple show the simulated power. The set temperature for this room was 16 degrees, the installed power is 530 Watts and the room temperature when the simulation has started was 19.7 degrees.

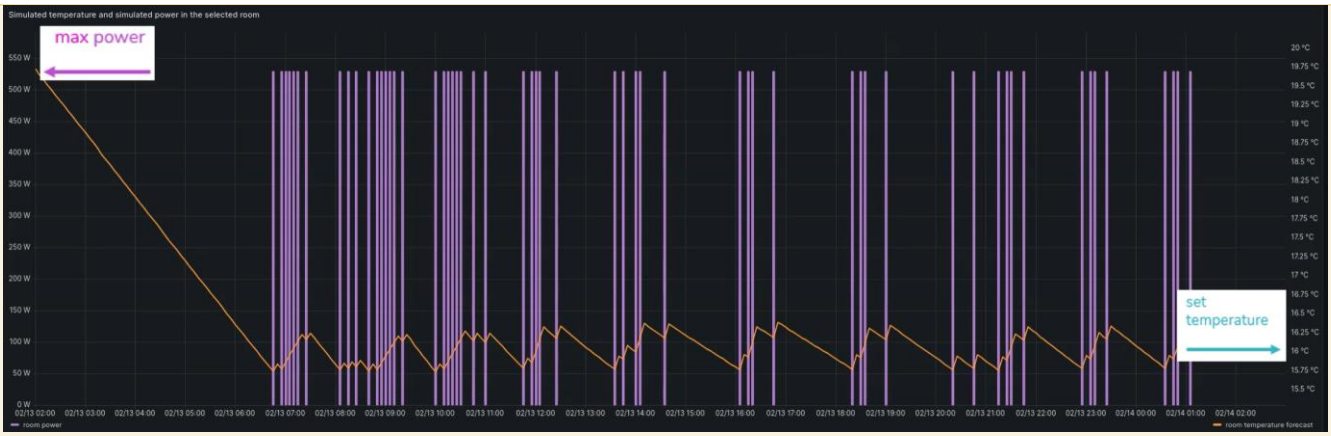


Figure 216 FCR-D-up: Simulation result visualization

In order to make a bid for the market day, the following prerequisites are satisfied:

- Flex market and market day are known
- Aggregator's pricing information is available
- Power forecast from room simulation is available (as described above)

Flex Manager has fetched the simulation results from the Measurements Database, specifically the power forecast, and has further aggregated those results into bid intervals. Flex Manager has created **bid objects** into the **Flex Database** and set the bid status as ready. The bid contains information about how much capacity is offered for each hour and at what price.

Figure 217 shows the flex group 1 that has been created for this test. It has been associated to flex_market_id 1 which is dedicated to FCR-D-up.

```
alfa_flex=> SELECT * FROM owflexdb_flexgroup WHERE id = 1;
 id |   name    | active_first_day | active_last_day | allow_simulate | description |            created            |            updated            | flex_market_id
----+-----------+------------------+-----------------+----------------+-------------+-------------------------------+-------------------------------+----------------
  1 | testgroup | 2025-10-01       | 2025-12-31      | t              | Test Group  | 2025-10-20 10:08:40.571643+00 | 2025-10-23 09:38:31.323929+00 |              1
(1 row)
```

Figure 217: Flex Group

Figure 218 shows the number of rooms used for this test and the amount of installed flexible power in Watt.

```
alfa_flex=> SELECT * FROM owflexdb_flexsimulation WHERE flex_group_id = 1 AND total_power_w >0;
 id | state | fail_reason | flex_group_id |            created            | market_day |            updated            | exp_data_count | iter_step_s | rooms_count | rooms_total | sequence | total_power_w
----+-------+-------------+---------------+-------------------------------+------------+-------------------------------+----------------+-------------+-------------+-------------+----------+---------------
 93 |    40 |             |             1 | 2026-01-19 12:53:58.008899+00 | 2026-01-20 | 2026-01-19 12:54:03.508902+00 |            288 |         300 |        7879 |        7879 |        1 |       9462134
(1 row)
```

Figure 218: Flex simulation input data

Figure 219 contains the output result of the simulations such as the power baseline in Watt.

```
alfa_flex=> SELECT * FROM owflexdb_flexperiodicresult WHERE flex_simulation_id IN (93);
 id |      result_start      |       result_end       | duration_s |  power_forecast_w  |            created            |            updated            | flex_simulation_id
----+------------------------+------------------------+------------+--------------------+-------------------------------+-------------------------------+--------------------
 73 | 2026-01-19 23:00:00+00 | 2026-01-20 00:00:00+00 |       3600 | 3547258.0833333284 | 2026-01-19 12:53:58.03011+00  | 2026-01-19 12:53:58.030122+00 |                 93
 74 | 2026-01-20 00:00:00+00 | 2026-01-20 01:00:00+00 |       3600 | 3872170.0000000014 | 2026-01-19 12:53:58.030467+00 | 2026-01-19 12:53:58.030476+00 |                 93
 75 | 2026-01-20 01:00:00+00 | 2026-01-20 02:00:00+00 |       3600 | 3811723.6666666656 | 2026-01-19 12:53:58.030502+00 | 2026-01-19 12:53:58.030508+00 |                 93
 76 | 2026-01-20 02:00:00+00 | 2026-01-20 03:00:00+00 |       3600 | 3776567.4999999995 | 2026-01-19 12:53:58.030527+00 | 2026-01-19 12:53:58.030532+00 |                 93
 77 | 2026-01-20 03:00:00+00 | 2026-01-20 04:00:00+00 |       3600 | 3679302.5833333344 | 2026-01-19 12:53:58.030551+00 | 2026-01-19 12:53:58.030555+00 |                 93
 78 | 2026-01-20 04:00:00+00 | 2026-01-20 05:00:00+00 |       3600 |  3336251.416666668 | 2026-01-19 12:53:58.030574+00 | 2026-01-19 12:53:58.030579+00 |                 93
 79 | 2026-01-20 05:00:00+00 | 2026-01-20 06:00:00+00 |       3600 |  3153553.749999997 | 2026-01-19 12:53:58.030597+00 | 2026-01-19 12:53:58.030602+00 |                 93
 80 | 2026-01-20 06:00:00+00 | 2026-01-20 07:00:00+00 |       3600 | 2080422.7499999984 | 2026-01-19 12:53:58.030624+00 | 2026-01-19 12:53:58.030629+00 |                 93
 81 | 2026-01-20 07:00:00+00 | 2026-01-20 08:00:00+00 |       3600 |  1954297.333333334 | 2026-01-19 12:53:58.030648+00 | 2026-01-19 12:53:58.030653+00 |                 93
 82 | 2026-01-20 08:00:00+00 | 2026-01-20 09:00:00+00 |       3600 | 2531462.9999999977 | 2026-01-19 12:53:58.030675+00 | 2026-01-19 12:53:58.03068+00  |                 93
 83 | 2026-01-20 09:00:00+00 | 2026-01-20 10:00:00+00 |       3600 | 3958590.4166666656 | 2026-01-19 12:53:58.030698+00 | 2026-01-19 12:53:58.030703+00 |                 93
 84 | 2026-01-20 10:00:00+00 | 2026-01-20 11:00:00+00 |       3600 |  3541795.916666665 | 2026-01-19 12:53:58.030721+00 | 2026-01-19 12:53:58.030726+00 |                 93
 85 | 2026-01-20 11:00:00+00 | 2026-01-20 12:00:00+00 |       3600 | 3626602.5000000037 | 2026-01-19 12:53:58.030746+00 | 2026-01-19 12:53:58.030753+00 |                 93
 86 | 2026-01-20 12:00:00+00 | 2026-01-20 13:00:00+00 |       3600 | 3559079.4999999977 | 2026-01-19 12:53:58.030771+00 | 2026-01-19 12:53:58.030776+00 |                 93
 87 | 2026-01-20 13:00:00+00 | 2026-01-20 14:00:00+00 |       3600 | 3488123.4166666637 | 2026-01-19 12:53:58.030794+00 | 2026-01-19 12:53:58.030799+00 |                 93
 88 | 2026-01-20 14:00:00+00 | 2026-01-20 15:00:00+00 |       3600 | 3397169.4166666702 | 2026-01-19 12:53:58.030817+00 | 2026-01-19 12:53:58.030822+00 |                 93
 89 | 2026-01-20 15:00:00+00 | 2026-01-20 16:00:00+00 |       3600 | 1857195.0000000023 | 2026-01-19 12:53:58.03084+00  | 2026-01-19 12:53:58.030845+00 |                 93
 90 | 2026-01-20 16:00:00+00 | 2026-01-20 17:00:00+00 |       3600 |  1912832.91666667  | 2026-01-19 12:53:58.030863+00 | 2026-01-19 12:53:58.030868+00 |                 93
 91 | 2026-01-20 17:00:00+00 | 2026-01-20 18:00:00+00 |       3600 |  4169015.583333334 | 2026-01-19 12:53:58.03089+00  | 2026-01-19 12:53:58.030895+00 |                 93
 92 | 2026-01-20 18:00:00+00 | 2026-01-20 19:00:00+00 |       3600 |  3719990.333333337 | 2026-01-19 12:53:58.030913+00 | 2026-01-19 12:53:58.030918+00 |                 93
 93 | 2026-01-20 19:00:00+00 | 2026-01-20 20:00:00+00 |       3600 |  3749899.333333335 | 2026-01-19 12:53:58.030936+00 | 2026-01-19 12:53:58.030941+00 |                 93
 94 | 2026-01-20 20:00:00+00 | 2026-01-20 21:00:00+00 |       3600 |   3611458.66666667 | 2026-01-19 12:53:58.030959+00 | 2026-01-19 12:53:58.030964+00 |                 93
 95 | 2026-01-20 21:00:00+00 | 2026-01-20 22:00:00+00 |       3600 | 3625373.9166666656 | 2026-01-19 12:53:58.030982+00 | 2026-01-19 12:53:58.030987+00 |                 93
 96 | 2026-01-20 22:00:00+00 | 2026-01-20 23:00:00+00 |       3600 |  3626003.91666667  | 2026-01-19 12:53:58.031006+00 | 2026-01-19 12:53:58.031013+00 |                 93
(24 rows)
```

Figure 219: Flex simulation results

Figure 220 contains an example of the detailed information of the bids for bid 8. It contains, for each hour of the market day, the available flexible power, the offered flexible capacity and the price in euro in the defined period. The offered flexible capacity is calculated from the available flexible power by multiplying by the scaling factor. The scaling factor is a safety measure for the aggregator to ensure that the offered flexible capacity can be maintained.

```
alfa_flex=> SELECT id, period_start, period_end, duration_s AS "duration_ seconds", raw_capacity_w AS "flex_power_watt", scaling_factor, capacity_mw AS "offered_flex_capacity_MW",
unit_price, amount_price_eur AS "price_in_EUR", bid_id FROM owflexdb_bidperiod WHERE bid_id = 8;
 id  |      period_start      |       period_end       | duration_ seconds |  flex_power_watt   | scaling_factor | offered_flex_capacity_MW | unit_price |     price_in_EUR      | bid_id
-----+------------------------+------------------------+-------------------+--------------------+----------------+--------------------------+------------+-----------------------+--------
 170 | 2025-10-26 23:00:00+00 | 2025-10-27 00:00:00+00 |              3600 |                125 |            0.7 |                  8.75e-05 |        100 |  0.008749999999999999 |      8
 178 | 2025-10-27 07:00:00+00 | 2025-10-27 08:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 171 | 2025-10-27 00:00:00+00 | 2025-10-27 01:00:00+00 |              3600 |                125 |            0.7 |                  8.75e-05 |        100 |  0.008749999999999999 |      8
 172 | 2025-10-27 01:00:00+00 | 2025-10-27 02:00:00+00 |              3600 |               62.5 |            0.7 |                  4.375e-05 |        100 | 0.0043749999999999995 |      8
 173 | 2025-10-27 02:00:00+00 | 2025-10-27 03:00:00+00 |              3600 |               62.5 |            0.7 |                  4.375e-05 |        100 | 0.0043749999999999995 |      8
 174 | 2025-10-27 03:00:00+00 | 2025-10-27 04:00:00+00 |              3600 |                125 |            0.7 |                  8.75e-05 |        100 |  0.008749999999999999 |      8
 175 | 2025-10-27 04:00:00+00 | 2025-10-27 05:00:00+00 |              3600 |               62.5 |            0.7 |                  4.375e-05 |        100 | 0.0043749999999999995 |      8
 176 | 2025-10-27 05:00:00+00 | 2025-10-27 06:00:00+00 |              3600 |               62.5 |            0.7 |                  4.375e-05 |        100 | 0.0043749999999999995 |      8
 177 | 2025-10-27 06:00:00+00 | 2025-10-27 07:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 179 | 2025-10-27 08:00:00+00 | 2025-10-27 09:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 180 | 2025-10-27 09:00:00+00 | 2025-10-27 10:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 181 | 2025-10-27 10:00:00+00 | 2025-10-27 11:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 182 | 2025-10-27 11:00:00+00 | 2025-10-27 12:00:00+00 |              3600 |              437.5 |            0.7 |                  0.00030625 |        100 |                 0.030625 |      8
 183 | 2025-10-27 12:00:00+00 | 2025-10-27 13:00:00+00 |              3600 |                125 |            0.7 |                  8.75e-05 |        100 |  0.008749999999999999 |      8
 184 | 2025-10-27 13:00:00+00 | 2025-10-27 14:00:00+00 |              3600 |               62.5 |            0.7 |                  4.375e-05 |        100 | 0.0043749999999999995 |      8
 185 | 2025-10-27 14:00:00+00 | 2025-10-27 15:00:00+00 |              3600 |            229.167 |            0.7 |   0.00016041689999999999 |        100 |  0.016041689999999997 |      8
 186 | 2025-10-27 15:00:00+00 | 2025-10-27 16:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 188 | 2025-10-27 17:00:00+00 | 2025-10-27 18:00:00+00 |              3600 | 291.66700000000003 |            0.7 |             0.0002041669 |        100 |  0.020416689999999998 |      8
 189 | 2025-10-27 18:00:00+00 | 2025-10-27 19:00:00+00 |              3600 |                  0 |            0.7 |                        0 |        100 |                     0 |      8
 190 | 2025-10-27 19:00:00+00 | 2025-10-27 20:00:00+00 |              3600 |  520.8330000000001 |            0.7 |   0.00036458310000000006 |        100 |   0.03645831000000001 |      8
 191 | 2025-10-27 20:00:00+00 | 2025-10-27 21:00:00+00 |              3600 | 291.66700000000003 |            0.7 |             0.0002041669 |        100 |  0.020416689999999998 |      8
 192 | 2025-10-27 21:00:00+00 | 2025-10-27 22:00:00+00 |              3600 |            229.167 |            0.7 |   0.00016041689999999999 |        100 |  0.016041689999999997 |      8
 193 | 2025-10-27 22:00:00+00 | 2025-10-27 23:00:00+00 |              3600 |  558.3340000000001 |            0.7 |             0.0003908338 |        100 |            0.03908338 |      8
 187 | 2025-10-27 16:00:00+00 | 2025-10-27 17:00:00+00 |              3600 |  520.8330000000001 |            0.7 |   0.00036458310000000006 |        100 |   0.03645831000000001 |      8
(24 rows)
```

Figure 220: Flex bid details

The Grafana plot in Figure 221 uses data from flex alfa database and shows the data of the bid 8 seen in Figure 220. The purple bars show the offered flexible capacity.

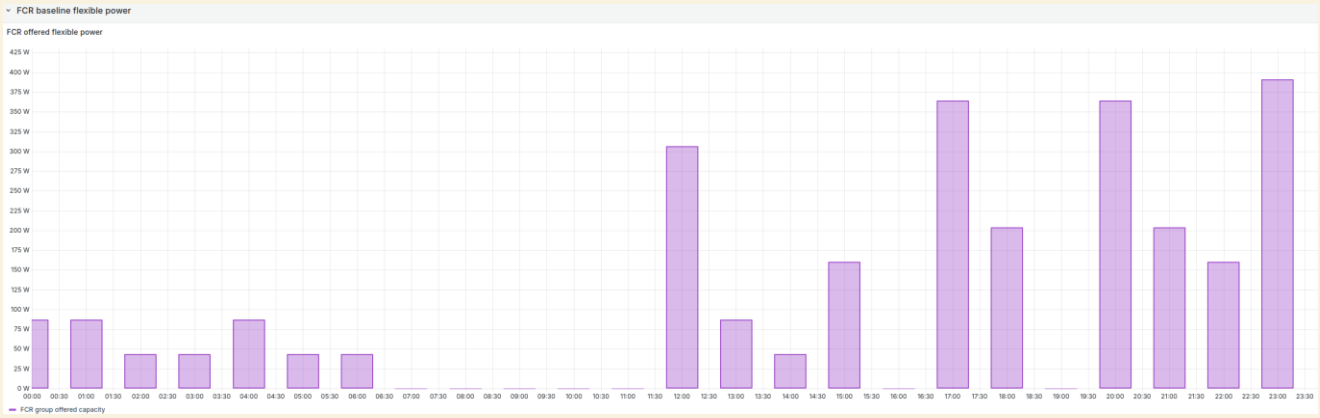


Figure 221: FCR-D-up: Bid data visualization

TSO Connector has fetched the bid in ready state and has created a bid document meant for the TSO.

Since in this experiment the interface to the TSO is simulated, the bid has not actually been sent to the TSO and the answer from the TSO is simulated.

Here we have assumed that the bid document was well formed and did not contain any errors, and thus, TSO Connector has set its state to accepted and has stored the accepted bid into Flex Database.

2) Frequency monitoring; FCR-D-up activation and deactivation

Flex Manager has transferred reserve allocations to the **Redis database** so Flex Server can use them for the upcoming market day. The Redis-server is used as a run-time database for Flex Server. It is very fast because data is kept in memory all the time.

Figure 222 shows the configuration for the Flex Server in the Redis database.

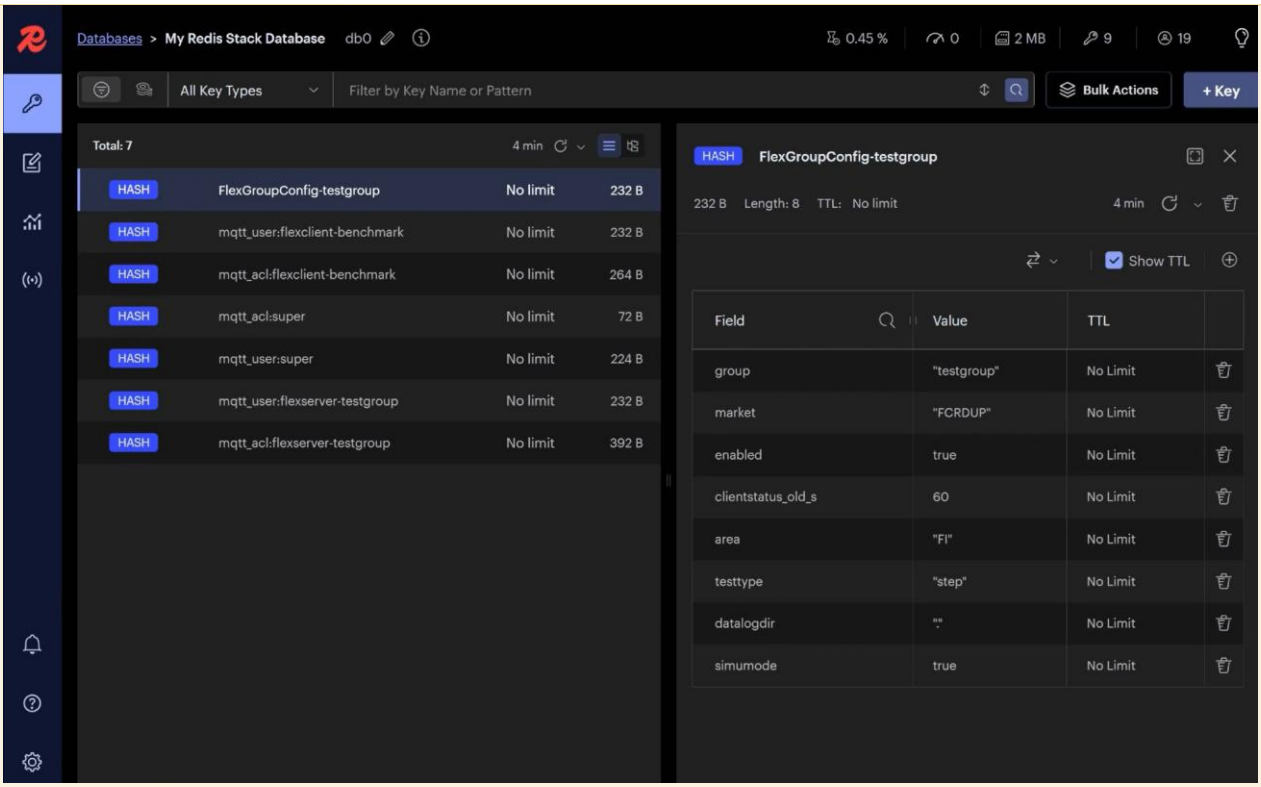


Figure 222: FCR-D-up: Flex Server configuration

Flex Server controls one flex group. The selected market is FCR-D up. The group is enabled and in simulation mode, which means that no real power is controlled. A similar test has been performed by controlling real load.

Figure 223 shows the status of the system when there is no disturbance that falls in the FCR-D range.



Figure 223: FCR-D-up is not activated yet

The simulated grid frequency has changed to 49.5 Hz to activate the flex group, which means **full activation**.

Controller output signal changes from zero to one and the activated power changes from zero to one megawatt. The change is shown in Figure 224.

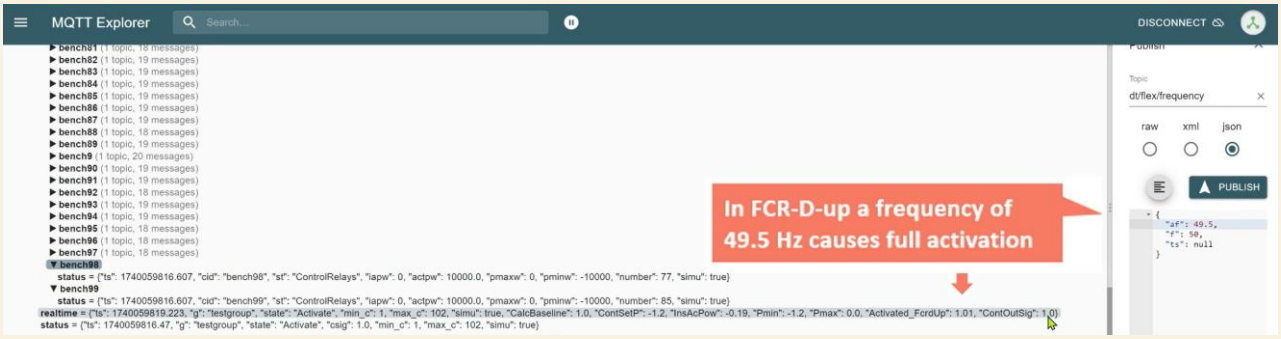


Figure 224: FCR-D-up full activation

The frequency is changed to 49.7 Hz, which means **50% activation**. The situation is shown in Figure 225.



Figure 225 FCR-D-up at 50% activation

The frequency is changed back to 49.9 Hz, which means **zero activation**. See Figure 226.



Figure 226: FCR-D-up deactivation

Flex Server has written a **FCR Log** when it was actively controlling the flex group.

The TSO may want to see this file to check how well this reserve works.

Since the interface to the TSO is simulated, the report with the essential information to the TSO every minute has not been sent.

FCR-D-up exception paths

- Case 1.1 ABNORMAL-flex-power-estimation-fails: PASSED
- Case 3.1 SUCCESSFUL-rejected-bid: PASSED (same as case 3.3)
- Case 3.2 ABNORMAL-no-answer-from-TSO: PASSED
- Case 3.3 ABNORMAL-error-from-TSO: PASSED
- Case 3.4 ABNORMAL-error-from-TSO-existing-bid: PASSED
- Case 8.1 SUCCESSFUL-freq-restored-during-ramp-up PASSED
- Case 8.2 ABNORMAL-no-answer-from-controller-FCR-act PASSED
- Case 8.3 ABNORMAL-error-from-controller-FCR-act PASSED
- Case 10.1 ABNORMAL-no-answer-from-controller-FCR-deact PASSED
- Case 10.2 ABNORMAL-error-from-controller-FCR-deact PASSED
- Case 12.1 SUCCESSFUL-bid-validity-expires-no-more-bids-freq-not-restored: PASSED
- Case 12.2 SUCCESSFUL-bid-validity-expires-no-more-bids-freq-restored: PASSED
- Case 12.3 SUCCESSFUL-bid-validity-expires-more-bids-freq-not-restored: PASSED

FCR-D-down main test case

Note: This case is tested with real load. Only 2 pilot apartments are used. Also, the Fingrid interface is simulated and the frequency is manually simulated.

1) Flexibility estimation and bid to the TSO

An **estimation of** how much power will be used during the market day by each room designated for demand-response has been performed by **Flex Simulator**.

Information about the clients within the Flex Group has been collected to be used an input for such simulation, including:

- heater powers installed in the designated rooms
- user settings, such as set temperature and selected spot price controls
- weather forecast for the market day
- starting room temperatures at the beginning of the simulation

The output of the simulation included:

- temperature forecast: how much room temperature changes between consecutive iterations
- **power forecast**: how much power is used between iterations

Those values have been stored into the **Measurements Database**.

The table in Figure 227 shows the table in the database containing the **simulation results**.

The simulation, which used a sampling interval of 5 minutes, covers a period of about 2 weeks for few selected rooms (9 rooms) corresponding to real flexibility assets.

```
alfa_measurements=> SELECT COUNT(*) FROM periodic_measurements WHERE metric IN (30, 31) AND mtimestamp >= '2025-11-06 00:00:00+02'
AND mtimestamp < '2025-11-25 00:00:00+02';
 count
-------
 98352
(1 row)

alfa_measurements=> SELECT DISTINCT(roomid) FROM periodic_measurements WHERE metric IN (30, 31) AND mtimestamp >= '2025-11-06 00:00
:00+02' AND mtimestamp < '2025-11-25 00:00:00+02';
 roomid
--------
  19992
  19995
  20429
   6128
   5908
  19993
  19994
  16654
   5903
(9 rows)

alfa_measurements=> SELECT mtimestamp, roomid, metric, mvalue AS "simulated_room_temperature" FROM periodic_measurements WHERE room
id = 19992 AND metric = 30 AND mtimestamp >= '2025-11-21 00:00:00+02' AND mtimestamp < '2025-11-25 00:00:00+02' LIMIT 10;
       mtimestamp       | roomid | metric | simulated_room_temperature
------------------------+--------+--------+----------------------------
 2025-11-24 21:55:00+00 |  19992 |     30 |          16.197055947306783
 2025-11-24 21:50:00+00 |  19992 |     30 |           16.17902107538503
 2025-11-24 21:45:00+00 |  19992 |     30 |          16.160975039111058
 2025-11-24 21:40:00+00 |  19992 |     30 |          16.142917831573655
 2025-11-24 21:35:00+00 |  19992 |     30 |          16.124849445857336
 2025-11-24 21:30:00+00 |  19992 |     30 |          16.106769875042335
 2025-11-24 21:25:00+00 |  19992 |     30 |            16.0886791122046
 2025-11-24 21:20:00+00 |  19992 |     30 |           16.07057715041579
 2025-11-24 21:15:00+00 |  19992 |     30 |           16.05246398274328
 2025-11-24 21:10:00+00 |  19992 |     30 |          16.034339602250153
(10 rows)

alfa_measurements=> SELECT mtimestamp, roomid, metric, mvalue AS "simulated_absorbed_power" FROM periodic_measurements WHERE roomid
 = 19992 AND metric = 31 AND mtimestamp >= '2025-11-21 00:00:00+02' AND mtimestamp < '2025-11-25 00:00:00+02' LIMIT 10;
       mtimestamp       | roomid | metric | simulated_absorbed_power
------------------------+--------+--------+--------------------------
 2025-11-24 21:55:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:50:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:45:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:40:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:35:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:30:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:25:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:20:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:15:00+00 |  19992 |     31 |                   1600.0
 2025-11-24 21:10:00+00 |  19992 |     31 |                   1600.0
(10 rows)
```

Figure 227: FCR-D-down - Simulation results

The Grafana dashboard in Figure 228 visualizes the data for one room. The line in orange colour in the plot shows the simulated temperature and the bars in purple show the simulated power. The installed power is

1.600 Watts and the room temperature when the simulation has started was 16.2 degrees. The set temperature is adjusted by the spot price settings since this customer does not have a fixed price contract.



Figure 228: FCR-D-down - Simulation result visualization

In order to make a bid for the market day, the following prerequisites are satisfied:

- Flex market and market day are known
- Aggregator's pricing information is available
- Power forecast from room simulation is available (as described above)

Flex Manager has fetched the simulation results from the Measurements Database, specifically the power forecast, and has further aggregated those results into bid intervals. Flex Manager has created **bid objects** into the **Flex Database** and set the bid status as ready. The bid contains information about how much capacity is offered for each hour and at what price.

Figure 229 shows that flex group 2 has been created for this test. It has been associated to FCR-D-down.

```
alfa_flex=> SELECT * FROM owflexdb_flexgroup WHERE id = 2;
 id |   name    | active_first_day | active_last_day | allow_simulate |         description          |            created            |            updated            | flex_market_id
----+-----------+------------------+-----------------+----------------+------------------------------+-------------------------------+-------------------------------+----------------
  2 | alfagroup | 2025-11-01       | 2026-06-30      | t              | Flex Group for Ljubljana demo | 2025-11-05 12:47:10.239871+00 | 2026-01-16 06:45:48.590326+00 |              2
(1 row)
```

Figure 229: Flex Group

Figure 230 shows the amount of rooms used for this test and the amount of installed flexible power in Watt.

```
alfa_flex=> SELECT * FROM owflexdb_flexsimulation WHERE flex_group_id = 2 AND total_power_w >0;
 id | state | fail_reason | flex_group_id |            created            | market_day |            updated            | exp_data_count | iter_step_s | rooms_count | rooms_total | sequence | total_power_w
----+-------+-------------+---------------+-------------------------------+------------+-------------------------------+----------------+-------------+-------------+-------------+----------+---------------
 92 |    40 |             |             2 | 2026-01-19 12:25:49.726223+00 | 2026-01-20 | 2026-01-19 12:25:49.789783+00 |            288 |         300 |           9 |           9 |        1 |          7500
 91 |    40 |             |             2 | 2026-01-19 11:26:48.242775+00 | 2026-01-16 | 2026-01-19 11:26:48.308578+00 |            288 |         300 |           9 |           9 |        2 |          7500
(2 rows)
```

Figure 230: Flex simulation input data

Figure 231 contains the output result of the simulations such as the power baseline in Watt.

```
alfa_flex=> SELECT * FROM owflexdb_flexperiodicresult WHERE flex_simulation_id IN (91, 92);
 id |       result_start        |        result_end         | duration_s |  power_forecast_w  |            created            |            updated            | flex_simulation_id
----+---------------------------+---------------------------+------------+--------------------+-------------------------------+-------------------------------+--------------------
 25 | 2026-01-15 23:00:00+00    | 2026-01-16 00:00:00+00    |       3600 |               1325 | 2026-01-19 11:26:48.262661+00 | 2026-01-19 11:26:48.262668+00 |                 91
 26 | 2026-01-16 00:00:00+00    | 2026-01-16 01:00:00+00    |       3600 | 1595.8333333333335 | 2026-01-19 11:26:48.262689+00 | 2026-01-19 11:26:48.262694+00 |                 91
 27 | 2026-01-16 01:00:00+00    | 2026-01-16 02:00:00+00    |       3600 | 1520.8333333333333 | 2026-01-19 11:26:48.262713+00 | 2026-01-19 11:26:48.262718+00 |                 91
 28 | 2026-01-16 02:00:00+00    | 2026-01-16 03:00:00+00    |       3600 | 1520.8333333333333 | 2026-01-19 11:26:48.262736+00 | 2026-01-19 11:26:48.26274+00  |                 91
 29 | 2026-01-16 03:00:00+00    | 2026-01-16 04:00:00+00    |       3600 | 1695.8333333333335 | 2026-01-19 11:26:48.262759+00 | 2026-01-19 11:26:48.262763+00 |                 91
 30 | 2026-01-16 04:00:00+00    | 2026-01-16 05:00:00+00    |       3600 |             1337.5 | 2026-01-19 11:26:48.262782+00 | 2026-01-19 11:26:48.262786+00 |                 91
 31 | 2026-01-16 05:00:00+00    | 2026-01-16 06:00:00+00    |       3600 | 1666.6666666666667 | 2026-01-19 11:26:48.262804+00 | 2026-01-19 11:26:48.262809+00 |                 91
 32 | 2026-01-16 06:00:00+00    | 2026-01-16 07:00:00+00    |       3600 |                950 | 2026-01-19 11:26:48.262827+00 | 2026-01-19 11:26:48.262831+00 |                 91
 33 | 2026-01-16 07:00:00+00    | 2026-01-16 08:00:00+00    |       3600 |                  0 | 2026-01-19 11:26:48.262849+00 | 2026-01-19 11:26:48.262854+00 |                 91
 34 | 2026-01-16 08:00:00+00    | 2026-01-16 09:00:00+00    |       3600 | 1483.3333333333333 | 2026-01-19 11:26:48.262872+00 | 2026-01-19 11:26:48.262877+00 |                 91
 35 | 2026-01-16 09:00:00+00    | 2026-01-16 10:00:00+00    |       3600 |             3487.5 | 2026-01-19 11:26:48.262895+00 | 2026-01-19 11:26:48.262899+00 |                 91
 36 | 2026-01-16 10:00:00+00    | 2026-01-16 11:00:00+00    |       3600 |  3170.833333333333 | 2026-01-19 11:26:48.262917+00 | 2026-01-19 11:26:48.262922+00 |                 91
 37 | 2026-01-16 11:00:00+00    | 2026-01-16 12:00:00+00    |       3600 |  3104.166666666667 | 2026-01-19 11:26:48.262944+00 | 2026-01-19 11:26:48.262949+00 |                 91
 38 | 2026-01-16 12:00:00+00    | 2026-01-16 13:00:00+00    |       3600 |  3008.333333333333 | 2026-01-19 11:26:48.263261+00 | 2026-01-19 11:26:48.263267+00 |                 91
 39 | 2026-01-16 13:00:00+00    | 2026-01-16 14:00:00+00    |       3600 |             2337.5 | 2026-01-19 11:26:48.263286+00 | 2026-01-19 11:26:48.263291+00 |                 91
 40 | 2026-01-16 14:00:00+00    | 2026-01-16 15:00:00+00    |       3600 |               2025 | 2026-01-19 11:26:48.263309+00 | 2026-01-19 11:26:48.263313+00 |                 91
 41 | 2026-01-16 15:00:00+00    | 2026-01-16 16:00:00+00    |       3600 |             2237.5 | 2026-01-19 11:26:48.263337+00 | 2026-01-19 11:26:48.263342+00 |                 91
 42 | 2026-01-16 16:00:00+00    | 2026-01-16 17:00:00+00    |       3600 | 2166.6666666666665 | 2026-01-19 11:26:48.26336+00  | 2026-01-19 11:26:48.263365+00 |                 91
 43 | 2026-01-16 17:00:00+00    | 2026-01-16 18:00:00+00    |       3600 |             2362.5 | 2026-01-19 11:26:48.263383+00 | 2026-01-19 11:26:48.263388+00 |                 91
 44 | 2026-01-16 18:00:00+00    | 2026-01-16 19:00:00+00    |       3600 | 2033.3333333333333 | 2026-01-19 11:26:48.263406+00 | 2026-01-19 11:26:48.26341+00  |                 91
 45 | 2026-01-16 19:00:00+00    | 2026-01-16 20:00:00+00    |       3600 |  2104.166666666667 | 2026-01-19 11:26:48.263432+00 | 2026-01-19 11:26:48.263437+00 |                 91
 46 | 2026-01-16 20:00:00+00    | 2026-01-16 21:00:00+00    |       3600 | 1491.6666666666665 | 2026-01-19 11:26:48.263455+00 | 2026-01-19 11:26:48.26346+00  |                 91
 47 | 2026-01-16 21:00:00+00    | 2026-01-16 22:00:00+00    |       3600 | 3491.6666666666665 | 2026-01-19 11:26:48.263478+00 | 2026-01-19 11:26:48.263483+00 |                 91
 48 | 2026-01-16 22:00:00+00    | 2026-01-16 23:00:00+00    |       3600 | 3170.8333333333335 | 2026-01-19 11:26:48.263501+00 | 2026-01-19 11:26:48.263505+00 |                 91
 49 | 2026-01-19 23:00:00+00    | 2026-01-20 00:00:00+00    |       3600 | 1083.3333333333335 | 2026-01-19 12:25:49.745665+00 | 2026-01-19 12:25:49.745673+00 |                 92
 50 | 2026-01-20 00:00:00+00    | 2026-01-20 01:00:00+00    |       3600 | 1216.6666666666665 | 2026-01-19 12:25:49.745694+00 | 2026-01-19 12:25:49.745699+00 |                 92
 51 | 2026-01-20 01:00:00+00    | 2026-01-20 02:00:00+00    |       3600 | 1383.3333333333333 | 2026-01-19 12:25:49.745717+00 | 2026-01-19 12:25:49.745722+00 |                 92
 52 | 2026-01-20 02:00:00+00    | 2026-01-20 03:00:00+00    |       3600 | 1320.8333333333333 | 2026-01-19 12:25:49.74574+00  | 2026-01-19 12:25:49.745744+00 |                 92
 53 | 2026-01-20 03:00:00+00    | 2026-01-20 04:00:00+00    |       3600 | 1866.6666666666665 | 2026-01-19 12:25:49.745762+00 | 2026-01-19 12:25:49.745767+00 |                 92
 54 | 2026-01-20 04:00:00+00    | 2026-01-20 05:00:00+00    |       3600 |                700 | 2026-01-19 12:25:49.745785+00 | 2026-01-19 12:25:49.74579+00  |                 92
 55 | 2026-01-20 05:00:00+00    | 2026-01-20 06:00:00+00    |       3600 | 1091.6666666666667 | 2026-01-19 12:25:49.745808+00 | 2026-01-19 12:25:49.745813+00 |                 92
 56 | 2026-01-20 06:00:00+00    | 2026-01-20 07:00:00+00    |       3600 |                  0 | 2026-01-19 12:25:49.74583+00  | 2026-01-19 12:25:49.745835+00 |                 92
 57 | 2026-01-20 07:00:00+00    | 2026-01-20 08:00:00+00    |       3600 |                  0 | 2026-01-19 12:25:49.745853+00 | 2026-01-19 12:25:49.745857+00 |                 92
 58 | 2026-01-20 08:00:00+00    | 2026-01-20 09:00:00+00    |       3600 |                  0 | 2026-01-19 12:25:49.745875+00 | 2026-01-19 12:25:49.74588+00  |                 92
 59 | 2026-01-20 09:00:00+00    | 2026-01-20 10:00:00+00    |       3600 | 4079.1666666666665 | 2026-01-19 12:25:49.745911+00 | 2026-01-19 12:25:49.745916+00 |                 92
 60 | 2026-01-20 10:00:00+00    | 2026-01-20 11:00:00+00    |       3600 | 2345.8333333333335 | 2026-01-19 12:25:49.745933+00 | 2026-01-19 12:25:49.745938+00 |                 92
 61 | 2026-01-20 11:00:00+00    | 2026-01-20 12:00:00+00    |       3600 | 1483.3333333333333 | 2026-01-19 12:25:49.745956+00 | 2026-01-19 12:25:49.745961+00 |                 92
 62 | 2026-01-20 12:00:00+00    | 2026-01-20 13:00:00+00    |       3600 | 1579.1666666666667 | 2026-01-19 12:25:49.745983+00 | 2026-01-19 12:25:49.745988+00 |                 92
 63 | 2026-01-20 13:00:00+00    | 2026-01-20 14:00:00+00    |       3600 |               1850 | 2026-01-19 12:25:49.746007+00 | 2026-01-19 12:25:49.746012+00 |                 92
 64 | 2026-01-20 14:00:00+00    | 2026-01-20 15:00:00+00    |       3600 |             2937.5 | 2026-01-19 12:25:49.74603+00  | 2026-01-19 12:25:49.746035+00 |                 92
 65 | 2026-01-20 15:00:00+00    | 2026-01-20 16:00:00+00    |       3600 |                  0 | 2026-01-19 12:25:49.746053+00 | 2026-01-19 12:25:49.746057+00 |                 92
 66 | 2026-01-20 16:00:00+00    | 2026-01-20 17:00:00+00    |       3600 |                  0 | 2026-01-19 12:25:49.746075+00 | 2026-01-19 12:25:49.74608+00  |                 92
 67 | 2026-01-20 17:00:00+00    | 2026-01-20 18:00:00+00    |       3600 |  4679.166666666667 | 2026-01-19 12:25:49.746098+00 | 2026-01-19 12:25:49.746103+00 |                 92
 68 | 2026-01-20 18:00:00+00    | 2026-01-20 19:00:00+00    |       3600 |  2570.833333333333 | 2026-01-19 12:25:49.74612+00  | 2026-01-19 12:25:49.746125+00 |                 92
 69 | 2026-01-20 19:00:00+00    | 2026-01-20 20:00:00+00    |       3600 |  2504.166666666667 | 2026-01-19 12:25:49.746143+00 | 2026-01-19 12:25:49.746148+00 |                 92
 70 | 2026-01-20 20:00:00+00    | 2026-01-20 21:00:00+00    |       3600 |  2083.333333333333 | 2026-01-19 12:25:49.746166+00 | 2026-01-19 12:25:49.74617+00  |                 92
 71 | 2026-01-20 21:00:00+00    | 2026-01-20 22:00:00+00    |       3600 | 2704.1666666666665 | 2026-01-19 12:25:49.746188+00 | 2026-01-19 12:25:49.746193+00 |                 92
 72 | 2026-01-20 22:00:00+00    | 2026-01-20 23:00:00+00    |       3600 |               3875 | 2026-01-19 12:25:49.746211+00 | 2026-01-19 12:25:49.746215+00 |                 92
(48 rows)
```

Figure 231: Flex simulation results

Figure 232 contains the most relevant information related the bids. Bids 21 to 40 have been created for different market days by using Flex Group 2.

```
alfa_flex=> SELECT id, created, updated, flex_group_id, market_day, submitted_at, ack_at, rejection_reason FROM owflexdb_bid WHERE flex_group_id = 2 AND market_day <= '2025-11-24' ORDER BY market_day;
 id |           created           |           updated           | flex_group_id | market_day |        submitted_at         |           ack_at            | rejection_reason
----+-----------------------------+-----------------------------+---------------+------------+-----------------------------+-----------------------------+------------------
 21 | 2025-11-05 14:00:02.475826+00 | 2025-11-05 14:16:03.67462+00  |             2 | 2025-11-06 | 2025-11-05 14:15:02.717823+00 | 2025-11-05 14:16:03.674515+00 | {}
 22 | 2025-11-06 14:00:02.7637+00   | 2025-11-06 14:16:03.722328+00 |             2 | 2025-11-07 | 2025-11-06 14:15:02.806292+00 | 2025-11-06 14:16:03.722227+00 | {}
 23 | 2025-11-07 14:00:02.660904+00 | 2025-11-07 14:16:03.605473+00 |             2 | 2025-11-08 | 2025-11-07 14:15:02.706772+00 | 2025-11-07 14:16:03.605361+00 | {}
 24 | 2025-11-08 14:00:02.08477+00  | 2025-11-08 14:16:03.442026+00 |             2 | 2025-11-09 | 2025-11-08 14:15:02.516002+00 | 2025-11-08 14:16:03.44189+00  | {}
 25 | 2025-11-09 14:00:02.946199+00 | 2025-11-09 14:16:04.187952+00 |             2 | 2025-11-10 | 2025-11-09 14:15:03.011621+00 | 2025-11-09 14:16:04.187779+00 | {}
 26 | 2025-11-10 14:00:02.617668+00 | 2025-11-10 14:16:03.575661+00 |             2 | 2025-11-11 | 2025-11-10 14:15:02.434552+00 | 2025-11-10 14:16:03.575555+00 | {}
 27 | 2025-11-11 14:00:03.020394+00 | 2025-11-11 14:16:03.039341+00 |             2 | 2025-11-12 | 2025-11-11 14:15:02.124015+00 | 2025-11-11 14:16:03.039204+00 | {}
 28 | 2025-11-12 14:00:02.016483+00 | 2025-11-12 14:16:03.10684+00  |             2 | 2025-11-13 | 2025-11-12 14:15:02.183546+00 | 2025-11-12 14:16:03.106718+00 | {}
 29 | 2025-11-13 14:00:02.947959+00 | 2025-11-13 14:16:03.409865+00 |             2 | 2025-11-14 | 2025-11-13 14:15:02.249028+00 | 2025-11-13 14:16:03.40972+00  | {}
 30 | 2025-11-14 14:00:02.752674+00 | 2025-11-14 14:16:03.6987+00   |             2 | 2025-11-15 | 2025-11-14 14:15:02.737346+00 | 2025-11-14 14:16:03.698591+00 | {}
 31 | 2025-11-15 14:00:02.899292+00 | 2025-11-15 14:16:03.679953+00 |             2 | 2025-11-16 | 2025-11-15 14:15:02.777063+00 | 2025-11-15 14:16:03.679828+00 | {}
 32 | 2025-11-16 14:00:02.252043+00 | 2025-11-16 14:16:02.903179+00 |             2 | 2025-11-17 | 2025-11-16 14:15:01.946931+00 | 2025-11-16 14:16:02.903053+00 | {}
 33 | 2025-11-17 14:00:02.190421+00 | 2025-11-17 14:16:03.672448+00 |             2 | 2025-11-18 | 2025-11-17 14:15:02.750691+00 | 2025-11-17 14:16:03.672336+00 | {}
 34 | 2025-11-18 14:00:02.87901+00  | 2025-11-18 14:16:04.032532+00 |             2 | 2025-11-19 | 2025-11-18 14:15:02.905456+00 | 2025-11-18 14:16:04.03238+00  | {}
 35 | 2025-11-19 14:00:02.547628+00 | 2025-11-19 14:16:03.738003+00 |             2 | 2025-11-20 | 2025-11-19 14:15:02.829751+00 | 2025-11-19 14:16:03.737838+00 | {}
 37 | 2025-11-20 13:06:00.770667+00 | 2025-11-20 14:16:03.153246+00 |             2 | 2025-11-21 | 2025-11-20 14:15:02.213283+00 | 2025-11-20 14:16:03.153133+00 | {}
 38 | 2025-11-21 14:00:02.522408+00 | 2025-11-21 14:16:03.526806+00 |             2 | 2025-11-22 | 2025-11-21 14:15:02.593857+00 | 2025-11-21 14:16:03.526693+00 | {}
 39 | 2025-11-22 14:00:02.468358+00 | 2025-11-22 14:16:03.572468+00 |             2 | 2025-11-23 | 2025-11-22 14:15:02.458299+00 | 2025-11-22 14:16:03.572315+00 | {}
 40 | 2025-11-23 14:00:02.796561+00 | 2025-11-23 14:16:02.959592+00 |             2 | 2025-11-24 | 2025-11-23 14:15:01.998618+00 | 2025-11-23 14:16:02.959476+00 | {}
(19 rows)
```

Figure 232: Flex bids

Figure 233 contains an example of the detailed information of the bids for bid 27. It contains, for each hour, the available flexible power, the offered flexible capacity and the price in euro in the defined period. The offered flexible capacity is calculated from the available flexible power by multiplying by the scaling factor.

```
alfa_flex=> SELECT id, period_start, period_end, duration_s AS "duration_ seconds", raw_capacity_w AS "flex_power_watt", scaling_factor, capacity_mw AS "offered_flex_capacoty_MW",
alfa_flex-> unit_price, amount_price_eur AS "price_in_EUR", bid_id FROM owflexdb_bidperiod WHERE bid_id = 27;
 id  |      period_start      |       period_end       | duration_ seconds |  flex_power_watt   | scaling_factor | offered_flex_capacoty_MW | unit_price |    price_in_EUR     | bid_id
-----+------------------------+------------------------+-------------------+--------------------+----------------+--------------------------+------------+---------------------+--------
 627 | 2025-11-12 00:00:00+00 | 2025-11-12 01:00:00+00 |              3600 |               1175 |            0.7 |                0.0008225 |        100 |             0.08225 |     27
 649 | 2025-11-12 22:00:00+00 | 2025-11-12 23:00:00+00 |              3600 |            2104.167 |            0.7 |               0.0014729169 |        100 |          0.14729169 |     27
 626 | 2025-11-11 23:00:00+00 | 2025-11-12 00:00:00+00 |              3600 |            3091.667 |            0.7 |               0.0021641669 |        100 |  0.21641668999999997 |     27
 633 | 2025-11-12 06:00:00+00 | 2025-11-12 07:00:00+00 |              3600 |            2204.167 |            0.7 |               0.0015429169 |        100 |  0.15429168999999998 |     27
 642 | 2025-11-12 15:00:00+00 | 2025-11-12 16:00:00+00 |              3600 | 1837.4999999999998 |            0.7 |    0.0012862499999999999 |        100 |               0.128625 |     27
 628 | 2025-11-12 01:00:00+00 | 2025-11-12 02:00:00+00 |              3600 | 1383.3339999999998 |            0.7 |    0.0009683337999999998 |        100 |  0.09683337999999998 |     27
 629 | 2025-11-12 02:00:00+00 | 2025-11-12 03:00:00+00 |              3600 |            1829.166 |            0.7 |    0.0012804161999999998 |        100 |  0.12804161999999997 |     27
 630 | 2025-11-12 03:00:00+00 | 2025-11-12 04:00:00+00 |              3600 |            1408.333 |            0.7 |               0.0009858331 |        100 |  0.09858331000000001 |     27
 631 | 2025-11-12 04:00:00+00 | 2025-11-12 05:00:00+00 |              3600 |            1591.667 |            0.7 |    0.0011141668999999999 |        100 |  0.11141668999999998 |     27
 632 | 2025-11-12 05:00:00+00 | 2025-11-12 06:00:00+00 |              3600 |             1837.5 |            0.7 |               0.00128625 |        100 |  0.12862500000000002 |     27
 634 | 2025-11-12 07:00:00+00 | 2025-11-12 08:00:00+00 |              3600 |            3204.167 |            0.7 |    0.0022429168999999996 |        100 |  0.22429168999999996 |     27
 635 | 2025-11-12 08:00:00+00 | 2025-11-12 09:00:00+00 |              3600 |            2845.833 |            0.7 |               0.0019920831 |        100 |           0.19920831 |     27
 636 | 2025-11-12 09:00:00+00 | 2025-11-12 10:00:00+00 |              3600 |            1904.166 |            0.7 |    0.0013329161999999998 |        100 |  0.13329161999999997 |     27
 637 | 2025-11-12 10:00:00+00 | 2025-11-12 11:00:00+00 |              3600 |            1641.667 |            0.7 |               0.0011491669 |        100 |  0.11491668999999999 |     27
 638 | 2025-11-12 11:00:00+00 | 2025-11-12 12:00:00+00 |              3600 |             1737.5 |            0.7 |               0.00121625 |        100 |  0.12162500000000001 |     27
 639 | 2025-11-12 12:00:00+00 | 2025-11-12 13:00:00+00 |              3600 | 1916.6660000000002 |            0.7 |               0.0013416662 |        100 |  0.13416662000000001 |     27
 640 | 2025-11-12 13:00:00+00 | 2025-11-12 14:00:00+00 |              3600 |            2004.167 |            0.7 |               0.0014029169 |        100 |          0.14029169 |     27
 641 | 2025-11-12 14:00:00+00 | 2025-11-12 15:00:00+00 |              3600 |               1575 |            0.7 |                0.0011025 |        100 |           0.11025 |     27
 643 | 2025-11-12 16:00:00+00 | 2025-11-12 17:00:00+00 |              3600 | 1379.1660000000002 |            0.7 |               0.0009654162 |        100 |  0.09654162000000001 |     27
 644 | 2025-11-12 17:00:00+00 | 2025-11-12 18:00:00+00 |              3600 |               1600 |            0.7 |                 0.00112 |        100 |  0.11199999999999999 |     27
 645 | 2025-11-12 18:00:00+00 | 2025-11-12 19:00:00+00 |              3600 |            1645.833 |            0.7 |               0.0011520831 |        100 |           0.11520831 |     27
 646 | 2025-11-12 19:00:00+00 | 2025-11-12 20:00:00+00 |              3600 | 1708.3339999999998 |            0.7 |               0.0011958338 |        100 |  0.11958337999999999 |     27
 647 | 2025-11-12 20:00:00+00 | 2025-11-12 21:00:00+00 |              3600 |            1641.667 |            0.7 |               0.0011491669 |        100 |  0.11491668999999999 |     27
 648 | 2025-11-12 21:00:00+00 | 2025-11-12 22:00:00+00 |              3600 | 2045.8329999999999 |            0.7 |    0.0014320830999999998 |        100 |  0.14320830999999998 |     27
(24 rows)
```

Figure 233: Flex bid details

The Grafana plot in Figure 234 uses data from flex alfa database and shows the data of the bid 27 seen in the last tables. The bar in purple shows the offered flexible power as seen in the table in Figure 233.

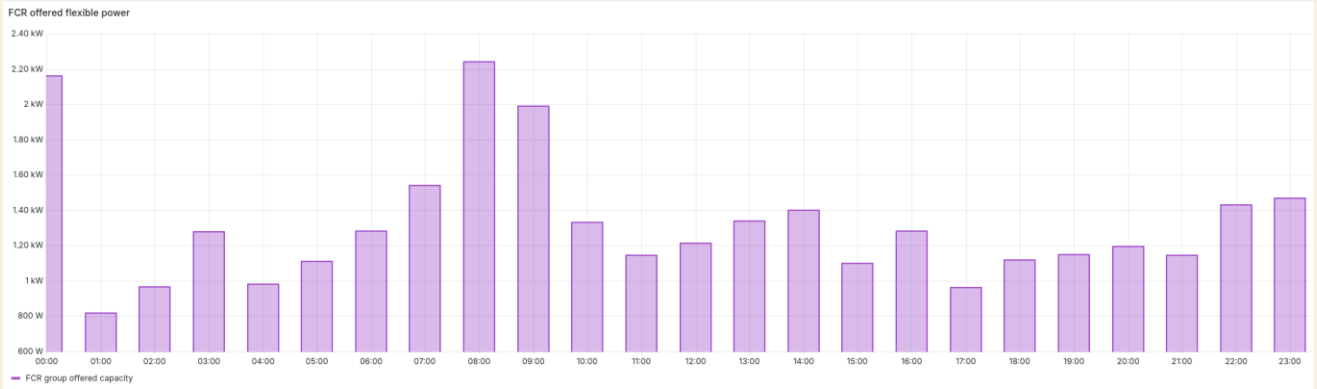


Figure 234: FCR-D-down: Bid data visualization

TSO Connector has fetched the bid in ready state and has created a bid document meant for the TSO.

Since in this experiment the interface to the TSO is simulated, the bid has not actually been sent to the TSO and the answer from the TSO is simulated.

Here we have assumed that the bid document was well formed and did not contain any errors, and thus, the TSO Connector has set its state to accepted and has stored the accepted bid into Flex Database.

2) Frequency monitoring; FCR-D-down activation and deactivation

The following figures are an extract of the FCR Log and show the FCR-D-down activation and deactivation effects.

Figure 235 shows the status of the system when there is no disturbance that falls in the FCR-D range. The system is monitoring the frequency for FCR-D-down service, as shown by the field ContStatus_FcrdDo = 1. The flex group ”alfagroup” has been dedicated fo FCR-D-down. There is no activated flexible power yet, as shown by the field Act_FcrdDo = 0

DateTime	InsAcPow	ApplFreqSig	Cap_FrcdDo	Pmax	Pmin	ContStatus_FcrdDo	RegStr_FcrdDo	Act_FcrdDo	Contmode_FcrdDo	ContOutSig	ContSetP
20251121T122137.855	-0.0011	**50,10**	**0.00481**	0.00	-0.0075	**1**	0.012025	**0.00**	**alfagroup**	**0.00**	-0.0011
20251121T122138.856	-0.0011	50,10	0.00481	0.00	-0.0075	1	0.012025	0.00	alfagroup	0.00	-0.0011
20251121T122139.857	-0.0011	50,10	0.00481	0.00	-0.0075	1	0.012025	0.00	alfagroup	0.00	-0.0011

Figure 235: FCR-D-down is not activated yet

Figure 236 shows what happens when the simulated grid frequency has changed to 50.5 Hz to activate the flex group, which means **full activation**. In 4 seconds, the activated power goes from 0 to 0,00565 MW (5,65 kW), as shown by the field Act_FcrdDo. The value is negative because it is absorbed power and it is so small because the experiment is using only the real load of 2 pilot apartments. The value of the activated power is bigger than

the value of the reserved capacity (Cap_FcrdDo) because in this testing there are only 2 apartments and therefore few heaters. So, the granularity at which power can be activated is limited in this test. The field CountOutSig shows the value -1 to indicate full activation of FCR-D-down. The value is negative because more load has been added.

DateTime	InsAcPow	ApplFreqSig	Cap_FcrdDo	Pmax	Pmin	ContStatus_FcrdDo	RegStr_FcrdDo	Act_FcrdDo	Contmode_FcrdDo	ContOutSig	ContSetP
20251121T122139.857	-0.0011	50,10	0.00481	0.00	-0.0075	1	0.012025	0.00	alfagroup	0.00	-0.0011
20251121T122140.858	-0.0011	50,50	**0.00481**	0.00	-0.0075	**1**	0.012025	0.00	**alfagroup**	-1.0	-0.0011
20251121T122141.859	-0.0037	50,50	0.00481	0.00	-0.0075	1	0.012025	-0.0026	alfagroup	-1.0	-0.0011
20251121T122142.860	-0.0049	50,50	0.00481	0.00	-0.0075	1	0.012025	-0.0038	alfagroup	-1.0	-0.0011
20251121T122143.861	-0.00635	50,50	0.00481	0.00	-0.0075	1	0.012025	-0.00525	alfagroup	-1.0	-0.0011
20251121T122144.862	-0.00675	50,50	0.00481	0.00	-0.0075	1	0.012025	-0.00565	alfagroup	-1.0	-0.0011

Figure 236: FCR-D- down full activation

The frequency is changed to 50.3 Hz, which means **50% activation**. The situation is shown in Figure 237. The value of the activated power (Act_FcrdDo) decreases and the reserve activation ratio (CountOutSig) shows that now only half reserve is activated. In this case the activated power is more than half of the reserved power because of the small amount of heatings assets used in the test and the consequent lack of fine granularity. The linear response is demonstrated in the tests which use full simulated load (1MW).

DateTime	InsAcPow	ApplFreqSig	Cap_FcrdDo	Pmax	Pmin	ContStatus_FcrdDo	RegStr_FcrdDo	Act_FcrdDo	Contmode_FcrdDo	ContOutSig	ContSetP
20251121T122341.966	-0.00565	50,50	0.00481	0.00	-0.0075	1	0.012025	-0.00565	alfagroup	-1.0	-0.0011
20251121T122342.967	-0.00565	50,30	0.00481	0.00	-0.0075	1	0.012025	-0.00565	alfagroup	-0.49999999	-0.0011
20251121T122343.968	-0.00425	50,30	0.00481	0.00	-0.0075	1	0.012025	-0.00425	alfagroup	-0.49999999	-0.0011

Figure 237: FCR-D- down at 50% activation

Figure 238 shows what happens when the frequency is changed back to 50 Hz, which means **zero activation**. The value of the activated power (Act_FcrdDo) decreases further and the reserve activation ratio (CountOutSig) shows that FCR-D-down has been deactivated.

DateTime	InsAcPow	ApplFreqSig	Cap_FcrdDo	Pmax	Pmin	ContStatus_FcrdDo	RegStr_FcrdDo	Act_FcrdDo	Contmode_FcrdDo	ContOutSig	ContSetP
20251121T122540.067	-0.00345	50,30	0.00481	0.00	-0.0075	1	0.012025	-0.00345	alfagroup	-0.49999999	-0.0011
20251121T122541.068	-0.00345	50,00	0.00405	0.00	-0.0075	1	0.010124999999	-0.00345	alfagroup	0.00	-0.00345
20251121T122542.069	-0.00085	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.00085	alfagroup	0.00	-0.00085
20251121T122543.070	-0.00085	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.00085	alfagroup	0.00	-0.00085
20251121T122544.071	-0.00085	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.00085	alfagroup	0.00	-0.00085
20251121T122545.072	-0.00085	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.00085	alfagroup	0.00	-0.00085
20251121T122546.073	-0.00085	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.00085	alfagroup	0.00	-0.00085
20251121T122547.074	-0.0004	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.0004	alfagroup	0.00	-0.0004
20251121T122548.075	-0.0004	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.0004	alfagroup	0.00	-0.0004
20251121T122549.076	-0.0004	50,00	0.00481	0.00	-0.0075	1	0.012025	-0.0004	alfagroup	0.00	-0.0004

Figure 238: FCR-D- down deactivation

FCR-D-down exception paths

- Case 1.1 ABNORMAL-flex-power-estimation-fails: PASSED
- Case 3.1 SUCCESSFUL-rejected-bid: PASSED
- Case 3.2 ABNORMAL-no-answer-from-TSO: PASSED
- Case 3.3 ABNORMAL-error-from-TSO: PASSED
- Case 3.4 ABNORMAL-error-from-TSO-existing-bid: PASSED
- Case 8.1 SUCCESSFUL-freq-restored-during-ramp-up PASSED
- Case 8.2 ABNORMAL-no-answer-from-controller-FCR-act PASSED
- Case 8.3 ABNORMAL-error-from-controller-FCR-act PASSED
- Case 10.1 ABNORMAL-no-answer-from-controller-FCR-deact PASSED
- Case 10.2 ABNORMAL-error-from-controller-FCR-deact PASSED
- Case 12.1 SUCCESSFUL-bid-validity-expires-no-more-bids-freq-not-restored PASSED
- Case 12.2 SUCCESSFUL-bid-validity-expires-no-more-bids-freq-restored PASSED
- Case 12.3 SUCCESSFUL-bid-validity-expires-more-bids-freq-not-restored PASSED

Qualitative analysis of the results

The results of this test scenario have met the expectations. The functionality of the system has been verified, including the abnormal test cases.

Experiment number	FI-UC.01.02
Name of the experiment	FCR-D-multiple-activations
Timeframe	February 2025 – June 2026 (M26-M45)
Targets	This test scenario is built on top of FI-UC.01.01 and verifies the case that, during the same bid hour, more than one FCR activation takes place. Several combinations are possible: one FCR-D-down after an FCR-D-up, one FCR-D-up after an FCR-D-down, multiple FCR-D activations of the same type, ... This is a very relevant case since on average there are about 100 FCR activations in one hour. A crucial difference between this test scenario and FI-UC.01.01 is that in FI-UC.01.01 the grid frequency was changed manually whereas in here is **historical data from the TSO with 10 Hz sampling interval is used to simulate the grid frequency**. This test scenario contains both test cases executed with simulated load and test cases executed using real load from pilot customers. • Tests will full simulated load (at least 1MW) are useful to test the linear response to frequency deviations • Tests with real load are useful to test the integration with spot-price based control and for calculating KPIs in a real environment This test scenario is part of use case FI01.
Actors	• TSO (Fingrid) – simulated interface • Aggregator (Optiwatti) • Pilot sites (OptiWatti controller in customer's building)
STREAM products	sFLEX, sDATA
Assets & systems	The required assets are the same as the ones needed for FI-UC.01.01: sFLEX Server, sFLEX Client, sFLEX Manager, sFLEX Simulator and sFLEX Controllers. Simulated sFLEX Controllers are needed in addition of the real OptiWatti controllers related to the pilot apartments. The frequency is coming from a simulated application (the simulated frequency is needed to test all the acceptance test cases that the TSO requires) and is sampled at 10 Hz. The interface with the TSO is simulated.
Description of the experiment	This test scenario is based on the test scenario FI-UC.01.01: "FCR-D". Being part of the flexible energy market requires estimating the available flexible load, that is, the amount of load that can be cut or added in case of need. Having tens of thousands of load elements requires algorithm to perform this estimation. The combined calculation for all the apartments participating in the FCR is made available directly to the market interface.

	Bids shall be done every day by 18:30 and are approved on the same day by 22:00 by the TSO. Within a bid document covering the next day, there is information per service for each hour. After activating the flexibility functionality in a building, it is necessary to prove that the required flexibility has been generated and therefore it is necessary to verify and report the used flexibility to the TSO. Also, the flexibility estimation reliability and the FCR activation speed are measured in this experiment by the Aggregator for monitoring the quality of the service and of the network. FCR-D (Frequence Containment Reserve for Disturbances) is the service prototyped in the Finnish pilot. It is activated in a short time interval of few seconds for relatively large frequency deviations in order to let slower frequency containment reserves have the time to activate, if the need still persists. The reference test case described here is: • FCR-D-up after an FCR-D-up with real load • Real load from pilot customers All the other combinations are described in the exception paths section. **Preconditions:** • sDATA is receiving periodic measurements from the apartments' OptiWatti controllers • Idle state • No bid validity interval is ongoing • Frequency is not monitored • No FCR is active **Steps:** 1. Flexible power estimation is performed by the Aggregator with the Flex Simulator component of sFLEX by taking into consideration also implicit flexibility. The value is stored in sDATA. 2. A bid is made to the TSO by the Flex Manager component of sFLEX, including the service type, the amount of available load and the price for each hour. 3. The bid is approved by the TSO. The result is stored in sDATA. 4. The bid validity timer starts (60 minutes) to monitor the reserve allocation period. 5. The grid frequency is monitored by sFLEX with a 10Hz sampled frequency and logging starts. 6. The aggregator reports the maintained reserve capacity to the TSO every minute. In the prototype this is done internally in the sFLEX since the interface to the TSO is simulated. 7. A frequency activation trigger is met (the frequency drops at 49.9 Hz or less (FCR-D-up). 8. The FCR activation procedure starts by cutting load (FCR-D-up) proportionally to the frequency deviation. The Flex Server module of the sFLEX sends the necessary instructions to the Flex Client module. The actual activated flexible power is stored in sDATA.

	9. A frequency deactivation trigger is met (the frequency is bigger than 49.9 Hz (FCR-D-up). 10. The FCR is deactivated. This means that load is reconnected (FCR-D-up). The Flex Server module of the sFLEX sends the necessary instructions to the Flex Client module. 11. A frequency activation trigger is met: the frequency drops at 49.9 Hz or less (FCR-D-up). 12. The FCR activation procedure starts by cutting load (FCR-D-up) proportionally to the frequency deviation. The actual activated flexible power is stored in sDATA. 13. A frequency deactivation trigger is met: the frequency is bigger than 49.9 Hz (FCR-D-up). 14. The FCR is deactivated. 15. The bid validity time expires. When the bid validity time elapses, procedures are followed based on whether the successive hour has an accepted bid or not. Here only the reference case is tested: if the successive hour has an approved bid and the frequency has been restored (and therefore the FCR has been deactivated), then a new bid validity interval shall start and the system shall keep monitoring grid frequency. 16. FI01_01 FCR activation speed and FI01_02 Flexibility estimation accuracy KPIs are calculated and the result is stored in sDATA. **Postconditions:** • The variables used to calculate the KPIs have been updated and stored in sDATA • The load has been modified in a linear kind of way (proportional to the frequency deviation) as defined in Fingrid specifications: after 7,5 seconds 86% of the reserve capacity shall be activated and 3.2 seconds * reserved_capacity MWs of energy has to be used, where reserved_capacity is the approved flexible load
Exception paths and scenarios of the experiment	Only the differences with the reference case are described in this section. • FCR-D-down-followed by FCR-D-down ○ 7.1. A frequency activation trigger is met: the frequency rises at 50.1 Hz or more (FCR-D-down). ○ 8.1. The FCR activation procedure starts by adding load (FCR-D-down) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA. ○ 9.1. A frequency deactivation trigger is met: the frequency is lower than 50.1 Hz (FCR-D-down). ○ 10.1. The FCR is deactivated. This means that load is cut (FCR-D-down). ○ 11.1. A frequency activation trigger is met: the frequency rises at 50.1 Hz or more (FCR-D-down). ○ 12.1. The FCR activation procedure starts by adding load (FCR-D-down) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA.

	○ 13.1. A frequency deactivation trigger is met: the frequency is lower than 50.1 Hz (FCR-D-down). ○ 14.1. The FCR is deactivated. • FCR-D-up-followed by FCR-D-down ○ 7.2. A frequency activation trigger is met: the frequency drops at 49.9 Hz or less (FCR-D-up). ○ 8.2. The FCR activation procedure starts by cutting load (FCR-D-up) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA. ○ 9.2. A frequency deactivation trigger is met: the frequency is bigger than 49.9 Hz (FCR-D-up). ○ 10.2. The FCR is deactivated. ○ 11.2. A frequency activation trigger is met: the frequency rises at 50.1 Hz or more (FCR-D-down). ○ 12.2. The FCR activation procedure starts by adding load (FCR-D-down) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA. ○ 13.2. A frequency deactivation trigger is met: the frequency is lower than 50.1 Hz (FCR-D-down). ○ 14.2. The FCR is deactivated. • FCR-D-down-followed by FCR-D-up ○ 7.3. A frequency activation trigger is met: the frequency rises at 50.1 Hz or more (FCR-D-down). ○ 8.3. The FCR activation procedure starts by adding load (FCR-D-down) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA. ○ 9.3. A frequency deactivation trigger is met: the frequency is lower than 50.1 Hz (FCR-D-down). ○ 10.3. The FCR is deactivated. ○ 11.3. A frequency activation trigger is met: the frequency drops at 49.9 Hz or less (FCR-D-up). ○ 12.3. The FCR activation procedure starts by cutting load (FCR-D-up) proportionally to the frequency deviation. The actual activated flexible power is stored is sDATA. ○ 13.3. A frequency deactivation trigger is met: the frequency is bigger than 49.9 Hz (FCR-D-up). ○ 14.3. The FCR is deactivated. • Full simulated load (1MW), FCR-D-up ○ This case has the following differences with the main test case described in the Description field ▪ Load is simulated and it complies the minimum load requirement from the TSO (1MW) ▪ Load normalization for linear response is tested ▪ No KPI is calculated • Full simulated load (3MW), FCR-D-down ○ This case has the following differences with the main test case described in the Description field

	▪ Load is simulated and it complies the minimum load requirement from the TSO (1MW) ▪ Load normalization for linear response is tested ▪ No KPI is calculated • 5.1. ABNORMAL-no-measured-freq. FCR-D-up. When frequency measurement is not working, no FCR activation is possible. The real-time parameter about the maintained capacity is set to zero. In the commercial version of the feature Fingrid (TSO) control center is informed. The system stays in monitoring state. No KPI is calculated in this case. • 5.2. ABNORMAL-no-measured-freq. FCR-D-down. When frequency measurement is not working, no FCR activation is possible. The real-time parameter about the maintained capacity is set to zero. In the commercial version of the feature Fingrid (TSO) control center is informed. The system stays in monitoring state. No KPI is calculated in this case.
Datasets required for the experiment	• FI_01 Configuration data • FI_02 Periodic measurements • FI_03 Energy spot prices • FI_04 Power consumption • FI_09 FCR group bid
Field data to be gathered	• FI_06 Baseline flex power forecast output • FI_11 FCR log • FI_12 FCR power estimation reliability KPI • FI_13 FCR activation success rate KPI
Related KPIs	KPI FI.01, KPI FI.02, KPI FI.05
Results of the Experiment	
Tests which use <u>real load from the pilot apartments</u>. Tests have been run for **12 days** by controlling real heating assets from the pilot apartments. The data collection has started on April 23rd 2026. 8 apartments have been used for the tests: 3 apartments located in North Finland have been used for FCR-D-up since at those latitudes there was still some active load to cut in this period of the year; 5 apartments located in South Finland have been used for FCR-D-down. Grid **frequency sampled at 10 Hz** has been used. The used simulated frequency has been taken **from Fingrid statistical data**. The frequency values of the previous year at the same time of the year have been used. The data is available at this link and contains one CSV file for each day: https://data.fingrid.fi/en/datasets/339 Figure 239 shows an extract of the used frequency time series.	

Time	Value
2025-04-23 00:00:00.000	50.0452
2025-04-23 00:00:00.100	50.0454
2025-04-23 00:00:00.200	50.0458
2025-04-23 00:00:00.300	50.0466
2025-04-23 00:00:00.400	50.0449
2025-04-23 00:00:00.500	50.0454
2025-04-23 00:00:00.600	50.0444
2025-04-23 00:00:00.700	50.0442
2025-04-23 00:00:00.800	50.0434
2025-04-23 00:00:00.900	50.0415

Figure 239: Example of used grid frequency

1) Flexibility estimation and bid to the TSO (steps 1-3)

An **estimation of** how much power will be used during each of the 12 the market days by each of the rooms of the selected pilot apartments has been performed by **Flex Simulator**.

Information about the clients within the Flex Group has been collected to be used an input for such simulation, including:

- heater powers installed in the designated rooms
- user settings, such as set temperature and selected spot price controls
- weather forecast for the market day
- starting room temperatures at the beginning of the simulation

The output of the simulation included:

- temperature forecast: how much room temperature changes between consecutive iterations
- **power forecast**: how much power is used between iterations

Those values have been stored into the **Measurements Database**. Figure 240 shows some SQL queries retrieving some details of the table in the database containing the **simulation results**.

There are overall over 400.000 entries containing simulation results using 65 rooms. The simulations contain the simulated room temperature (metric 30) and the simulated absorbed power (metric 31) of each of such rooms with a sampling interval of 5 minutes. Few examples of the actual entries are shown. Note that the bids are done in CET (Central European Time) or, as in the case of the test, in CEST (Central European Summer Time).

```
alfa_measurements=> SELECT count(*) FROM periodic_measurements WHERE metric IN (30, 31) AND mtimestamp::TEXT >= '2026-04-2
3 00:00:00+02' AND mtimestamp < '2026-05-05 00:00:00+02';
 count
--------
 401678
(1 row)

Time: 41180.026 ms (00:41.180)
alfa_measurements=> SELECT count(DISTINCT(roomid)) FROM periodic_measurements WHERE metric IN (30, 31) AND mtimestamp::TEX
T >= '2026-04-23 00:00:00+02' AND mtimestamp < '2026-05-05 00:00:00+02';
 count
-------
    65
(1 row)

Time: 158075.963 ms (02:38.076)
alfa_measurements=> SELECT mtimestamp AS "timestamp", roomid AS "room_id", metric, mvalue AS "simulated_room_temperature"
FROM periodic_measurements WHERE roomid = 18361 AND metric = 30 AND mtimestamp::TEXT >= '2026-04-23 01:00:00+02' AND mtime
stamp < '2026-05-05 00:00:00+02' LIMIT 10;
       timestamp        | room_id | metric | simulated_room_temperature
------------------------+---------+--------+----------------------------
 2026-04-23 01:05:00+00 |   18361 |     30 |          21.30540470354219
 2026-04-23 01:10:00+00 |   18361 |     30 |         21.264834477884172
 2026-04-23 01:15:00+00 |   18361 |     30 |         21.442711306899653
 2026-04-23 01:20:00+00 |   18361 |     30 |         21.401866742465142
 2026-04-23 01:25:00+00 |   18361 |     30 |         21.361103785524804
 2026-04-23 01:30:00+00 |   18361 |     30 |         21.320422273026757
 2026-04-23 01:35:00+00 |   18361 |     30 |         21.279822042244895
 2026-04-23 01:40:00+00 |   18361 |     30 |         21.457609215111628
 2026-04-23 01:45:00+00 |   18361 |     30 |         21.416734884636657
 2026-04-23 01:50:00+00 |   18361 |     30 |         21.375942221128447
(10 rows)

Time: 1515.496 ms (00:01.515)
alfa_measurements=> SELECT mtimestamp AS "timestamp", roomid AS "room_id", metric, mvalue AS "simulated_absorbed_power_W"
FROM periodic_measurements WHERE roomid = 18361 AND metric = 31 AND mtimestamp::TEXT >= '2026-04-23 01:00:00+02' AND mtime
stamp < '2026-05-05 00:00:00+02' LIMIT 10;
       timestamp        | room_id | metric | simulated_absorbed_power_W
------------------------+---------+--------+----------------------------
 2026-04-23 01:05:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:10:00+00 |   18361 |     31 |                      800.0
 2026-04-23 01:15:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:20:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:25:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:30:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:35:00+00 |   18361 |     31 |                      800.0
 2026-04-23 01:40:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:45:00+00 |   18361 |     31 |                        0.0
 2026-04-23 01:50:00+00 |   18361 |     31 |                        0.0
(10 rows)

Time: 29.902 ms
```

Figure 240: Details about the simulation results for the tests with real load.

The Grafana dashboard in Figure 241 visualizes the data for one room (room id 18361). The line in orange color in the plot shows the simulated temperature and the bars in purple show the simulated power. The installed power is 800 Watts and the room temperature when the simulation has started was 21.5 degrees. The set temperature is adjusted by the spot price settings since this customer does not have a fixed price contract.

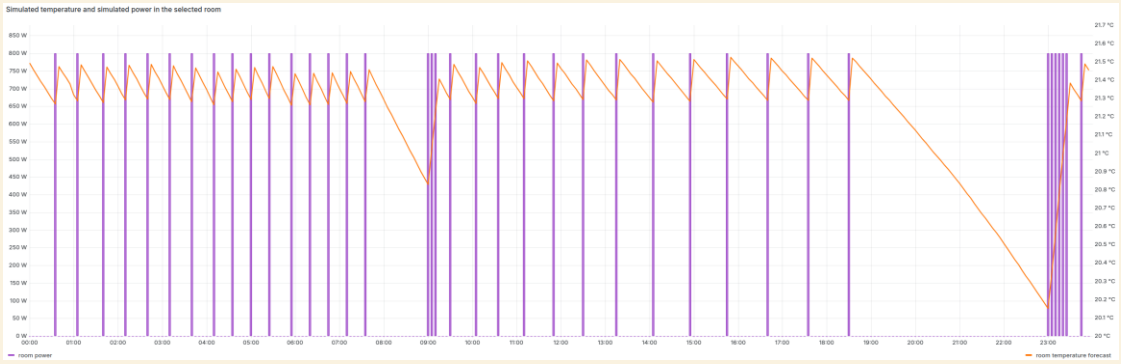


Figure 241: A visualization of an example of the simulation results

Flex Manager has fetched the simulation results from the Measurements Database, specifically the power forecast, and has further aggregated those results into bid intervals. This power forecast provided the power baseline. The results are visible in the table in Figure 242 from the **Flex Database** which contains the power baseline for each hour of the first day of the test (April 23rd) for FCR-D-down.

```
alfa_flex=> SELECT result_start AS "period start", result_end AS "period end", power_forecast_w AS "FCR group power baseline", flex_simulation_id FROM owflexdb_flexperiodicresult WHERE
 flex_simulation_id = (SELECT id FROM owflexdb_flexsimulation WHERE flex_group_id = 6 AND market_day = '2026-04-23');
      period start       |       period end       | FCR group power baseline | flex_simulation_id
-------------------------+------------------------+--------------------------+--------------------
 2026-04-22 22:00:00+00 | 2026-04-22 23:00:00+00 |        7307.083333333333 |                176
 2026-04-22 23:00:00+00 | 2026-04-23 00:00:00+00 |        9219.666666666668 |                176
 2026-04-23 00:00:00+00 | 2026-04-23 01:00:00+00 |        9398.333333333332 |                176
 2026-04-23 01:00:00+00 | 2026-04-23 02:00:00+00 |                     8937 |                176
 2026-04-23 02:00:00+00 | 2026-04-23 03:00:00+00 |                 10139.25 |                176
 2026-04-23 03:00:00+00 | 2026-04-23 04:00:00+00 |        8021.833333333333 |                176
 2026-04-23 04:00:00+00 | 2026-04-23 05:00:00+00 |                  5273.75 |                176
 2026-04-23 05:00:00+00 | 2026-04-23 06:00:00+00 |                        0 |                176
 2026-04-23 06:00:00+00 | 2026-04-23 07:00:00+00 |        6956.666666666666 |                176
 2026-04-23 07:00:00+00 | 2026-04-23 08:00:00+00 |        6356.083333333334 |                176
 2026-04-23 08:00:00+00 | 2026-04-23 09:00:00+00 |        6915.666666666667 |                176
 2026-04-23 09:00:00+00 | 2026-04-23 10:00:00+00 |        5199.416666666666 |                176
 2026-04-23 10:00:00+00 | 2026-04-23 11:00:00+00 |                  4578.25 |                176
 2026-04-23 11:00:00+00 | 2026-04-23 12:00:00+00 |        4869.916666666667 |                176
 2026-04-23 12:00:00+00 | 2026-04-23 13:00:00+00 |        3964.916666666667 |                176
 2026-04-23 13:00:00+00 | 2026-04-23 14:00:00+00 |        3736.583333333335 |                176
 2026-04-23 14:00:00+00 | 2026-04-23 15:00:00+00 |        3731.166666666665 |                176
 2026-04-23 15:00:00+00 | 2026-04-23 16:00:00+00 |        3550.166666666665 |                176
 2026-04-23 16:00:00+00 | 2026-04-23 17:00:00+00 |        33.33333333333336 |                176
 2026-04-23 17:00:00+00 | 2026-04-23 18:00:00+00 |         491.6666666666667 |                176
 2026-04-23 18:00:00+00 | 2026-04-23 19:00:00+00 |        4321.416666666667 |                176
 2026-04-23 19:00:00+00 | 2026-04-23 20:00:00+00 |                   3239.5 |                176
 2026-04-23 20:00:00+00 | 2026-04-23 21:00:00+00 |                    13880 |                176
 2026-04-23 21:00:00+00 | 2026-04-23 22:00:00+00 |                    12906 |                176
(24 rows)
```

Figure 242: Example of power baseline for the test with real load

As shown in Figure 243, two Flex Groups have been created: pilot_up (flex group 5) to be used for the FCR-D-up market and pilot_do (flex group 6) to be used for the FCR-D-down market.

```
alfa_flex=> SELECT id, name, active_first_day, active_last_day, description, created, updated, flex_market_id FROM owflexdb_flexgroup WHERE name LIKE'pilot%';
 id |   name   | active_first_day | active_last_day |                        description                        |            created            |            updated            | flex_market_id
----+----------+------------------+-----------------+-----------------------------------------------------------+-------------------------------+-------------------------------+----------------
  6 | pilot_do | 2026-03-01       | 2026-06-30      | Pilot clients group for FCR-D Down for non-AV pilot clients. | 2026-03-25 09:51:27.318448+00 | 2026-04-15 06:15:47.78651+00  |              2
  5 | pilot_up | 2026-03-01       | 2026-06-30      | Pilot clients group for FCR-D Up comprising AV pilot clients. | 2026-03-25 09:51:01.876608+00 | 2026-04-15 06:20:07.815469+00 |              1
(2 rows)
```

Figure 243: Flex groups used for the test with real load

Figure 244 shows the used installed power for each market day and for each service. 7 rooms have been used for FCR-D-up and up to 58 rooms have been used for FCR-D-down.

```
alfa_flex=> SELECT id, flex_group_id, market_day, rooms_count, total_power_w AS "used_installed_power_w" FROM owf
lexdb_flexsimulation WHERE flex_group_id IN(5, 6) AND market_day >= '2026-04-23' AND market_day < '2026-05-05';
 id  | flex_group_id | market_day | rooms_count | used_installed_power_w
-----+---------------+------------+-------------+------------------------
 177 |             5 | 2026-04-23 |           7 |                   8050
 179 |             5 | 2026-04-24 |           7 |                   8050
 181 |             5 | 2026-04-25 |           7 |                   8050
 183 |             5 | 2026-04-26 |           7 |                   8050
 185 |             5 | 2026-04-27 |           7 |                   8050
 187 |             5 | 2026-04-28 |           7 |                   8050
 189 |             5 | 2026-04-29 |           7 |                   8050
 191 |             5 | 2026-04-30 |           7 |                   8050
 193 |             5 | 2026-05-01 |           7 |                   8050
 195 |             5 | 2026-05-02 |           7 |                   8050
 197 |             5 | 2026-05-03 |           7 |                   8050
 199 |             5 | 2026-05-04 |           7 |                   8050
 176 |             6 | 2026-04-23 |          58 |                  48070
 178 |             6 | 2026-04-24 |          58 |                  48070
 180 |             6 | 2026-04-25 |          47 |                  40875
 182 |             6 | 2026-04-26 |          58 |                  48069
 184 |             6 | 2026-04-27 |          58 |                  48069
 186 |             6 | 2026-04-28 |          58 |                  48069
 188 |             6 | 2026-04-29 |          47 |                  37364
 190 |             6 | 2026-04-30 |          47 |                  37364
 192 |             6 | 2026-05-01 |          47 |                  37364
 194 |             6 | 2026-05-02 |          47 |                  37364
 196 |             6 | 2026-05-03 |          47 |                  37364
 198 |             6 | 2026-05-04 |          47 |                  37364
(24 rows)
```

Figure 244: Used installed power for the test with real load

Flex Manager has created **bid objects** into the Flex Database and set the bid status as ready. The bid contains information about how much capacity is offered for each hour and at what price.

The table ”owflexdb_bid” shown in Figure 245 contains information about the prepared bids, including the id, the used Flex Group, the market day and fields containing the status such as time of submission and time of acceptance. 24 bids have been created for the 12 different days, 12 for each service. Note that the pilot_up flex froup and the pilot_do flex group are used for the same market days but they use different heating assets.

```
alfa_flex=> SELECT id, created, updated, flex_group_id, flexgroup_name, market_day, ready_at, submitted_at, ack_at FROM owflexdb_bid WHERE flex_group_id IN(5,6) AND market_day >= '2026-04-23' AND market_day < '2026-05-0
5' ORDER BY flex_group_id, market_day;
 id  |          created           |          updated           | flex_group_id | flexgroup_name | market_day |          ready_at          |        submitted_at        |          ack_at
-----+----------------------------+----------------------------+---------------+----------------+------------+----------------------------+----------------------------+----------------------------
 185 | 2026-04-22 12:30:08.97355+00  | 2026-04-22 13:00:41.834878+00 |             5 | pilot_up       | 2026-04-23 | 2026-04-22 12:30:12.224182+00 | 2026-04-22 13:00:05.48251+00  | 2026-04-22 13:00:41.834739+00
 187 | 2026-04-23 12:30:09.006802+00 | 2026-04-23 13:00:41.06581+00  |             5 | pilot_up       | 2026-04-24 | 2026-04-23 12:30:12.209944+00 | 2026-04-23 13:00:05.177406+00 | 2026-04-23 13:00:41.065702+00
 189 | 2026-04-24 12:30:08.307678+00 | 2026-04-24 13:00:41.953983+00 |             5 | pilot_up       | 2026-04-25 | 2026-04-24 12:30:11.504686+00 | 2026-04-24 13:00:05.866215+00 | 2026-04-24 13:00:41.953848+00
 191 | 2026-04-25 12:30:09.311084+00 | 2026-04-25 13:00:41.319545+00 |             5 | pilot_up       | 2026-04-26 | 2026-04-25 12:30:12.543302+00 | 2026-04-25 13:00:05.487269+00 | 2026-04-25 13:00:41.31944+00
 193 | 2026-04-26 12:30:09.1037+00   | 2026-04-26 13:00:41.820206+00 |             5 | pilot_up       | 2026-04-27 | 2026-04-26 12:30:12.580793+00 | 2026-04-26 13:00:05.925378+00 | 2026-04-26 13:00:41.820097+00
 195 | 2026-04-27 12:30:08.861007+00 | 2026-04-27 13:00:41.566989+00 |             5 | pilot_up       | 2026-04-28 | 2026-04-27 12:30:12.21059+00  | 2026-04-27 13:00:05.559241+00 | 2026-04-27 13:00:41.5668B+00
 197 | 2026-04-28 12:30:09.397514+00 | 2026-04-28 13:00:42.310708+00 |             5 | pilot_up       | 2026-04-29 | 2026-04-28 12:30:12.695615+00 | 2026-04-28 13:00:06.021996+00 | 2026-04-28 13:00:42.310559+00
 199 | 2026-04-29 12:30:08.53629+00  | 2026-04-29 13:00:42.266564+00 |             5 | pilot_up       | 2026-04-30 | 2026-04-29 12:30:11.843751+00 | 2026-04-29 13:00:06.121431+00 | 2026-04-29 13:00:42.266457+00
 201 | 2026-04-30 12:30:08.970411+00 | 2026-04-30 13:00:42.065911+00 |             5 | pilot_up       | 2026-05-01 | 2026-04-30 12:30:12.314622+00 | 2026-04-30 13:00:05.966219+00 | 2026-04-30 13:00:42.065785+00
 203 | 2026-05-01 12:30:09.344718+00 | 2026-05-01 13:00:40.908059+00 |             5 | pilot_up       | 2026-05-02 | 2026-05-01 12:30:12.844906+00 | 2026-05-01 13:00:04.96957+00  | 2026-05-01 13:00:40.907946+00
 205 | 2026-05-02 12:30:08.766347+00 | 2026-05-02 13:00:41.298946+00 |             5 | pilot_up       | 2026-05-03 | 2026-05-02 12:30:12.070687+00 | 2026-05-02 13:00:05.427234+00 | 2026-05-02 13:00:41.298837+00
 207 | 2026-05-03 12:30:09.502929+00 | 2026-05-03 13:00:41.25894+00  |             5 | pilot_up       | 2026-05-04 | 2026-05-03 12:30:13.096845+00 | 2026-05-03 13:00:05.289928+00 | 2026-05-03 13:00:41.258828+00
 184 | 2026-04-22 12:30:02.711574+00 | 2026-04-22 13:00:38.660732+00 |             6 | pilot_do       | 2026-04-23 | 2026-04-22 12:30:06.029799+00 | 2026-04-22 13:00:02.281586+00 | 2026-04-22 13:00:38.660588+00
 186 | 2026-04-23 12:30:02.752911+00 | 2026-04-23 13:00:38.104798+00 |             6 | pilot_do       | 2026-04-24 | 2026-04-23 12:30:06.110841+00 | 2026-04-23 13:00:02.198767+00 | 2026-04-23 13:00:38.104691+00
 188 | 2026-04-24 12:30:02.161905+00 | 2026-04-24 13:00:38.866932+00 |             6 | pilot_do       | 2026-04-25 | 2026-04-24 12:30:05.399587+00 | 2026-04-24 13:00:02.699407+00 | 2026-04-24 13:00:38.866795+00
 190 | 2026-04-25 12:30:02.716843+00 | 2026-04-25 13:00:38.381658+00 |             6 | pilot_do       | 2026-04-26 | 2026-04-25 12:30:06.363343+00 | 2026-04-25 13:00:02.538295+00 | 2026-04-25 13:00:38.381552+00
 192 | 2026-04-26 12:30:02.432673+00 | 2026-04-26 13:00:38.822762+00 |             6 | pilot_do       | 2026-04-27 | 2026-04-26 12:30:06.146791+00 | 2026-04-26 13:00:02.963298+00 | 2026-04-26 13:00:38.822654+00
 194 | 2026-04-27 12:30:02.107833+00 | 2026-04-27 13:00:38.534206+00 |             6 | pilot_do       | 2026-04-28 | 2026-04-27 12:30:05.69183+00  | 2026-04-27 13:00:02.601778+00 | 2026-04-27 13:00:38.534076+00
 196 | 2026-04-28 12:30:02.633774+00 | 2026-04-28 13:00:39.160458+00 |             6 | pilot_do       | 2026-04-29 | 2026-04-28 12:30:06.475465+00 | 2026-04-28 13:00:02.994859+00 | 2026-04-28 13:00:39.160345+00
 198 | 2026-04-29 12:30:01.913776+00 | 2026-04-29 13:00:39.264414+00 |             6 | pilot_do       | 2026-04-30 | 2026-04-29 12:30:05.599865+00 | 2026-04-29 13:00:02.982332+00 | 2026-04-29 13:00:39.264306+00
 200 | 2026-04-30 12:30:02.346028+00 | 2026-04-30 13:00:39.065495+00 |             6 | pilot_do       | 2026-05-01 | 2026-04-30 12:30:06.044495+00 | 2026-04-30 13:00:02.981401+00 | 2026-04-30 13:00:39.065383+00
 202 | 2026-05-01 12:30:02.646199+00 | 2026-05-01 13:00:37.962916+00 |             6 | pilot_do       | 2026-05-02 | 2026-05-01 12:30:06.388945+00 | 2026-05-01 13:00:02.019481+00 | 2026-05-01 13:00:37.962806+00
 204 | 2026-05-02 12:30:02.11389+00  | 2026-05-02 13:00:38.344201+00 |             6 | pilot_do       | 2026-05-03 | 2026-05-02 12:30:05.627793+00 | 2026-05-02 13:00:02.391252+00 | 2026-05-02 13:00:38.344057+00
 206 | 2026-05-03 12:30:02.573636+00 | 2026-05-03 13:00:38.253968+00 |             6 | pilot_do       | 2026-05-04 | 2026-05-03 12:30:06.335809+00 | 2026-05-03 13:00:02.28229+00  | 2026-05-03 13:00:38.253861+00
(24 rows)
```

Figure 245: Bids used for the test with real load

The table ”owflexdb_bidperiod” in Figure 246 contains the details of a one of such bids and more exactly the bid done on the first day of the test (April 23rd) for FCR-D-down. It includes the offered flexible capacity and the price in euro in the defined period. The offered flexible capacity is calculated from the theoretical flexible capacity by multiplying by the scaling factor. The scaling factor is a safety measure for the aggregator. It is a coefficient which is optimized over time and whose scope is to ensure that the aggregator can maintain the offered flexible capacity. In this test the scaling factor has been set to 1 due to the low amount of flexible capacity that was available by using the assets of the pilot apartments.

```
alfa_flex=> SELECT id, period_start, period_end, duration_s AS "duration_seconds", raw_capacity_w AS "theorethical_flex_capacity_W", scaling_factor, capacity_mw AS "offered_flexible_capacity_MW"
, unit_price, amount_price_eur AS "Price_EUR", bid_id  FROM owflexdb_bidperiod WHERE bid_id = 184;
  id  |      period_start      |       period_end       | duration_seconds | theorethical_flex_capacity_W | scaling_factor | offered_flexible_capacity_MW | unit_price | Price_EUR | bid_id
------+------------------------+------------------------+------------------+------------------------------+----------------+------------------------------+------------+-----------+--------
 4392 | 2026-04-22 22:00:00+00 | 2026-04-22 23:00:00+00 |             3600 |           40762.916666666664 |              1 |          0.04076291666666666 |        100 |      4.08 |    184
 4393 | 2026-04-22 23:00:00+00 | 2026-04-23 00:00:00+00 |             3600 |            38850.33333333333 |              1 |          0.03885033333333333 |        100 |      3.89 |    184
 4394 | 2026-04-23 00:00:00+00 | 2026-04-23 01:00:00+00 |             3600 |           38671.66666666667 |              1 |          0.03867166666666674 |        100 |      3.87 |    184
 4395 | 2026-04-23 01:00:00+00 | 2026-04-23 02:00:00+00 |             3600 |                        39133 |              1 |                        0.039133 |        100 |      3.91 |    184
 4396 | 2026-04-23 02:00:00+00 | 2026-04-23 03:00:00+00 |             3600 |                     37930.75 |              1 |                   0.03793075 |        100 |      3.79 |    184
 4397 | 2026-04-23 03:00:00+00 | 2026-04-23 04:00:00+00 |             3600 |           40048.166666666664 |              1 |          0.04004816666666666 |        100 |         4 |    184
 4398 | 2026-04-23 04:00:00+00 | 2026-04-23 05:00:00+00 |             3600 |                     42796.25 |              1 |                    0.04279625 |        100 |      4.28 |    184
 4399 | 2026-04-23 05:00:00+00 | 2026-04-23 06:00:00+00 |             3600 |                        48070 |              1 |                       0.04807 |        100 |      4.81 |    184
 4400 | 2026-04-23 06:00:00+00 | 2026-04-23 07:00:00+00 |             3600 |           41113.333333333336 |              1 |          0.04111333333333335 |        100 |      4.11 |    184
 4401 | 2026-04-23 07:00:00+00 | 2026-04-23 08:00:00+00 |             3600 |           41713.916666666664 |              1 |          0.04171391666666666 |        100 |      4.17 |    184
 4402 | 2026-04-23 08:00:00+00 | 2026-04-23 09:00:00+00 |             3600 |           41154.333333333336 |              1 |          0.04115433333333334 |        100 |      4.12 |    184
 4403 | 2026-04-23 09:00:00+00 | 2026-04-23 10:00:00+00 |             3600 |           42870.583333333336 |              1 |          0.04287058333333334 |        100 |      4.29 |    184
 4404 | 2026-04-23 10:00:00+00 | 2026-04-23 11:00:00+00 |             3600 |                     43491.75 |              1 |                    0.04349175 |        100 |      4.35 |    184
 4405 | 2026-04-23 11:00:00+00 | 2026-04-23 12:00:00+00 |             3600 |           43200.083333333336 |              1 |          0.04320008333333333 |        100 |      4.32 |    184
 4406 | 2026-04-23 12:00:00+00 | 2026-04-23 13:00:00+00 |             3600 |           44105.083333333336 |              1 |          0.04410508333333336 |        100 |      4.41 |    184
 4407 | 2026-04-23 13:00:00+00 | 2026-04-23 14:00:00+00 |             3600 |           44333.416666666664 |              1 |          0.04433341666666667 |        100 |      4.43 |    184
 4408 | 2026-04-23 14:00:00+00 | 2026-04-23 15:00:00+00 |             3600 |           44338.833333333336 |              1 |          0.04433883333333334 |        100 |      4.43 |    184
 4409 | 2026-04-23 15:00:00+00 | 2026-04-23 16:00:00+00 |             3600 |           44519.833333333336 |              1 |          0.04451983333333335 |        100 |      4.45 |    184
 4410 | 2026-04-23 16:00:00+00 | 2026-04-23 17:00:00+00 |             3600 |           48036.666666666664 |              1 |          0.04803666666666665 |        100 |       4.8 |    184
 4411 | 2026-04-23 17:00:00+00 | 2026-04-23 18:00:00+00 |             3600 |           47578.333333333336 |              1 |          0.04757833333333334 |        100 |      4.76 |    184
 4412 | 2026-04-23 18:00:00+00 | 2026-04-23 19:00:00+00 |             3600 |           43748.583333333336 |              1 |          0.04374858333333334 |        100 |      4.37 |    184
 4413 | 2026-04-23 19:00:00+00 | 2026-04-23 20:00:00+00 |             3600 |                        44830.5 |              1 |                    0.0448305 |        100 |      4.48 |    184
 4414 | 2026-04-23 20:00:00+00 | 2026-04-23 21:00:00+00 |             3600 |                        34190 |              1 |                      0.03419 |        100 |      3.42 |    184
 4415 | 2026-04-23 21:00:00+00 | 2026-04-23 22:00:00+00 |             3600 |                        35164 |              1 |                      0.035164 |        100 |      3.52 |    184
(24 rows)
```

Figure 246: Bids' details

The Grafana plot in Figure 247 uses data from flex alfa database and shows the data of the bid 184 used for FCR-D-down on April 23rd. The bar in green shows the power baseline for the example seen in the table in Figure 242. The bars in purple show the offered flexible power as seen in the table in Figure 246. The line in blue shows the used installed power for the flex group which has been seen in Figure 244.

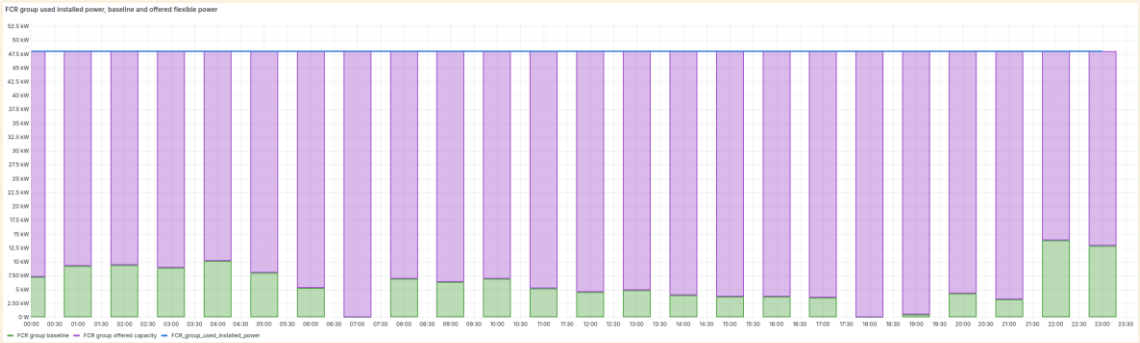


Figure 247: Bid data visualization: FCR-D-down case

The plot in Figure 248 shows the power baseline and the flexible power on the same day (April 23rd) for FCR-D-up.

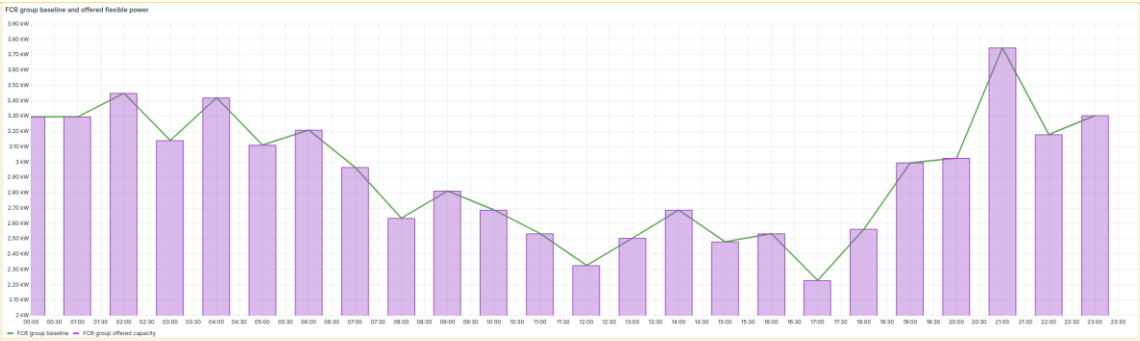


Figure 248: Bid data visualization: FCR-D-up case

TSO Connector has fetched the bid in ready state and has created a bid document meant for the TSO.

Since in this experiment the interface to the TSO is simulated the bid has not actually been sent to the TSO and the answer from the TSO is simulated. Implementing the connection to the TSO is not part of the prototype created for the STREAM project.

Here we have assumed that the bid document was well formed and did not contain any errors, and thus, TSO Connector has set its state to accepted and has stored the accepted bid into Flex Database.

2) Frequency monitoring; FCR-D-up and FCR-D-down activation and deactivation (steps 4-15)

The behaviour of the system when the grid frequency changes as well as the FCR-D activation and deactivation events are monitored by using the FCR Logs. Such log contains an entry for each second for each service. There are about 2 million entries related to the tests with real load with pilot customers. Few tens of them are shown in this document as examples of FCR-D activation and deactivation events.

Figure 249 shows an extract of one log file to provide an example of FCR-D activation, in particular FCR-D-down.

- Row 4431. The grid frequency is it the standard frequency range. The log section starts on April 25th 2026 at 23:13:53 UTC as seen in **DateTime**.
- Row 4432. The **service status** (ContStatus_FcrdDo) shows that the system is monitoring the grid frequency for FCR-D-down service by using the **flex group** (Contmode_FcrdDo) pilot-do. The available **power baseline** (Baseline) is 12kW.
- Row 4433. The **regulating strength** (RegStr_FcrdDo) is the ratio between the **maintained flexible capacity** (Cap_FcrdDo) the and the frequency range of FCR-D-down service (0.4 Hz). The maintained flexible capacity is 30 kW.
- Rows 4434-4436. The **frequency** goes above 50.1 Hz to 50.125 Hz into the FCR-D-down range: the **reserve activation ratio** (ContOutSig) goes to 0.06 to indicate the FCR-D-down activation has started with a power that is proportional to the frequency deviation (0.025 Hz is 0.06% of the frequency range of the service which is 0.4 Hz). The **instantaneous active power injection** (InsAcPow) decreases (more load is added). InsAcPow is the instantaneous active power injection in MW (negative value for absorbed power).
- Row 4438. After 4 seconds from the frequency deviation, production of **activated flexible power** (Act_FcrdDo) starts. The value of Act_FcrdD is above 86% of CountOutSig*Cap_FcrdDo and this happens before 7 seconds from the FCR-D-down activation have elapsed. ContSetP is the value of InsActPow before FCR activation.
- Row 4440. **Full activation**: after 6 seconds from the frequency deviation, the activated flexible power (Act_FcrdDo) reaches the value of the product of CountOutSig (reserve activation ratio which tells how much of maintained capacity shall be activated) and Cap_FcrdDo (maintained flexible capacity): 0.06*0.03024 = 0.0018

1	DateTime	ContStatus_FcrdDo	Contmode_FcrdDo	Baseline	Pmax	Pmin	ApplFreqSig	Cap_FcrdDo	ContOutSig	InsAcPow	ContSetP	Act_FcrdDo	RegStr_FcrdDo
4431	**20260425T231353.347**	1	pilot_do	-0.01203	0	-0.03297	50.1	0.03024	0	-0.00273	-0.00273	0	0.0756
4432	20260425T231354.348	**1**	**pilot_do**	**-0.01203**	0	-0.03297	50.1	0.03024	0	-0.00273	-0.00273	0	0.0756
4433	20260425T231355.348	1	pilot_do	-0.01203	0	-0.03297	50.1	**0.03024**	0	-0.00273	-0.00273	0	**0.0756**
4434	20260425T231356.349	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00326	-0.00273	0	0.0756
4435	20260425T231357.350	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00426	-0.00273	0	0.0756
4436	20260425T231358.351	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00507	-0.00273	0	0.0756
4437	20260425T231359.352	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00507	-0.00273	0	0.0756
4438	20260425T231400.352	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00637	**-0.00273**	-0.00143	0.0756
4439	20260425T231401.353	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00537	-0.00273	-0.00143	0.0756
4440	20260425T231402.354	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00577	-0.00273	-0.00183	0.0756
4441	20260425T231403.355	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00487	-0.00273	-0.00183	0.0756
4442	20260425T231404.356	1	pilot_do	-0.01203	0	-0.03297	50.125	0.03024	-0.0625	-0.00487	-0.00273	-0.00183	0.0756

Figure 249: Extract of a Log file showing the FCR-D-down activation phase

Figure 250 shows an extract of one log file to provide an example of FCR-D de-activation.

- Row 41189. The grid frequency (ApplFreqSig) is still outside the standard frequency range and therefore the reserve activation ration (ContOutSig) has still a negative value as well as the activated flexible capacity (Act_FcrdDo).
- Row 41190. At 09:27:04 the frequency returns to the standard frequency range (ApplFreqSig = 50.1) and the reserve activation ratio (ContOutSig) goes back to zero indicating that **the FCR-D deactivation procedure has started**.
- Row 41195. After 5 seconds from the beginning of the FCR-D deactivation procedure, the absolute value of the instantaneous injected power (InsAcPow) starts to decrease indicating a **smaller load** and the absolute value of the activated flexible power (Act_FcrdDo) starts to decrease as well. ContSetP is "locked" when the disturbance starts. It is "unlocked" when there is no disturbance anymore. So, now it is following the value of InsAcPow.
- Row 41197. After 7 seconds from the beginning of the FCR-D deactivation procedure, the value of the instantaneous injected power (InsAcPow) stabilizes and the value of the activated flexible power (Act_FcrdDo) goes to zero indicating the **completion of the FCR-D deactivation procedure**.

1	DateTime	ContStatus_FcrdDo	Contmode_FcrdDo	Baseline	Pmax	Pmin	ApplFreqSig	Cap_FcrdDo	ContOutSig	InsAcPow	ContSetP	Act_FcrdDo	RegStr_FcrdDo
41189	20260426T092703.854	1	pilot_do	-0.00559	0	-0.03297	**50.125**	0.02679	**-0.0625**	-0.01246	-0.00618	**-0.0029**	0.066975
41190	20260426T092704.855	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41191	20260426T092705.856	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41192	20260426T092706.857	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41193	20260426T092707.857	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41194	20260426T092708.858	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41195	20260426T092709.859	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02151	0	**-0.01146**	-0.01146	**-0.0019**	0.053775
41196	20260426T092710.860	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02151	0	-0.01146	-0.01146	-0.0019	0.053775
41197	20260426T092711.862	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02341	0	**-0.00956**	-0.00956	**0**	0.058525
41198	20260426T092712.863	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02341	0	**-0.00956**	-0.00956	0	0.058525

Figure 250: Extract of a Log file showing the FCR-D-down de-activation phase

Figure 251 shows the activated flexible power in the pilot apartments that have been used for FCR-D-up. The power is positive since it corresponds to load that has been cut.

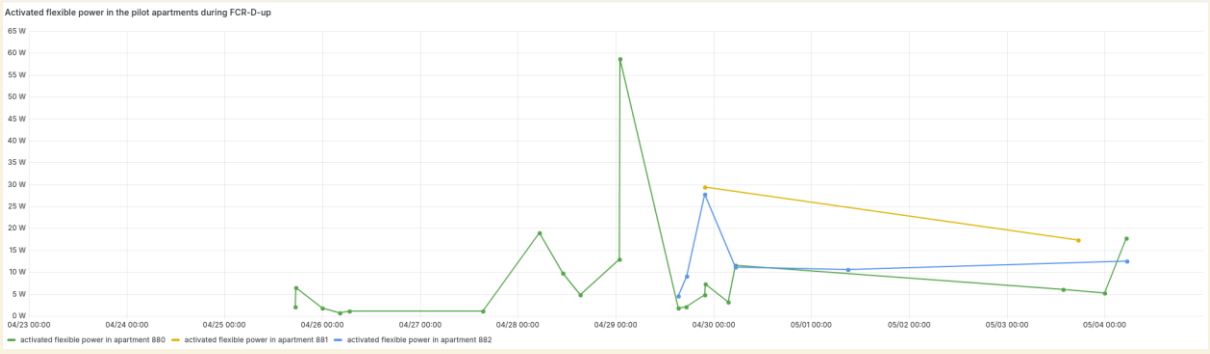


Figure 251: Activated flexible power in the pilot apartments during FCR-D-up

Figure 252 shows the activated flexible power in the pilot apartments that have been used for FCR-D-down. The power is negative since it is absorbed power.

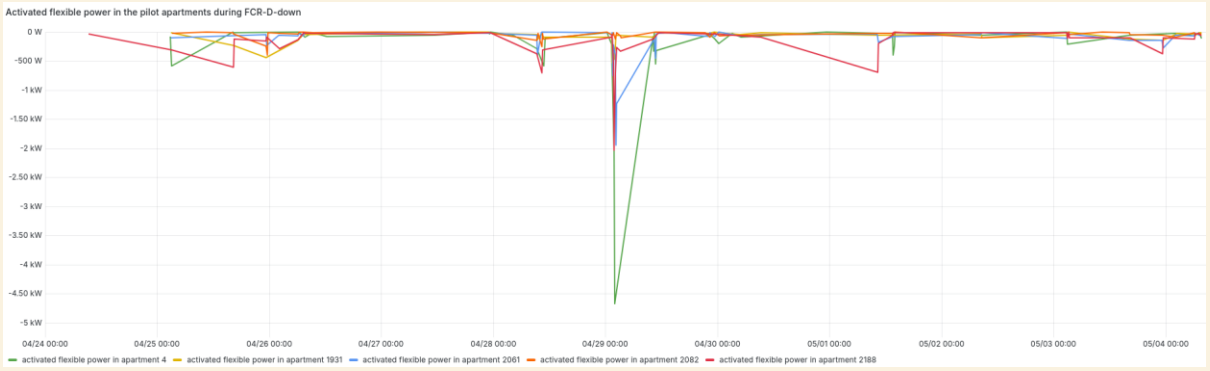


Figure 252: Activated flexible power in the pilot apartments during FCR-D-down

3) Calculation of the technical KPIs (step 16)

One the goals of the Finnish Pilot was to verify if the challenging requirements related to activation times would have been met. Therefore, the related KPIs have been verified already during the demonstration phase.

The **activation KPIs** have been calculated by using few python scripts. The logic of the scripts, which contain few hundreds of lines of code, is summarized as follows:

- Monitor the reserve activation ratio (ContOutSig), which tells if FCR-D is activated, how much and in which direction
- When value != 0, count time & monitor the activated flexible power (Act_x) till ContOutSig deviates in the opposite direction
- If after 5 seconds, Act_x >= 50%*Cap_x*ContOutSig, then 50%actKPI = 1 (Cap_x is the reserved capacity; Cap_x * ContOutSig tells how much reserved capacity shall be activated based on the actual frequency deviation)
- If after 7 seconds, Act_x >= 86%*Cap_x*ContOutSig, then 86%actKPI = 1
- If after 30 seconds, Act_x >= 86%*Cap_x*ContOutSig, then 100%actKPI I = 1
- Calculate the average of the events KPIs within one Log file (one day)
- Calculate the average of the Log files KPIs for the selected group of logs (spanning for example through a week)

Note that the current version of the scripts sees only full activation cases, that is, cases where the frequency variations are such that the frequency does not go back to the standard frequency range before the FCR-D activation is complete.

The results obtained by running the scripts with the Logs obtained in the tests with pilot customers are shown in Figure 253 for FCR-D-down and in Figure 254 for FCR-D-up. All the KPIs are under 0.9 showing that in most cases the activation has been quick enough.

```
ubuntu@ip-172-31-32-81:~/measurements-mgmt/kpi_calculation$ python3 FCR_D_activation_KPIs.py

Script start time (UTC): 2026-05-13 19:34:08

This script loops through all the FCR logs contained in a defined directory and for each of them collects a summary of the results of the activation KPIs.
Then, it calculates the overall amount of source entries, the overall amount of activation events and the average values of the activation KPIs.
It shall be run only on Logs related to the same service.

Summary of each single Log file

| file_name                              |   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|:---------------------------------------|-----------------:|--------------------:|-------------:|-------------:|--------------:|
| pilot_do_FcrdDo_FI_UTC_20260423.csv |            47565 |                   0 |          nan |          nan |           nan |
| pilot_do_FcrdDo_FI_UTC_20260424.csv |            86300 |                   2 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260425.csv |            86323 |                  20 |         0.95 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260426.csv |            86324 |                  11 |         0.91 |         0.91 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260427.csv |            86234 |                   2 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260428.csv |            86323 |                  12 |         0.83 |         0.92 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260429.csv |            86324 |                 140 |         0.92 |         0.93 |          0.99 |
| pilot_do_FcrdDo_FI_UTC_20260430.csv |            86324 |                   6 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260501.csv |            86323 |                   9 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260502.csv |            86324 |                   4 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260503.csv |            86324 |                  12 |         0.92 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260504.csv |            86323 |                  12 |         0.92 |         0.92 |             1 |

Summary of the all time period

|   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|-----------------:|--------------------:|-------------:|-------------:|--------------:|
|           997011 |                 230 |         0.95 |         0.97 |             1 |

Script end time (UTC): 2026-05-13 19:34:31
Script duration: 0:00:23
```

Figure 253: Calculation of the activation KPIs for FCR-D-down in the tests with real load

```
ubuntu@ip-172-31-32-81:~/measurements-mgmt/kpi_calculation$ python3 FCR_D_activation_KPIs.py

Script start time (UTC): 2026-05-18 07:06:34

This script loops through all the FCR logs contained in a defined directory and for each of them collects a summary of the results of the activation KPIs.
Then, it calculates the overall amount of source entries, the overall amount of activation events and the average values of the activation KPIs.
It shall be run only on Logs related to the same service.

Summary of each single Log file

| file_name                              |   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|:---------------------------------------|-----------------:|--------------------:|-------------:|-------------:|--------------:|
| pilot_up_FcrdUp_FI_UTC_20260423.csv |            47595 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260424.csv |            86324 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260425.csv |            86323 |                   7 |         0.86 |         0.86 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260426.csv |            86323 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260427.csv |            86231 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260428.csv |            86324 |                   5 |          0.6 |          0.6 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260429.csv |            86324 |                  36 |         0.92 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260430.csv |            86324 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260501.csv |            86324 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260502.csv |            86323 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260503.csv |            86325 |                   5 |          0.8 |          0.8 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260504.csv |            86324 |                   3 |            1 |            1 |             1 |

Summary of the all time period

|   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|-----------------:|--------------------:|-------------:|-------------:|--------------:|
|           997064 |                  59 |          0.9 |         0.91 |             1 |

Script end time (UTC): 2026-05-18 07:06:57
Script duration: 0:00:23
```

Figure 254: Calculation of the activation KPIs for FCR-D-up in the tests with real load

Qualitative analysis of the results

- The tests with real load were done by using **only 8 of the 10 pilot apartments** because, at the time of the tests, the remaining 2 apartments had an old version of the Edge device (OptiWatti controller) and the necessary SW updates could not be done remotely.
- The reserve activation ratio tells how much of maintained capacity shall be activated. The absolute value of Act_FcrdDo (activated flexible power) is not always the same as InsAcPow-ContSetP (instantaneous active power injection - reserve activation ratio). The reason is that in the tests with real load there are quite few heaters and each has a certain minimum size (nominal power). So, in such tests it is **hard to activate exactly the flexible power what would be strictly needed**, due to the small amount of heaters and to their size.
- The maintained flexible capacity (Cap_FcrdDo) should show not only the free flexible capacity that can be activated but the value should contain also the amount of flexible capacity that has been activated. That was not the case at the time of the tests. However, the necessary changes to the SW have been done at the time of finalizing this document as shown in Figure 255.

1	DateTime	ContStatus_FcrdDo	Contmode_FcrdDo	Baseline	Pmax	Pmin	GridFre	Cap_FcrdDo	ContOutSig	InsAcPow	ContSetP	Act_FcrdDo	RegStr_FcrdDo	Pavailable	Comments
50879	20260605T120844.106	1	megagroup_do	-0.079308333	0	-0.13715	50	0.09353	0	-0.04362	-0.04362	0	0.233825	0.09353	
50880	20260605T120845.107	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.05979	-0.04362	-0.01617	0.233825	0.09353	Cap_FcrdDo and CointSetP freeze
50881	20260605T120846.107	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.10746	-0.04362	-0.06383	0.233825	0.09353	50% activation in 2 seconds
50882	20260605T120847.107	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13314	-0.04362	-0.08951	0.233825	0.09353	86% activartion in 3 seconds
50883	20260605T120848.109	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13514	-0.04362	-0.09151	0.233825	0.09353	
50884	20260605T120849.109	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13514	-0.04362	-0.09151	0.233825	0.09353	
50885	20260605T120850.110	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13655	-0.04362	-0.09292	0.233825	0.09353	
50886	20260605T120851.111	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13655	-0.04362	-0.09292	0.233825	0.09353	
50887	20260605T120852.112	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13715	-0.04362	-0.09352	0.233825	0.09353	Full activation in 8 seconds
50888	20260605T120853.114	1	megagroup_do	-0.079308333	0	-0.13715	50.5	0.09353	-1	-0.13715	-0.04362	-0.09352	0.233825	0.09353	Signs are correct

Figure 255: FCR Log after corrections to the Cap_X writing logic

Experiment number	**FI-UC.05.01**
Name of the experiment	Cust-flex-profitability: Evaluating the profitability for the customer when using explicit flexibility
Timeframe	August 2025 – June 2026 (M35-M45)
Targets	This test scenario verifies use case FI05 “Evaluating the flexibility profitability for the customer”.
Actors	• Aggregator (Optiwatti)
STREAM products	sFLEX, sDATA
Assets & systems	• sFLEX Analyser • sFLEX Simulator
Description of the experiment	This test scenario uses a simulated interface to the TSO. It is based on the main test scenarios for FCR-D: FI-UC.01.01 and FI-UC.01.2. There are several possible factors that affect the costs for the user: • Extra heating due to FCR-D-down service • Load cut due to the FCR-D-up service (this is a “negative” cost) • Re-heating after a load cut due to FCR-D-up service • Compensation for being part of a FCR group (this is a “negative” cost) **Preconditions:** • Test cases FI-UC.01.01 and FI-UC.01.2. have been run **Steps:**

	1. A preliminary calculation is performed by using statical data provided by the TSO 2. Estimation of extra costs by using flexibility is run 3. The results of the two calculation methods are compared 4. The result is stored in sDATA **Postconditions:** • Extra customers costs when using flexibility are available
Exception paths and scenarios of the experiment	There are no exception paths in this test scenario.
Datasets required for the experiment	• FI_14 Customer profitability input
Field data to be gathered	• FI_15 Customer profitability output
Related KPIs	None

Results of the Experiment

1) Preliminary calculation

A preliminary calculation about the potential economic impact for the customers of using heating assets for FCR-D services has been done by **using statistical data from the TSO**.

Figure 256 shows the daily average number of minutes per year that grid frequency was outside the standard frequency range during the years 2019-2024.

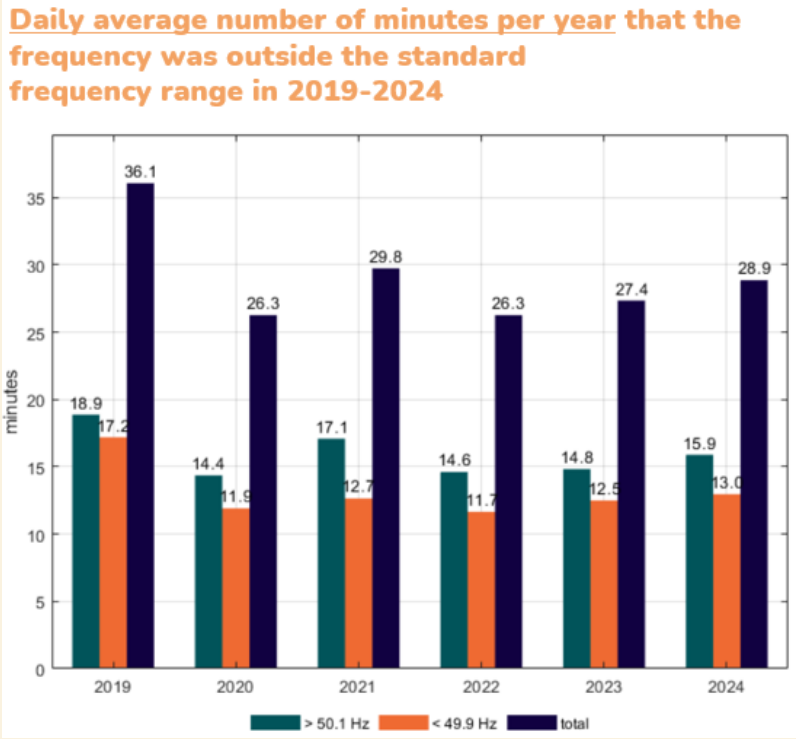


Figure 256: Daily average number of minutes per year the frequency was outside the standard frequency range

Based on this data, the total time in a year that the frequency was outside the standard frequency range in each direction has been calculated as shown in Table 49.

Estimated data based on Fingrid statistics: https://www.fingrid.fi/globalassets/dokumentit/frequency-quality-analysis-2024.pdf		
Variable	**Value**	**Unit**
FCR-D-up (frequency lower than the standard frequency range) - data averaged over the last 6 years		
Daily average number of minutes per year that the frequency was outside the standard frequency range	13.2	minute
Number of minutes per year that the frequency was outside the standard frequency range	4818	minute
Total time in a year the frequency was outside the standard frequency range	**80.3**	**hours**
FCR-D-down (frequency higher than the standard frequency range) - data averaged over the last 6 years		
Daily average number of minutes per year that the frequency was outside the standard frequency range	15.9	minute
Number of minutes per year that the frequency was outside the standard frequency range	5803.5	minute
Total time in a year the frequency was outside the standard frequency range	**96.73**	**hours**

Table 49: Total time in a year that the frequency was outside the standard frequency range in each direction (averaged over 6 years)

Then, based on configuration data and periodic measurements of real customers, a **typical apartment profile** has been created as shown in Table 50.

Basic data about the apartment			
Variable	**Value**	**Unit**	**Notes**
Average installed power theorethically usable for flexibility (electric radiators and floor heating)	9.97	kW	Data source: measured data from configuration
Average installed power usable for flexibility (electric radiators and floor heating)	4.98	kW	Due to few reduction factors (spot price control, possible demand-response related customer settings, aggregator-defined scaling factor, TSO-defined capacity reduction factor), the power usable for flexibility is estimated to be 50% of the installed power
Estimated average yearly energy cost per kWh	0.05	€	Average spot price (energy cost only)
Estimated energy transfer cost per kWh	0.03	€	
Estimated average energy cost per kWh, including taxes	**0.09**	€	Excluding basic fee, insurances, ...
Estimated average energy used in one year	17078.00	kWh	Data source: periodic measurements (average over the last 3 years)
Estimated average yearly energy cost	1513.96	€	Excluding basic fee, insurances, ...

Table 50: Typical apartment profile

By using a typical **load profile for an aggregator** in Finland, it has been calculated that a certain installed load which is suitable for flexible load usage can be used only 25% of the time for FCR-D-up and for about 75% of the time it will be used for FCR-D-down. This is due to the fact that houses in Finland are quite well insulated thermally and each room typically has a considerable amount of installed load that for most of the time is cut off. So, it is much easier for an aggregator to find load to add rather that to find load to be cut. Figure 257 shows a proof of this. The plot shows the average daily power used for heating by 2.500 apartment in year 2025. Such apartments have a cumulative installed power theoretically usable for flexibility of 25 MW whereas the plot does not reach 11MW even in the coldest winter days.

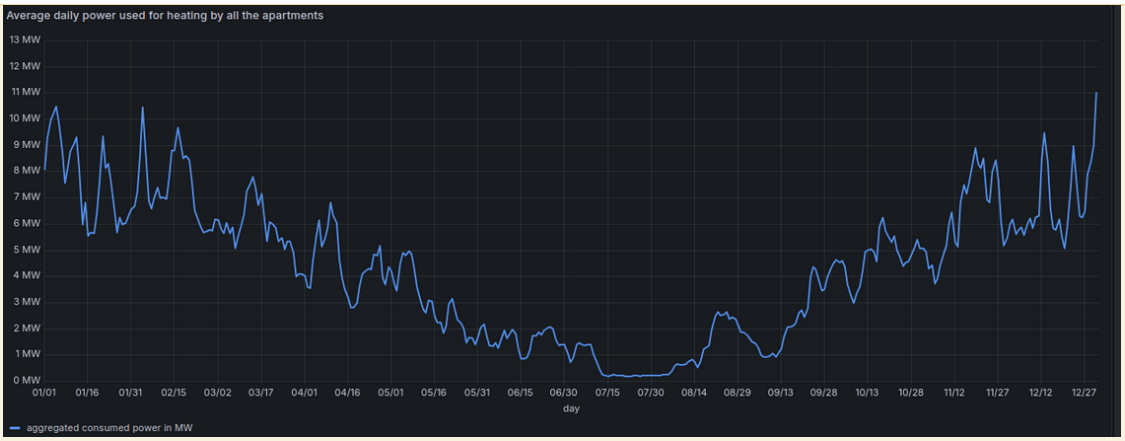


Figure 257: Average daily power used for heating cumulatively by all apartments in year 2025

The results obtained so far have been used to produce the data shown in Table 51.

Customers costs and profits			
Variable	**Value**	**Unit**	**Notes**
Probability that the heating asset is used for FCR-D-up	0.25		Data obtained by using periodic measurements and configuration data
Estimated average yearly amount of hours the assets can be used for FCR-D-up	**20.08**	**hours**	
Estimated average **savings in 1 year due to FCR-D-up load cut**	**-4.43**	**€**	estimated average energy cost per kWh * installed flexible power * estimated average yearly amount of hours the assets can be used for FCR-D-up (negative because it is saving). The result is divided by 2 because the customer load is not used for the all time of the frequency deviation since the flexible power shall be proportional to the actual frequency deviation
Percentage of energy costs saved due to FCR-D-up load cuts	**0.00**	**€**	estimated average savings in 1 year due to FCR-D-up load cut / estimated average yearly energy cost
Probability that the heating asset is used for FCR-D-down	0.75		Data obtained by using periodic measurements and configuration data
Estimated average yearly amount of hours the assets are used for FCR-D-down	**72.54**	**hours**	
Estimated average **extra costs in 1 year due to FCR-D-down**	**16.03**	**€**	estimated average energy cost per kWh * installed flexible power * estimated average yearly amount of hours the assets can be used for FCR-D-down. The result is divided by 2 because the customer load is not used for the all time of the frequency deviation since the flexible power shall be proportional to the actual frequency deviation
Percentage of extra energy costs due to FCR-D-down extra load	**0.01**	**€**	estimated average extra costs in 1 year due to FCR-D-down / estimated average yearly energy cost
Estimated extra costs in 1 year due to re-heating after load cut due to FCR-D-up	0.00	€	Most of the frequency deviations last less than a minute and in such short time the temperature sensors in the rooms will not notice any difference
Estimated monetary customer compensation in 1 year from the aggregator	0.00	€	Based on the above results there is no ground for a customer compensation
Estimated overall extra cost in 1 year for the customer to be part of a FCR	**11.59**	**€**	

Table 51: Preliminary calculation of customers. Profit and loss due to usage of heating assets for demand-response

The conclusion of this calculation is that an average apartment will see an **increase in annual bill of less than 12 euros** when being part of an FCR.

Note that this calculation has assumed that all customers have spot price. In Finland, only about one third of households have spot-price based tariffs. So, the energy costs could differ and could be a bit higher in practice but this does not change the percentage of saved costs / additional costs due to the usage of the heating assets for flexibility.

2) Calculation of customers' profit/losses due to usage of heating assets for flexibility by using measured data from tests with real load

Once data from tests with real load from pilot customers was available, the calculations done based on statistical data from the TSO as well as on the configuration data and on the periodic measurements by the aggregator (OptiWatti), have been verified by making new calculations using different source of data.

The input data for the calculation has been:

- Flex Market or service which here is either FCR-D-Down or FCR-D-Up
- Flex Group hierarchy, specifically the IDs of the apartments
- Energy prices for each apartment for every market day
  - Include energy costs, transfer costs and all relevant taxes
- Flexible activation data from the periodic measurements database
  - Flex Market / service specific
  - Apartment specific
  - Time resolution is 10 min
- Signed values, the sign depends on whether power was absorbed from adding load (zero or negative values) or injected to the grid by cutting load (zero or positive values)

The following algorithm that has been used in the calculation:

- For each Flex Client (apartment) within the Flex Group
  - For each hour of the whole test duration
- Determine the number of 10 min periods with flexible power activation
- Calculate the activated flexible energy
- Calculate the corresponding monetary value
- Store these three values

The process is shown in Figure 258.

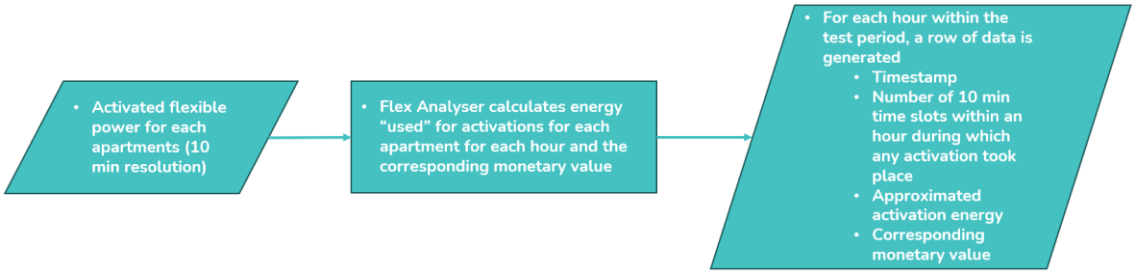


Figure 258: Process used in the calculation of customers profit / losses due to usage of the assets for demand-response based on measured data from tests with real load

The output of this calculation has been the extra costs or savings that the customers owning the pilot apartments have had during a week within the test period in spring 2026. The results have been normalized by extrapolating the results to the whole year and provided an average extra cost per year for each apartment of 5,5 €.

Qualitative analysis of the results

Comparison of the results obtained with different methods:

The preliminary calculations were done for typical apartments with an average installed power of 9.97 kW whereas the apartments used for the tests with real load had an average installed power of 5,6 kW. By considering this, the result obtained by using data for the tests with the pilot customers should be adjusted as follows:

adjusted result = measured result * installed power of typical apartment / average installed power of pilot apartments = 5,6 * 9,97 / 5,6 = **10 €**.

This value is in the same range of the value that has been calculated based on statistical data from Fingrid. The small difference could be explained by the fact that during the testing period there has been a slight lower number of frequency deviations than usually.

The calculation based on the results of the tests with real load confirms the earlier assumption that customer costs due to flexibility are a **very small percentage of the yearly bill.**

9 ANNEX C — DATASETS GATHERED

9.1 SLOVENIAN PILOT SITE

DS SI.01	
Data Element	Historical timeseries measurement data (P and Q)
Description of the data	sPLAN and sGRID will use the historical measurement data for loads, which it will use to perform load flow calculations.
Availability of the data	Confidential
Access to data	This data is the property of EPR as the DSO and is sensitive in nature (reflects user behaviour patterns), therefore it cannot be shared in Zenodo.
Source of data	smart meters from DSO
Measurement units	kW and kVAr
Sampling period(s)	15 minutes
Related experiment(s)	SI-UC.01.01, SI-UC.05.01, SI_sDATA-UC.01
Related Products	sPLAN, sGRID, sDATA
Related KPIs	KPI SI.04
Graphical support	Not available for confidential data.

DS SI.02	
Data Element	Grid topology data (CIM or GIS)
Description of the data	sDATA retrieves the grid topology data from the DSO. The grid data will serve for grid analysis, performed by other STREAM tools, such as congestion forecast performed by sGRID.
Availability of the data	Confidential. Anonymised technical parameters for a subset of MV/LV transformer stations are publicly available.
Access to data	Grid topology data is property of the DSO. This data is sensitive, since it reflects the real state of the grid and a misuse of this data may jeopardise the security of the energy supply. Anonymised

	transformer station parameters (rated power, impedance characteristics, losses) are available at Zenodo.
Source of data	EPR's data base
Measurement units	/
Sampling period(s)	/
Related experiment(s)	SI-UC.01.01, SI-UC.05.01, SI_sDATA-UC.01
Related Products	sGRID, sDATA
Related KPIs	KPI sDATA.01, KPI SI.04, KPI SI.05
Graphical support	Not feasible for grid topology data.

DS SI.03	
Data Element	Timeseries measurement data (AMI)
Description of the data	sGRID will use the measurement data for loads, which it will use to perform load flow calculations. sGRID will receive this data from sDATA. sDATA retrieves the timeseries measurement data from the DSO. The measurement data will serve for power system analysis, performed by other STREAM tools, such as congestion forecast performed by sGRID.
Availability of the data	Confidential for individual consumer measurements. Anonymised control measurements from MV/LV transformer stations are publicly available.
Access to data	Timeseries measurement data is property of the DSO. This data is sensitive, since it reflects the real state of the power system and a misuse of this data may jeopardise the security of the energy supply. Anonymised active and reactive power measurements (15-min resolution, year 2025) from a subset of MV/LV transformer stations are available at Zenodo
Source of data	EPR's database (this gets data from AMI systems)
Measurement units	Various (kW, kVAr, V, A)
Sampling period(s)	15 min for P, Q 10 min for U, I
Related experiment(s)	SI-UC.01.01, SI-UC.05.01, SI_sDATA-UC.01

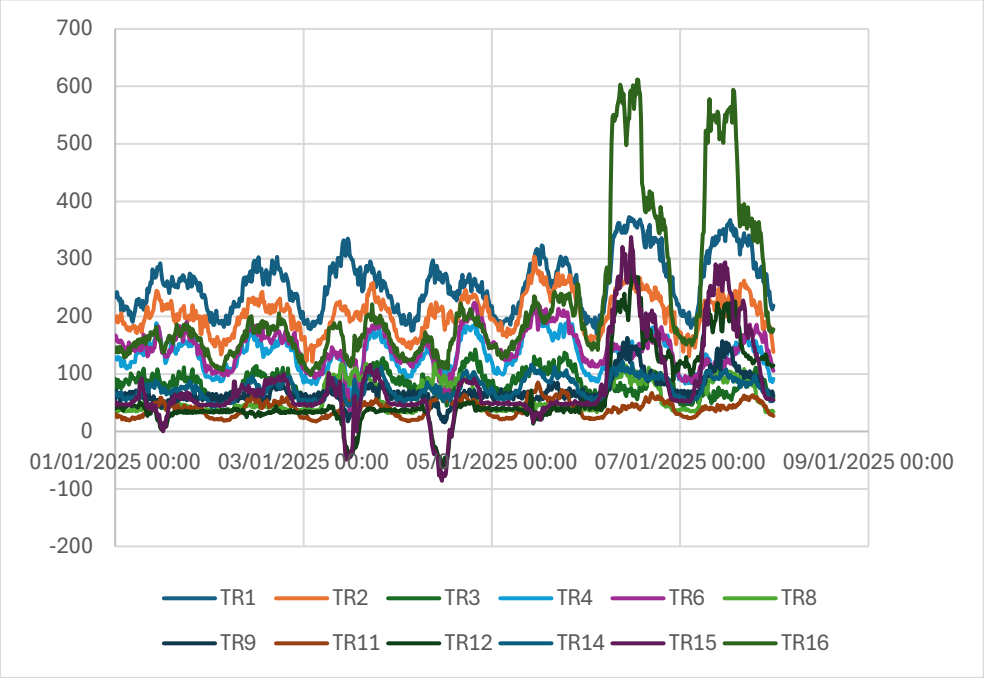
Related Products	sGRID, sDATA
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.04, KPI SI.05
Graphical support	

Figure 259: Anonymized values for AMI timeseries data

DS SI.04	
Data Element	Timeseries measurement data (SCADA)
Description of the data	sGRID will use the measurement data for loads, which it will use to perform load flow calculations, but will need measurements also from some parts of the grid (mostly substations) to validate the results. sGRID will receive this data from sDATA. sDATA retrieves the timeseries measurement data from the DSO. The measurement data will serve for power system analysis, performed by other STREAM tools, such as congestion forecast performed by sGRID.
Availability of the data	Confidential
Access to data	Timeseries measurement data is property of the DSO. This data is sensitive, since it reflects the real state of the power system and a misuse of this data may jeopardize the security of the energy supply.
Source of data	EPR's database (this gets data from SCADA systems)
Measurement units	Various (kWh, kVArh, V, A)
Sampling period(s)	15 min for P, Q

	10 min for U, I
Related experiment(s)	SI_sDATA-UC.01, SI-UC.05
Related Products	sGRID, sDATA
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.05
Graphical support	Not available for confidential data.

DS SI.05	
Data Element	Weather data (solar irradiation, temperature etc and wind speed)
Description of the data	sGRID will use weather data to be able to forecast congestions in the grid. The reason why weather data is important is that many devices operate differently depending on the weather (e.g. PVs produce more with higher solar irradiation, coolers need to operate with higher power when the ambient temperature is higher…)
Availability of the data	Public
Access to data	Data is public and was gathered from Openmeteo portal via their API.
Source of data	Openmeteo
Measurement units	$°C, {}^{W}/_{m^2}, km/h$
Sampling period(s)	/
Related experiment(s)	SI-UC.05
Related Products	sGRID
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.04, KPI SI.05

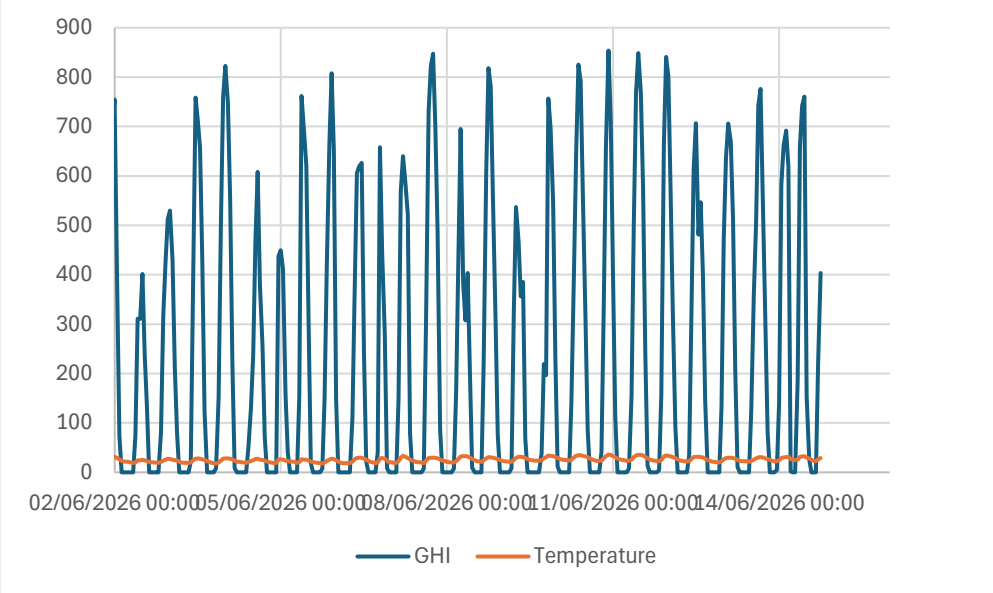
Graphical support	

Figure 260: Sample weather data

DS SI.06	
Data Element	Grid limits
Description of the data	To be able to forecast congestions in the grid, sGRID will need to have a clearly defined list of limits (planning and operational) stored in the connected databases.
Availability of the data	Confidential
Access to data	Data is confidential as it includes sensitive information connected with stable operation of the distribution network.
Source of data	Defined together by EPR and UL
Measurement units	kVA
Sampling period(s)	/
Related experiment(s)	SI-UC.05.01
Related Products	sGRID, sDATA
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.04, KPI SI.05
Graphical support	Not available for confidential data.

DS SI.07	
Data Element	Congestion forecast results (TLS status)
Description of the data	sMART will receive the results of performed congestion forecast from sGRID
Availability of the data	Confidential
Access to data	Data is confidential as it includes sensitive information connected with stable operation of the distribution network.
Source of data	sGRID
Measurement units	/
Sampling period(s)	/
Related experiment(s)	SI-UC.05.01
Related Products	sMART, sGRID
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.05, KPI SI.06
Graphical support	Not available for confidential data.

DS SI.08	
Data Element	Flexibility sources measurements
Description of the data	Measurements received from flexibility sources (EVs, industrial consumer assets), which are connected to the sFLEX aggregation platform either directly or through a HEMS device. This includes: • Active power of flexibility assets in 1min resolution
Availability of the data	Partially confidential
Access to data	Data collected in the KOL's databases can be accessed by KOL and they can be exported to asset owners if needed. External access is not possible.
Source of data	Flexibility sources
Measurement units	MW
Sampling period(s)	Minutes
Related experiment(s)	SI-UC.02.01, SI-UC.06.01, SI-UC.06.02
Related Products	sFLEX

Related KPIs	KPI SI.01, KPI SI.02, KPI SI.06
Graphical support	

Figure 261: Example of flexibility sources measurements

DS SI.09	
Data Element	EV charging station (CS) measurements
Description of the data	CS charging power measurements received from AVA CSs.
Availability of the data	Partially confidential
Access to data	Data collected in the KOL's databases can be accessed by KOL and they can be exported to asset owners if needed. External access is not possible.
Source of data	AVA CSs
Measurement units	kW
Sampling period(s)	Minutes
Related experiment(s)	SI-UC.02.01, SI-UC.06.01
Related Products	sFLEX
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.06
Graphical support	

Figure 262: Example of EV charging station sources measurements

DS SI.10	
Data Element	Device Registration Information
Description of the data	The data is collected through registration of flexibility devices in the Device Registry. The register of the devices will serve as a collection of flexible devices that could provide their flexibility for relevant market products/services.
Availability of the data	Confidential
Access to data	Access is restricted due to its sensitive nature, potentially revealing commercially sensitive information about asset owners (FDOs) and their flexibility potential.
Source of data	Directly provided by the FDO during the online registration process, or by an authorized Aggregator on behalf of the FDO.
Measurement units	Varies depending on the specific data element.
Sampling period(s)	Data is provided during registration and updated as needed
Related experiment(s)	SI-UC.07.01
Related Products	sDATA
Related KPIs	KPI SI.07, KPI SI.08
Graphical support	Not available for confidential data.

DS SI.11	
Data Element	Device Measurement Data for Prequalification
Description of the data	This dataset includes real-time and historical measurements collected from flexibility sources as part of the prequalification test activation in SI-UC.08.01. This data is crucial for validating the technical capabilities of devices to deliver the promised flexibility and for calculating baselines.
Availability of the data	Confidential
Access to data	Access is limited to authorized stakeholders, including the DSO, and potentially selected market participants involved in the prequalification process (Aggregator).
Source of data	Directly obtained from the flexibility sources themselves through various communication protocols.
Measurement units	Typical measurements include active power (kW) and potentially other parameters depending on the specific asset type.

Sampling period(s)	The sampling frequency can vary depending on the capabilities of the measurement infrastructure and the requirements for prequalification. It could range from minutes to seconds.
Related experiment(s)	SI-UC.08.01
Related Products	sDATA
Related KPIs	KPI SI.01, KPI SI.02, KPI SI.09, KPI SI.10, KPI SI.11, KPI SI.12
Graphical support	Not available for confidential data.

DS SI.sDATA.01	
Data Element	Distributed ledger history data
Description of the data	sDATA saves access events data into the distributed ledger. The data can be utilized for investigative purposes to determine whether it is accessed by the users who have been granted the appropriate permissions.
Availability of the data	Confidential
Access to data	The history log of access in the sDATA portal is confidential and only users with permissions can access this data. This data is sensitive, since it reflects the real state of data access processes and it might include some users' personal information (e.g. time of the login, logout, etc.).
Source of data	Distributed ledger database.
Measurement units	/
Sampling period(s)	/
Related experiment(s)	SI_sDATA-UC.02
Related Products	sDATA
Related KPIs	KPI sDATA.02
Graphical support	Not available for confidential data.

DS SI.sDATA.02	
Data Element	Master data

Description of the data	Master data management system manages master data, including user data and access rights, and power system master data, such as EV charging station master data, power grid master data, etc.
Availability of the data	Confidential
Access to data	The master data in the sDATA portal is confidential and only users with permissions can access this data. This data is sensible, since it reflects the real state of the power system and users included in the project.
Source of data	Master data management system database.
Measurement units	/
Sampling period(s)	/
Related experiment(s)	SI_sDATA-UC.03
Related Products	sDATA
Related KPIs	KPI sDATA.02
Graphical support	Not available for confidential data.

9.2 SPANISH PILOT SITE

DS ES.01	
Data Element	LV and MV grid topology
Description of the data	A GIS file containing the information and location of the assets of the grid is necessary to build the grid topology in sGRID. This model parametrizes the limits of the grid and will establish the values that will be the basis to detect congestions and voltage violations in the grid. The grid topology also helps to locate and enable the flexibility assets that will be part of the local flexibility market.
Availability of the data	Confidential
Access to data	The grid topology is owned by the DSO. These data include detailed information about the physical assets of the network, and locations of substations and other critical infrastructures which is sensitive. A malicious use of these data may cause cybersecurity vulnerabilities and manipulation of the grid performance.
Source of data	ENER's GIS
Measurement units	-

Sampling period(s)	-
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02
Related Products	sGRID
Related KPIs	KPI ES.01, KPI ES.02, KPI ES.03, KPI ES.04, KPI ES.07
Graphical support	Not available for confidential data.

DS ES.02	
Data Element	Active and reactive power value at grid lines
Description of the data	sGRID retrieves the power values at the grid lines every few minutes from the SCADA system of ENER. These power values will serve to provide grid forecasts and to detect in real-time congestion issues in the network.
Availability of the data	Confidential
Access to data	Data gathered from SCADA system are property of the DSO. This data is sensitive, since it reflects the real state of the grid and a misuse of this data may jeopardize the security of the energy supply.
Source of data	ENER's SCADA
Measurement units	kW, kvar
Sampling period(s)	Minutes
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02
Related Products	sGRID
Related KPIs	KPI ES.01, KPI ES.02, KPI ES.03, KPI ES.04
Graphical support	Not available for confidential data.

DS ES.03	
Data Element	Voltage and angle of busbars
Description of the data	sGRID retrieves the voltage and frequency of the grid buses every few minutes from the SCADA system of ENER. These voltage measures will help to forecast and detect voltage violations in the grid.

Availability of the data	Confidential
Access to data	Data gathered from SCADA system are property of the DSO. This data is sensitive, since it reflects the real state of the grid and a misuse of this data may jeopardize the security of the energy supply.
Source of data	ENER's SCADA
Measurement units	kV, Hz
Sampling period(s)	Minutes
Related experiment(s)	ES-UC.02.01, ES-UC.02.02
Related Products	sGRID
Related KPIs	KPI ES.07
Graphical support	Not available for confidential data.

DS ES.04	
Data Element	Active and reactive power of PV + community battery installation
Description of the data	These data monitor the power generated by the community PV installation, as well as the active and reactive power injected and stored by the battery.
Availability of the data	Public
Access to data	The data has been uploaded to Zenodo and can be accessed through STREAM ES-UC.04.01 Active and reactive power of the hybrid PV + community BESS installation - Spanish pilot site | Zenodo
Source of data	Read and stored by ENER, access provided via HTTP API
Measurement units	kW, kvar
Sampling period(s)	Minutes
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX

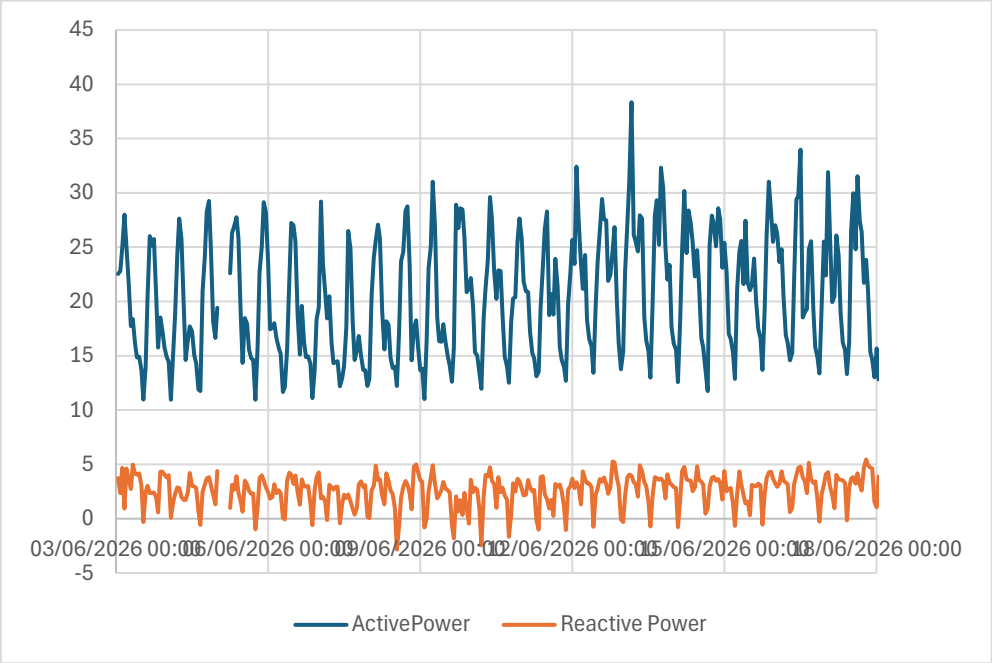
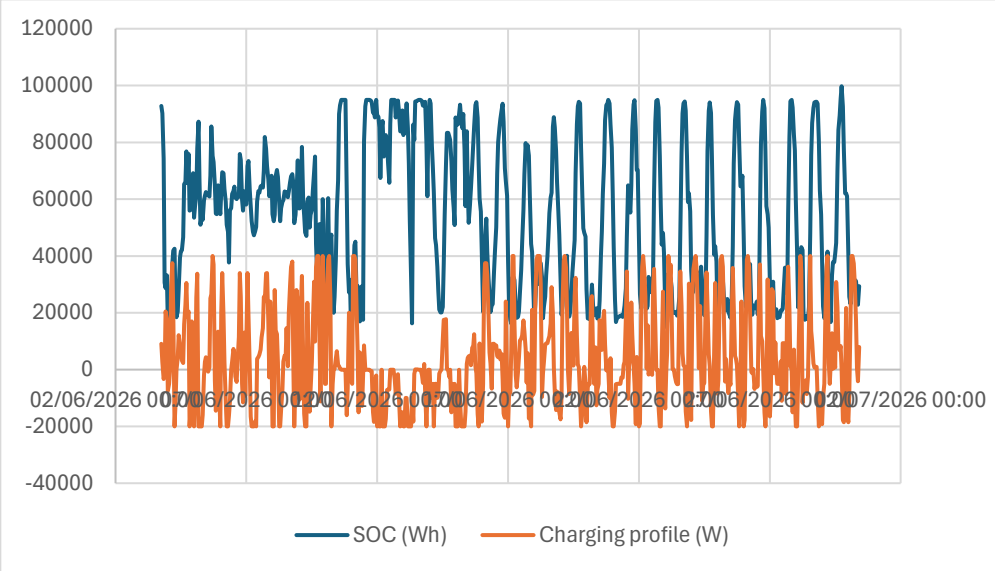
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.13, KPI ES.14
Graphical support	

Figure 263: Graphical support for the active and reactive power of the PV+BESS installation active and reactive power

DS ES.05	
Data Element	Community battery SOC
Description of the data	The community battery SOC provides information of the amount of energy that the battery can deliver, and the energy that can currently be stored. The dataset includes the SOC in Wh and the charging profile (charging/discharging) of the battery in W.
Availability of the data	Public
Access to data	The data has been uploaded to Zenodo and can be accessed through STREAM ES-UC.04.01 Community battery State of Charge - Spanish pilot site | Zenodo
Source of data	Read and stored by ENER, access provided via HTTP API
Measurement units	Wh, W
Sampling period(s)	Minutes

Related experiment(s)	ES-UC.01.02, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.14
Graphical support	 *Figure 264: Graphical support for the community battery state of charge*

DS ES.06	
Data Element	Prosumers' consumption and generation
Description of the data	This dataset includes the active and reactive energy consumed and generated by the prosumers connected to Enercoop's grid, including the EnC members with active participation in the project. This data will serve as input both to the grid forecast and the power flow analysis.
Availability of the data	Confidential
Access to data	Data gathered from the AMI system of the DSO belong to third parties and cannot be publicly shared.
Source of data	AMI system through an FTP
Measurement units	kWh, kvarh
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01

Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.14
Graphical support	Not available for confidential data.

DS ES.07	
Data Element	Generation from EnC collective self-consumption installations
Description of the data	Energy generated by collective self-consumption installations in the municipality's buildings.
Availability of the data	Confidential
Access to data	These data are owned by third parties and cannot be public.
Source of data	HTTP API
Measurement units	kWh, kvarh
Sampling period(s)	Minutes
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.14
Graphical support	Not available for confidential data.

DS ES.08	
Data Element	Domestic batteries SOC
Description of the data	The domestic batteries SOC provides information of the amount of energy that the battery can deliver, and the energy that can currently be stored.
Availability of the data	Confidential
Access to data	These data are owned by third parties and cannot be public.
Source of data	HTTP API
Measurement units	Wh, W
Sampling period(s)	Minutes

Related experiment(s)	ES-UC.01.02, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.14
Graphical support	Not available for confidential data.

DS ES.09	
Data Element	Active and reactive energy of EV chargers
Description of the data	These data include the energy that is being consumed by the EV chargers for EV charging, as well as the energy that has been injected to the grid.
Availability of the data	Confidential
Access to data	These data are owned by third parties and cannot be public.
Source of data	EV chargers via OCPP or Modbus
Measurement units	kWh, kvarh
Sampling period(s)	Charging sessions
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.14
Graphical support	Not available for confidential data.

DS ES.10	
Data Element	Weather data
Description of the data	Current data and forecasts of the relative humidity, ambient temperature close to the PV installations of the pilot site, and solar radiation in the pilot site are used as inputs for the generation forecasts of the generators and self-consumption installations of the pilot site.
Availability of the data	Public
Access to data	The data has been uploaded to Zenodo and can be accessed through STREAM ES-UC.04.01 Weather data - Spanish pilot site | Zenodo

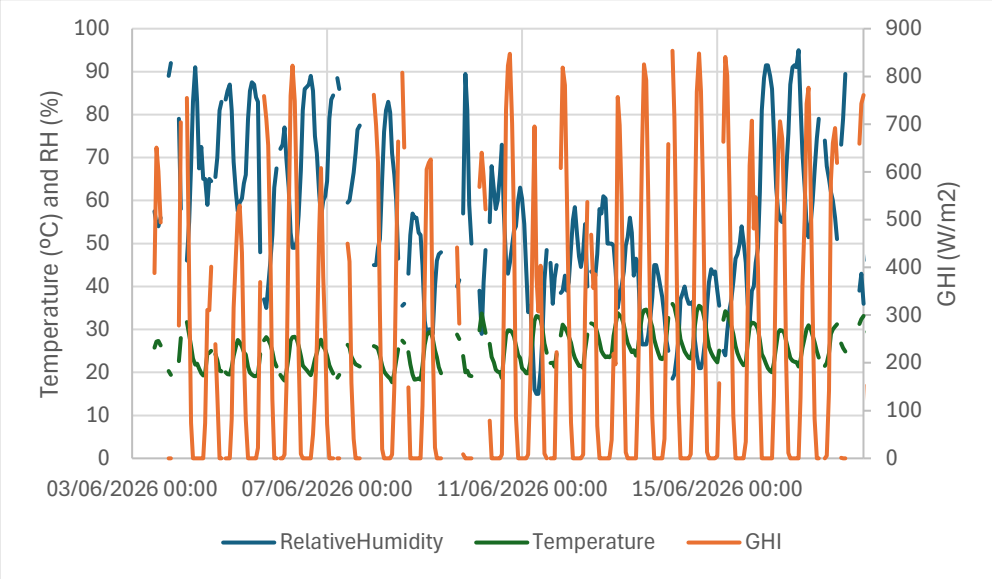
Source of data	External provider
Measurement units	%, ºC, W/m^2
Sampling period(s)	Hourly (current, 48-hour forecast)
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02, ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sGRID, sENC, sFLEX
Related KPIs	KPI ES.06, KPI ES.09, KPI ES.10, KPI ES.11, KPI ES.12, KPI ES.14
Graphical support	

Figure 265: Graphical support for the Weather data

DS ES.11	
Data Element	Prosumer's energy tariffs
Description of the data	Dataset including the energy tariffs that apply for each prosumer participating in the project. This dataset contains information regarding the hour variable energy cost (€/kWh), and the capacity cost (€/kW).
Availability of the data	Public

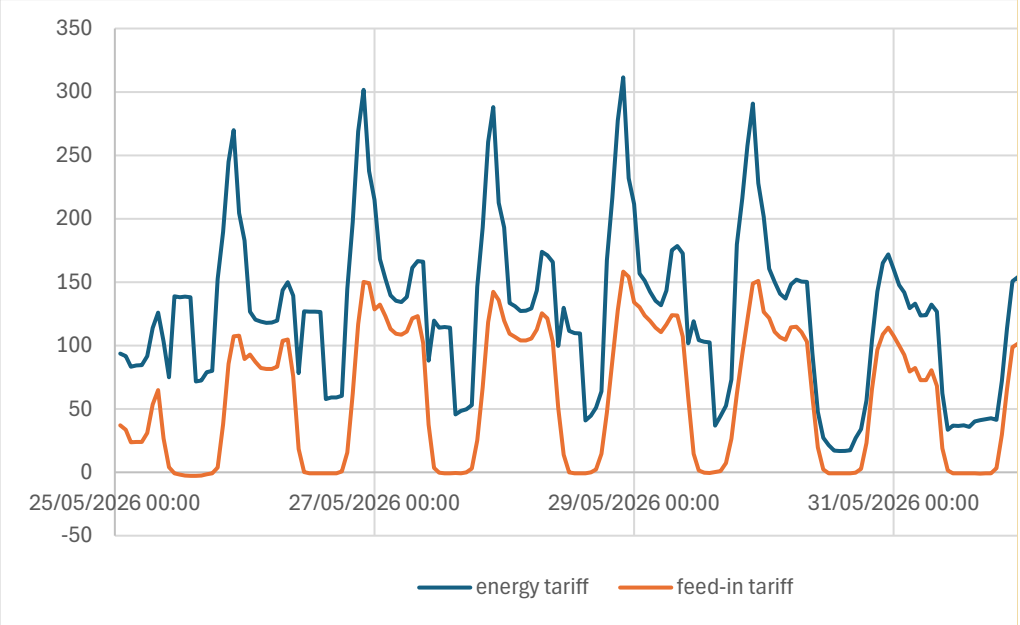
Access to data	This data is published by the TSO through the esios website and can be accessed through PVPC | ESIOS electricidad · datos · transparencia
Source of data	Regulated tariff prices obtained through esios (TSO's webpage)
Measurement units	€/kWh
Sampling period(s)	Hourly, 25/05/2026 – 30/06/2026
Related experiment(s)	ES-UC.03.01, ES-UC.03.02, ES-UC.06.01, ES-UC.07.01
Related Products	sENC
Related KPIs	KPI ES.13
Graphical support	

Figure 266: Energy tariff dataset graphical representation

DS ES.12	
Data Element	Demand and production forecasts at grid level
Description of the data	The demand and production forecast at grid level estimates the generation of the DERs connected to the DSO's grid and the consumption and generation of the supply points in order to estimate the future power flow in the grid, which in turn will serve to detect

	and forecast congestions and voltage deviations in the grid. The demand and production forecasts are calculated for the next 24 hours, based on historical data, characterisation of the day and weather-related exogenous variables.
Availability of the data	Confidential
Access to data	This data is derived from the data gathered from SCADA system that is property of the DSO. This data is sensitive, since it reflects the estimated state of the grid and a misuse of this data may jeopardize the security of the energy supply.
Source of data	Forecasts generated by sGRID.
Measurement units	kWh, kvarh
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02
Related Products	sGRID
Related KPIs	KPI ES.02, KPI ES.03
Graphical support	Not available for confidential data.

DS ES.13	
Data Element	Power flows forecast
Description of the data	Contains hourly forecast of power flows among grid elements. The power flows include the Active Power, Reactive Power and Intensity flowing through the network's feeders, and the Voltage and angle at the nodes, and will be the basis to forecast and detect congestions and voltage deviations.
Availability of the data	Confidential
Access to data	This data is derived from the data gathered from SCADA system that is property of the DSO. This data is sensitive, since it reflects the estimated state of the grid and a misuse of this data may jeopardize the security of the energy supply.
Source of data	Forecasts generated by sGRID.
Measurement units	kW, kvar, A, V, deg
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.01.01, ES-UC.01.02, ES-UC.02.01, ES-UC.02.02

Related Products	sGRID
Related KPIs	KPI ES.01, KPI ES.02, KPI ES.03, KPI ES.04, KPI ES.07
Graphical support	Not available for confidential data.

DS ES.14	
Data Element	Congestion forecast
Description of the data	The congestion forecast is obtained through sGRID by comparing the forecasted power flows with the technical restrictions of the different elements of the grid.
Availability of the data	Confidential
Access to data	This data is derived from the data gathered from SCADA system that is property of the DSO. This data is sensitive, since it reflects the estimated state of the grid and a misuse of this data may jeopardize the security of the energy supply.
Source of data	Forecasts generated by sGRID.
Measurement units	kW
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.01.01, ES-UC.01.02
Related Products	sGRID
Related KPIs	KPI ES.01, KPI ES.02, KPI ES.03, KPI ES.04
Graphical support	Not available for confidential data.

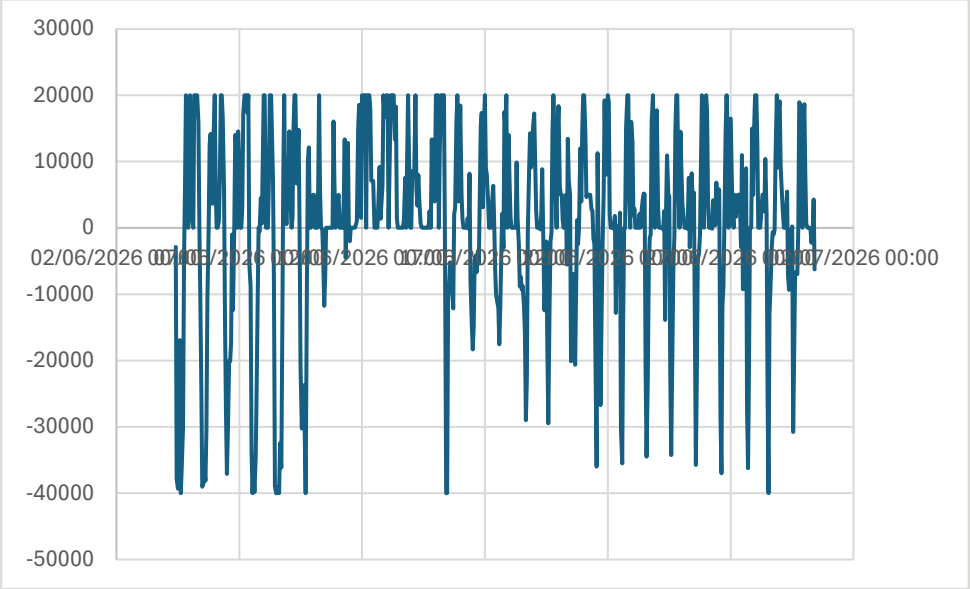
DS ES.15	
Data Element	Voltage deviations forecast
Description of the data	The voltage deviations forecast is obtained through sGRID by comparing the forecasted power flow data with the nominal voltage at each node.
Availability of the data	Confidential
Access to data	This data is derived from the data gathered from SCADA system that is property of the DSO. This data is sensitive, since it reflects the estimated state of the grid and a misuse of this data may jeopardize the security of the energy supply.

Source of data	Forecasts generated by sGRID.
Measurement units	V
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.02.01, ES-UC.02.02
Related Products	sGRID
Related KPIs	KPI ES.07
Graphical support	Not available for confidential data.

DS ES.16	
Data Element	Flexibility bids, asks and requests
Description of the data	These datasets contain the information about the flexibility energy offered by the FSPs to the Local Flexibility Market, both upon the reception of a DSO's requirement or for peer-to-peer operations. They also include the requirements sent to the LFM by the DSO. The datasets include the information of the delivery period, the asset or aggregation of assets offering the flexibility, the flexibility quantity and the price. The datasets are generated by sGRID, sENC and/or sFLEX, and are sent to sMART.
Availability of the data	Confidential
Access to data	This data is derived from the consumption and generation of the prosumers of the grid, which is confidential, and from the congestions forecast, which are sensitive.
Source of data	Generated by the aggregator or the FSPs through sENC and/or sFLEX. Generated by the DSO through sGRID.
Measurement units	MWh, €/MWh
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.04.01, ES-UC.06.01
Related Products	sGRID, sENC, sFLEX, sMART
Related KPIs	KPI ES.05, KPI ES.10, KPI ES.12, KPI ES.13
Graphical support	Not available for confidential data.

DS ES.17	
Data Element	Flexibility market results
Description of the data	These datasets contain the information about the results of an auction of the local flexibility market, containing the delivery period, resulting price and energy matched. The dataset is generated by sMART and retrieved by sENC, sFLEX and sGRID.
Availability of the data	Confidential
Access to data	This data contains sensitive information of the prosumers of the grid since it explicitly states the activation and deactivation of their assets, so it must be kept confidential.
Source of data	Generated by sMART
Measurement units	MWh, €/MWh
Sampling period(s)	Hourly
Related experiment(s)	ES-UC.04.01, ES-UC.06.01
Related Products	sGRID, sENC, sFLEX, sMART
Related KPIs	KPI ES.05, KPI ES.10, KPI ES.12, KPI ES.13
Graphical support	Not available for confidential data.

DS ES.18	
Data Element	Community battery setpoint
Description of the data	Contains schedule of the community battery as a result of the optimization algorithms run by sFLEX to optimize the energy use and cost of the Energy Community, including the constraints due to the LFM participation. This information includes the datetime, active power and setpoints
Availability of the data	Public
Access to data	The dataset has been made public in Zenodo and can be accessed through STREAM ES-UC.04.01 Community battery setpoint - Spanish pilot site | Zenodo
Source of data	Generated by sFLEX and sent to the battery through HTTP API
Measurement units	kW
Sampling period(s)	Hourly

Related experiment(s)	ES-UC.01.02, ES-UC.02.02, ES-UC.04.01, ES-UC.07.01
Related Products	sFLEX
Related KPIs	KPI ES.06, KPI ES.13
Graphical support	 *Figure 267: Graphical support to the community battery setpoint*

DS ES.19	
Data Element	Consumption, generation and flexibility forecasts
Description of the data	Flexibility, production and consumption profile of each flexibility asset and day type. The baseline is used to verify the flexibility provision compliance, comparing it to the real consumption/generation.
Availability of the data	Restricted (only public for the community battery flexibility forecast)
Access to data	The dataset has been made public in Zenodo and can be accessed through STREAM ES-UC.04.01 Consumption, generation and flexibility forecasts of energy community assets - Spanish pilot site | Zenodo
Source of data	Generated by sENC and/or sFLEX.
Measurement units	kWh
Sampling period(s)	Hourly

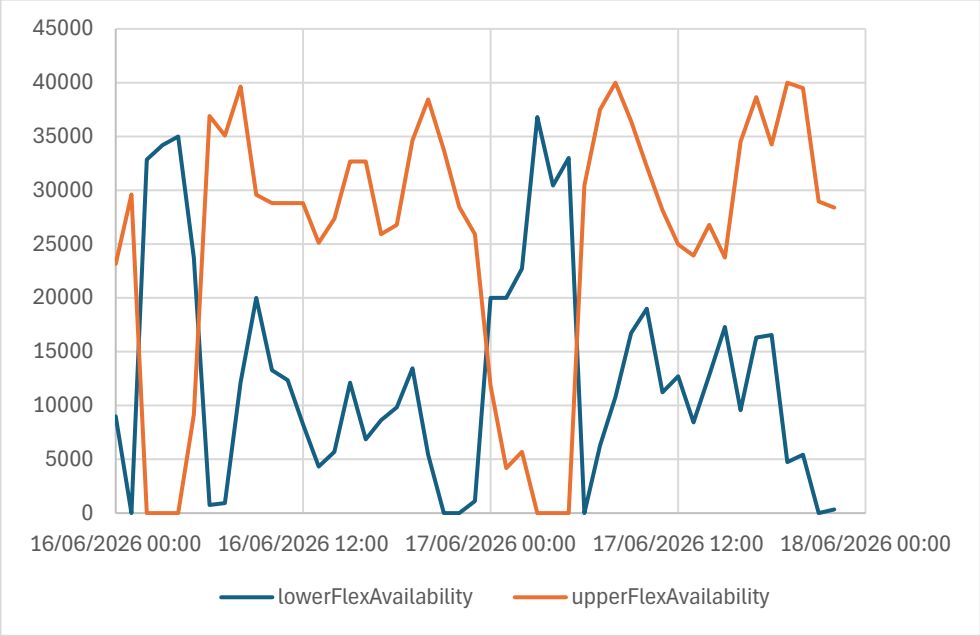
Related experiment(s)	ES-UC.04.01, ES-UC.06.01, ES-UC.07.01
Related Products	sFLEX, sENC
Related KPIs	KPI ES.10, KPI ES.12, KPI ES.14
Graphical support	

Figure 268: Graphical support for the flexibility forecast of the community battery

DS ES.20	
Data Element	Flexibility delivery compliance
Description of the data	This dataset compares the baseline of the flexibility assets with their actual consumption or production during the delivery period of a flexibility service. The goal is to verify whether the assets or aggregations have provided the flexibility assigned in the market session.
Availability of the data	Confidential
Access to data	This dataset contains the real consumption and generation of users of the grid, which is confidential.
Source of data	sGRID
Measurement units	kWh
Sampling period(s)	Hourly

Related experiment(s)	ES_UC.04.01, ES_UC.04.02, ES_UC.05.01
Related Products	sENC, sFLEX
Related KPIs	KPI ES.12
Graphical support	Not available for confidential data.

DS ES.21	
Data Element	Self-consumption allocation coefficients
Description of the data	This dataset provides the supply points associated to the self-consumption installations of the energy community and their associated sharing ratios.
Availability of the data	Confidential
Access to data	The data is confidential since it is related to prosumers data which must be kept confidential.
Source of data	Provided by ENER as Energy Community manager
Measurement units	N/A
Sampling period(s)	N/A
Related experiment(s)	ES_UC.06.01
Related Products	sENC
Related KPIs	KPI ES.06
Graphical support	Not available for confidential data

9.3 ITALIAN PILOT SITE

DS IT.01	
Data Element	Network topology and electrical parameters of grid elements
Description of the data	In order to evaluate the correctness of the reconstruction of the grid topology in sGRID, a GIS file with the information and location of the MV lines is required. In addition, the information about the nominal power or the maximum current of transformers is required for the evaluation and forecast of congestion.
Availability of the data	Confidential and restricted to project consortium
Access to data	The grid topology is owned by the DSO. These data include detailed

	information about the physical assets of the network, and locations of substations. The dataset is confidential to prevent unauthorized access to critical grid information, which could compromise the reliability and security of the electricity supply.
Source of data	ASM's GIS file
Measurement units	Line resistance [Ω/km] Line reactance [Ω/km] Line length [km] Transformer nominal power [MVA]
Sampling period(s)	-
Related experiment(s)	IT-UC.01.01
Related Products	sGRID
Related KPIs	KPI IT.07
Graphical support	Not available for confidential data.

DS IT.02	
Data Element	Grid impedance matrix
Description of the data	To demonstrate the functionality of the grid reconstruction, a grid impedance matrix is calculated from the measurements of the voltages in the grid and the consumption/generation powers on MV/LV transformers.
Availability of the data	Confidential and restricted to project consortium
Access to data	As this data is basically the same type as the MV GIS grid model, the same rules for access apply.
Source of data	sGRID tool
Measurement units	Line impedance matrix [Ω]
Sampling period(s)	-
Related experiment(s)	IT-UC.01.01
Related Products	sGRID
Related KPIs	KPI IT.07
Graphical support	Not available for confidential data.

DS IT.03	
Data Element	Power and voltage values at MV/LV transformers
Description of the data	Measurements of voltage and power are required to reconstruct the grid topology. Ideally, the measurements are synchronized with each other and are not averaged over the interval. The energy consumed by consumers that are directly connected to the MV grid is also monitored for the grid congestion forecast.
Availability of the data	Confidential and restricted to project consortium
Access to data	DSO is the owner of the data and the access to this data is restricted to project partners. Relevant data is shared from DSO SCADA in a secure way since it is from critical energy infrastructure. The dataset is confidential to prevent unauthorized access to critical grid information, which could compromise the reliability and security of the electricity supply.
Source of data	Power quality analyzers
Measurement units	Instantaneous voltage in all three phases [V] Instantaneous active power in all three phases [kW] Instantaneous reactive power in all three phases [kVAr] Energy consumed on MV loads[kWh] – 15min
Sampling period(s)	1 Minute
Related experiment(s)	IT-UC.01.01, IT-UC.02.01
Related Products	sGRID
Related KPIs	KPI IT.05, KPI IT.07
Graphical support	Not available for confidential data.

DS IT.04	
Data Element	Weather data (solar irradiation, temperature, precipitation etc.)
Description of the data	sGRID and sFLEX will use weather data to be able to forecast congestions in the grid and the relationship between temperature and end consumer consumption for heating and cooling purposes
Availability of the data	Public

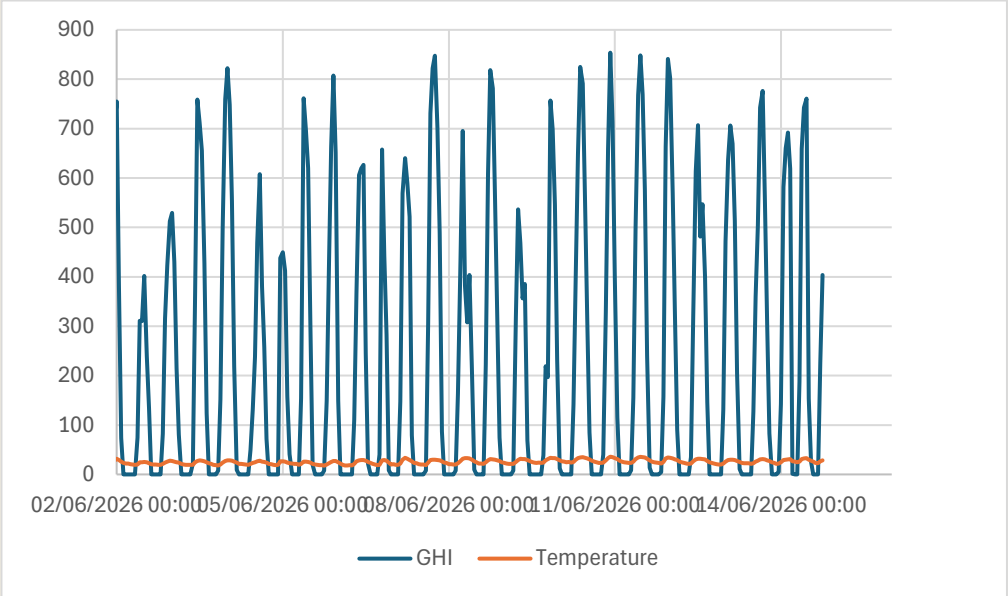
Access to data	Data is public and will be gathered from open-meteo portal or through some other weather data providers.
Source of data	Open-meteo (or other weather data providers)
Measurement units	℃, W/m^2, mm
Sampling period(s)	1 hour / 15min
Related experiment(s)	IT-UC.02.01, IT-UC.05.01
Related Products	sGRID, sFLEX
Related KPIs	KPI IT.03, KPI IT.05
Graphical support	

Figure 269: Graphical support for the weather data

DS IT.05	
Data Element	Loading forecast results
Description of the data	A day ahead loading forecast for MV/LV or MV/MV transformer is generated.
Availability of the data	Confidential

Access to data	Data is confidential as it includes sensitive information connected with stable operation of the distribution network.
Source of data	sGRID
Measurement units	Power [kVA]
Sampling period(s)	15 min
Related experiment(s)	IT-UC.02.01, IT-UC.06.01
Related Products	sGRID
Related KPIs	KPI IT.05
Graphical support	Not available for confidential data.

KPI IT.06	
Data Element	Water pumps data
Description of the data	This data is collected and stored in Water network operator SCADA. The data is confidential because these sensors are deployed in the water distribution critical infrastructure. Any misuse of this data could compromise the water distribution operations. The digital twin retrieves power consumption, water level, water flow, and water pressure data from the water pump sensors.
Availability of the data	Confidential
Access to data	Data is confidential
Source of data	SCADA of the water distribution network
Measurement units	reservoir level (cm) water flow rate (l/s) Consumed energy [kWh]
Sampling period(s)	reservoir level – 10s water flow rate – 10s Consumed energy - 15 min
Related experiment(s)	IT-UC.04.01, IT-UC.06.01
Related Products	sFLEX
Related KPIs	KPI IT.04

Graphical support	Not available for confidential data.

DS IT.07	
Data Element	Schedule for water pump operation
Description of the data	Scheduled setpoints and baseline of water pumps operation for day ahead. The baseline represents the reference water pump operation, while the optimised schedule shows how pump operation can be shifted or adjusted according to the selected objective, while respecting the operational constraints of the water system.
Availability of the data	Public
Access to data	The data has been published in Zenodo and can be accessed through STREAM IT-UC.06.01 Day ahead schedule for water pump opeartion | Zenodo
Source of data	Generated by sFLEX
Measurement units	On/off signal
Sampling period(s)	15 min
Related experiment(s)	IT-UC.04.01, IT-UC.06.01
Related Products	sENC, sFLEX
Related KPIs	IT.04

Graphical support

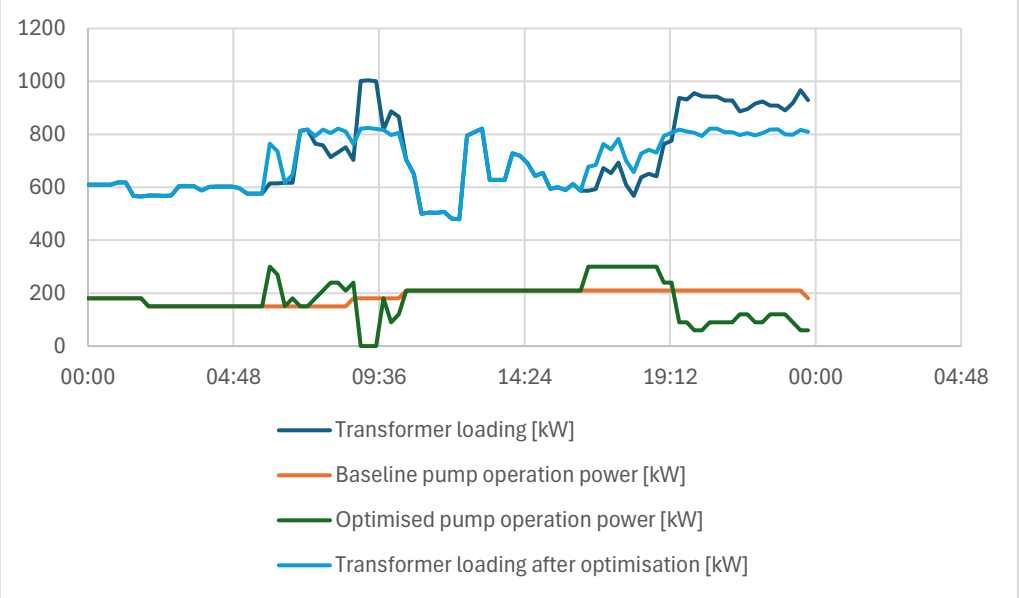


Figure 270: Graphical support for the optimized water pump operation for congestion management

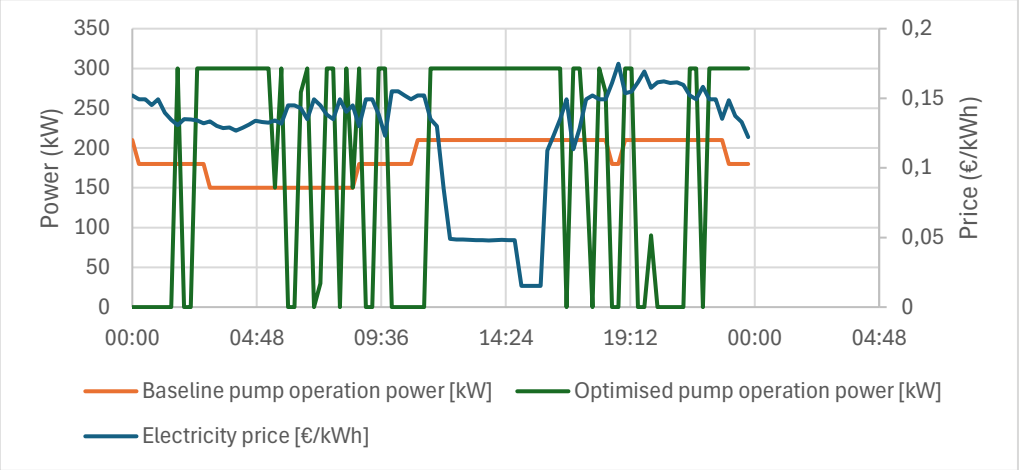


Figure 271: Graphical support for the optimized water pump operation for cost minimization

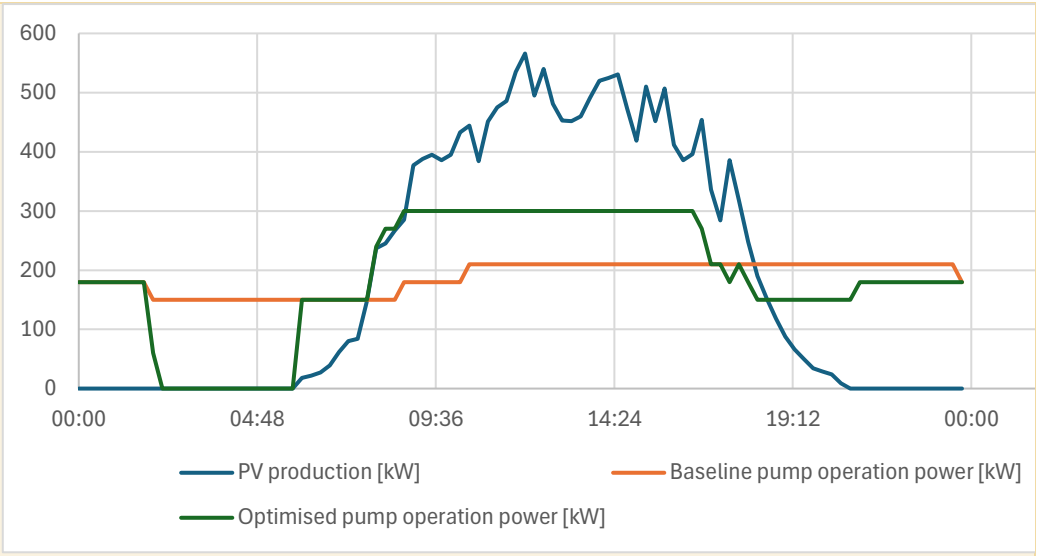


Figure 272: Graphical support for the optimized water pump operation for maximization of RES generated energy consumption

DS IT.08	
Data Element	Power values of end-user
Description of the data	Measurements of power at a very granular level (every 10 seconds) are collected to accurately capture the dynamic consumption patterns of the end-user. This high-resolution data provides detailed insights into the variations in power usage, including peak demand periods and instances of under-utilization. By analyzing these fluctuations, it becomes possible to assess the end-user's flexibility potential, such as identifying periods when power consumption can be reduced or shifted without compromising operations.
Availability of the data	Confidential
Access to data	Data is confidential
Source of data	Monophase smart meters connected in parallel to the billing meters. The dataset is confidential to protect consumer privacy and prevent unauthorized access to sensitive energy production and consumption information, ensuring compliance with data protection regulations.
Measurement units	Average active power of all three phases for previous interval [kW] Average reactive power of all three phases for previous interval [kVAr]
Sampling period(s)	10 seconds
Related experiment(s)	IT-UC.05.01
Related Products	sFLEX

Related KPIs	KPI IT.03
Graphical support	Not available for confidential data.

DS IT.09	
Data Element	HVAC flexibility
Description of the data	End users' power measurements are used together with weather data to estimate how much energy is used to heat and cool the apartment, which can be used as a flexibility reserve at community level.
Availability of the data	Confidential
Access to data	Data is confidential. The dataset is confidential to protect consumer privacy and prevent unauthorized access to sensitive energy production and consumption information, ensuring compliance with data protection regulations.
Source of data	sFLEX
Measurement units	kWh
Sampling period(s)	/
Related experiment(s)	IT-UC.05.01
Related Products	sFLEX
Related KPIs	KPI IT.03
Graphical support	Not available for confidential data

DS IT.10	
Data Element	Production of PV power plants on LV
Description of the data	Power profiles
Availability of the data	Confidential
Access to data	Restricted to project consortium and confidential. The dataset is confidential to protect consumer privacy and prevent unauthorized access to sensitive energy production and consumption information, ensuring compliance with data protection regulations.
Source of data	Power Quality Analyzers
Measurement units	Average active power of all three phases for previous interval [kW]

Sampling period(s)	15 min
Related experiment(s)	IT-UC.06.01
Related Products	sENC
Related KPIs	IT.04
Graphical support	Not available for confidential data.

DS IT.11	
Data Element	Voltages, Power and charging station plug status info
Description of the data	EMOT charging stations exchange data through a modem connected to a single-board computer; charging station protocols are OCPP, the application protocol for communication between charging stations and EMOT central management system, and websocket, the computer communications protocol, providing full-duplex communication channels over a single TCP connection. Charging station data format is JSON.
Availability of the data	Confidential
Access to data	**Data is confidential for privacy and security reasons.**
Source of data	Charging Stations
Measurement units	Instantaneous voltage (U) in phase L3 [V] Instantaneous voltage (U) in phase L2 [V] Instantaneous voltage (U) in phase L1 [V] Positive active power (A+) [kW] Plug status [free/occupied] State-of-Charge [%] Odometer [km] In charge [false/true]
Sampling period(s)	1 second
Related experiment(s)	IT-UC.08.01, IT-UC.03.01
Related Products	sMART, sENC
Related KPIs	KPI IT.02
Graphical support	Not available for confidential data

DS IT.12	
Data Element	State-of-Charge, Odometer
Description of the data	EMOT use an on-board diagnostic (OBD) device to retrieve data from the EV; OBD is a IoT component that utilizes a TCP/IP communication to a TCP/IP server. The network connectivity of the OBD device is via data SIM (UMTS), thanks to a modem, and the server is a python software; OBD protocol is MQTT and the sampling rate is 5 seconds. The OBD connects to the diagnostic interface from which it is able to extract the information from the electric vehicle control unit using the CAN-bus protocol. The output data format of the OBD is an ASCII string; when the data is sent to the server, it is reorganized into a wrapper, thus obtaining a grouping of the data in JSON format.
Availability of the data	Confidential
Access to data	**Data is confidential for privacy and security reasons**
Source of data	Electric Vehicles
Measurement units	State-of-Charge [%] Odometer [km] In charge [false/true]
Sampling period(s)	5 seconds
Related experiment(s)	IT-UC.08.01
Related Products	
Related KPIs	KPI IT.02
Graphical support	Not available for confidential data

DS IT.sDATA.01	
Data Element	Distributed ledger history data
Description of the data	sDATA saves access events data into the distributed ledger. The data can be utilized for investigative purposes to determine whether it is accessed by the users who have been granted the appropriate permissions.
Availability of the data	Confidential
Access to data	The history log of access in the sDATA portal is confidential and only users with permissions can access this data. This data is sensitive, since it reflects the real state of data access processes

	and it might include some users' personal information (e.g. time of the login, logout, etc.).
Source of data	Distributed ledger database.
Measurement units	/
Sampling period(s)	/
Related experiment(s)	sDATA
Related Products	sDATA
Related KPIs	KPI sDATA.02
Graphical support	Not available for confidential data.

DS IT.sDATA.01	
Data Element	Master data
Description of the data	Master data management system manages master data, including user data and access rights, and power system master data, such as EV charging station master data, power grid master data, etc.
Availability of the data	Confidential
Access to data	The master data in the sDATA portal is confidential and only users with permissions can access this data. This data is sensible, since it reflects the real state of the power system and users included in the project.
Source of data	Master data management system database.
Measurement units	/
Sampling period(s)	/
Related experiment(s)	TBD once test cases are defined
Related Products	sDATA
Related KPIs	KPI sDATA.02
Graphical support	Not available for confidential data.

9.4 FINNISH PILOT SITE

DS FI.01	
Data Element	Configuration data

Description of the data	This data set consists in settings contained in the relational control database (MySQL). It includes an apartment specific table and a room specific table.
	• Apartment info
	  ○ Apartment id
	  ○ Presence of outdoor temperature and humidity sensors (yes/no)
	  ○ Number of rooms
	  ○ Total installed power in radiators and floor heating in Watt
	  ○ Water boiler amount
	  ○ Car heaters amount
	  ○ Solar panels amount
	  ○ Calendar integration (yes/no)
	  ○ Spot price control (yes/no)
	• Room info
	  ○ Room id
	  ○ Apartment id
	  ○ Heater type (electric radiator, surface electric floor heating., deep electric floor heating, …)
	  ○ Total installed power in the room in Watt
	  ○ Heating method (‘)
	  ○ Hysteresis (‘’)
	  ○ Heat pump (yes/no)
	  ○ Temperature sensor (yes/no)
	  ○ Humidity sensor (yes/no)
	  ○ CO2 sensor (yes/no)
	  ○ Water leak sensor (yes/no)
	(‘) Pro-active method forecasts how long it takes for the room to heat up from the current temperature to the set temperature and puts the heating on early enough so that the room temperature is at the set temperature at the time defined in user's settings. Similarly, it forecasts when to stop heating in order to have the wished room temperature at the time defined in user's settings. This is very useful when deep floor heating is installed. However, even with deep floor heating it might be preferred to use the basic method in order to save money.
	(‘’) Hysteresis prevents the system from being unstable when the temperature is around the set temperature. It defines how many fractions of a degree to add or remove to the set temperature before switching heating on or off. For example, if the set temperature is 22 and hysteresis is 0,2, heating is set off when the temperature reaches 22,2 and it is set on when the temperature reaches 21,8.
	Currently, the system does not store past values of such parameters.
	This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.

Room id	All data owned by OptiWatti is company confidential.

Access to data	The data set consists in data related to the configuration and the usage of customers' apartments and therefore it is protected by GDPR. A subset of such data, that is the data related to the 10 pilot apartments, is anonymized and copied into a file. Such data is exchanged with Finnish partners by encrypted file. However, since this data set contains data at apartment/room level, it cannot be published as a CSV file.
Source of data	OptiWatti configuration tool
Measurement units	id, text, integer, bool, decimal, W
Sampling period(s)	not applicable
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	None
Graphical support	Figure 273 is a snapshot of the apartment-specific data sheet: STREAM Stream Project Finland OptiWatti VTT Configuration data (data set FI01_01): Apartment info (*) radiators + floor heating *Figure 273: Configuration data: apartment-level info* Figure 274 is an extract (first 10 entries) from the longer room-specific data sheet: STREAM Stream Project Finland OptiWatti VTT Configuration data (data set FI01_01): Room info *Figure 274: Configuration data: room-level info*

Apartment id	Outdoor temperature sensor	Outdoor humidity sensor	Number of rooms	Total installed power (W) (*)	Water boilers	Car heaters	Solar panels	Calendar Integration	Spot price control
4	yes	yes	15	7194	1	1	20	no	yes
338	yes	yes	8	4400	3 (including swimming pool)	1	yes but not in OW system	no	yes
880	yes	yes	3	4350	0	0	0	yes	no
881	yes	yes	3	4350	0	0	0	yes	no
882	yes	yes	3	4350	0	0	0	yes	no
1014	yes	yes	11	12205	1	2 (1 car charger)	20	no	yes
1931	yes	yes	8	6875	1	1 (car charger)	20	no	yes
2061	yes	yes	20	This is	1	0	10	no	yes
2082	yes	yes	8	3900	1	2	0 (meters installed)	no	yes
2188	yes	yes	10	7195	1	0	0 (meters installed)	no	yes
TOTAL	10	10	89	63519	9	7	70	3	7

Room id	Apartment id	Heater type	Total installed power (W)	Heating method (1)	Hysteresis (2)	Heat pump	Temperature sensor	Humidity sensor	CO2 sensor	Water leak sensor
5	4	electric radiator	400	Pro-active	0.40	no	yes	yes	yes	no
7	4	surface electric floor heating	500	Basic	0.20	no	yes	no	no	no
8	4	deep electric floor heating	724	Pro-active	0.20	no	yes	no	no	no
9	4	deep electric floor heating	163	Pro-active	0.40	no	yes	yes	no	no
10	4	deep electric floor heating	807	Pro-active	0.20	no	yes	yes	no	no
11	4	electric radiator	1000	Pro-active	0.20	no	yes	yes	no	no
12	4	electric radiator	800	Pro-active	0.20	no	yes	yes	no	no
14	4	surface electric floor heating	900	Basic	0.20	no	yes	yes	yes	no
15	4	electric radiator	1000	Pro-active	0.20	no	yes	yes	no	no
16	4	none (only heat pump)	0	Pro-active	0.20	yes	yes	yes	no	no

DS FI.02	
Data Element	Periodic measurements
Description of the data	This data set consists of periodic measurement in the form of time series that are done currently with a 10-minutes interval. It includes the following data: • Outdoor temperature in Celsius • Outdoor relative humidity in % • Room temperature in Celsius • Room relative humidity in % • Set temperature for the room in Celsius • Water leak indication (Boolean) • CO2 (in parts per million) • Cumulative value in kWh of the energy coming from the grid for phases 1, 2 and 3 (used for solar panels installations) • Cumulative value in kWh of the energy going to the grid for phases 1, 2 and 3 (used for solar panels installations) • Cumulative value in kWh of the energy coming from solar panels production for phases 1, 2 and 3 (used for solar panels installations) • Activated flexible power in Watt for FCR-D-up and for FCR-D-down (apartment-specific info) Activated flexible power for FCR-D-up and for FCR-D-down are two new metrics that have been introduced for demand-response. There are very useful for calculating how much more energy has been used for FCR-D-down and how much less energy has been used due to FCR-D-up and they have been used in the test scenario FI-UC.05.01 “Cust-flex-profitability”. The data is identified by the following key: • Timestamp • Apartment id • Room id • Sensor id (device identifier) • Metric type This data is aggregated in hourly, daily and weekly views (count, average, standard deviation, max, min and sum) and purged according to the defined retention policy (10 minutes measurements are kept for 1 year, hour aggregates are kept for 3 years, day aggregates are kept for 5 years, week aggregates are kept for 10 years). This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	All data owned by OptiWatti is company confidential.
Access to data	The data set consists in data related to the usage of customers' apartments and therefore it is protected by GDPR. A subset of such data, that is the data related to the 10 pilot apartments, is anonymized and copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a

	selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes. However, since this data set contains data at apartment/room level, it cannot be published as a CSV file.
Source of data	Sensors send information to the apartment controllers which sends the information to the backend which writes into the periodic measurement database in Timescale.
Measurement units	time stamp, id, °C, %, ppm, kWh, bool
Sampling period(s)	10 minutes / event based
Related experiment(s)	FI-UC.01.01, FI-UC.01.02,
Related Products	sFLEX, sDATA
Related KPIs	None
Graphical support	Figure 275 contains an example of direct SQL query to the periodic measurements database related to one pilot apartment and to a recent day (April 28th 2026). The first 10 entries are shown and are related to the metrics 1 (room temperature in Celsius) and 2 (Room relative humidity in %). *Figure 275: Example of periodic measurements query in the database* The last column of the query in Figure 276 shows the value of the activated flexible power in Watt for FCR-D-down in one pilot apartment during the tests with real load. The value is negative because it is absorbed power. The room id is zero because this metric is not room-specific.

```
production_measurements=> SELECT mtimestamp, apartmentid, roomid, sensorid, metric, ROUND(mvalue, 2)
 AS value FROM periodic_measurements WHERE mtimestamp::TEXT LIKE '2026-04-28%' AND apartmentid = 193
1 AND roomid != 0 LIMIT 10;
       mtimestamp       | apartmentid | roomid | sensorid | metric | value
------------------------+-------------+--------+----------+--------+-------
 2026-04-28 23:59:12+00 |        1931 |  18364 |    38967 |      1 | 21.17
 2026-04-28 23:59:12+00 |        1931 |  18364 |    38975 |      2 | 25.62
 2026-04-28 23:59:12+00 |        1931 |  18360 |    38963 |      1 | 20.10
 2026-04-28 23:59:12+00 |        1931 |  18360 |    38971 |      2 | 26.20
 2026-04-28 23:59:12+00 |        1931 |  18365 |    38968 |      1 | 20.84
 2026-04-28 23:59:12+00 |        1931 |  18365 |    38976 |      2 | 25.20
 2026-04-28 23:59:12+00 |        1931 |  18361 |    38964 |      1 | 23.48
 2026-04-28 23:59:12+00 |        1931 |  18361 |    38972 |      2 | 33.02
 2026-04-28 23:59:12+00 |        1931 |  18367 |    38970 |      1 | 20.90
 2026-04-28 23:59:12+00 |        1931 |  18367 |    38979 |      2 | 24.10
(10 rows)
```

```
production_measurements=> SELECT mtimestamp, apartmentid, roomid, sensorid, metric, ROUND(mvalue, 2)
 AS value FROM periodic_measurements WHERE mtimestamp::TEXT >= '2026-04-23 00:00:00' AND apartmentid
 = 1931 AND metric IN (32, 33) LIMIT 10;
       mtimestamp       | apartmentid | roomid | sensorid | metric |  value
------------------------+-------------+--------+----------+--------+---------
 2026-04-29 21:19:13+00 |        1931 |      0 |        0 |     33 |   -6.90
 2026-04-29 20:19:13+00 |        1931 |      0 |        0 |     33 |   -4.33
 2026-04-29 19:19:13+00 |        1931 |      0 |        0 |     33 |  -24.75
 2026-04-29 08:29:12+00 |        1931 |      0 |        0 |     33 |  -12.74
 2026-04-29 07:29:13+00 |        1931 |      0 |        0 |     33 |   38.53
 2026-04-29 07:19:12+00 |        1931 |      0 |        0 |     33 |  -87.95
 2026-04-29 00:19:13+00 |        1931 |      0 |        0 |     33 |   30.86
 2026-04-28 23:19:12+00 |        1931 |      0 |        0 |     33 |  -59.59
 2026-04-28 23:09:12+00 |        1931 |      0 |        0 |     33 | -259.98
 2026-04-28 22:59:12+00 |        1931 |      0 |        0 |     33 | -363.43
(10 rows)
```

Figure 276: Example of activated flexible power during tests with real load in one pilot apartment

The following plots are produced with anonymized data of pilot apartments.

Figure 277 shows the temperature and humidity in one room of one pilot apartment during one day (March 5th 2026).

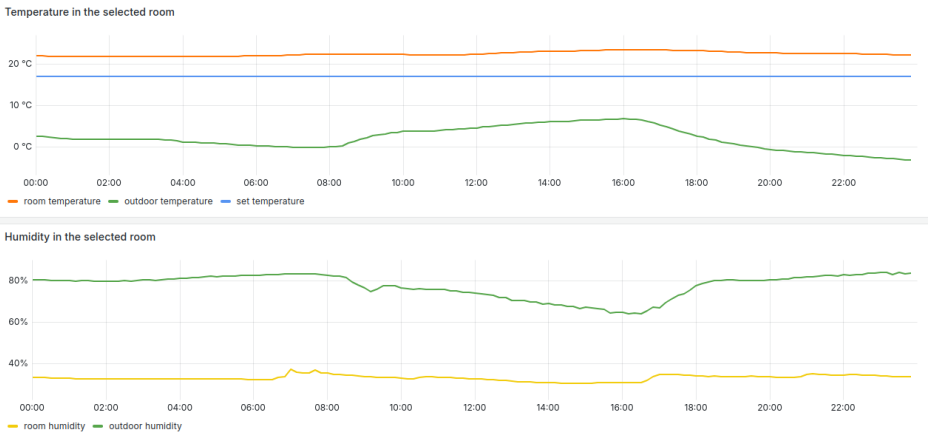


Figure 277: Temperature and humidity in one room in one pilot apartment during one day

Figure 278 shows the produced, bought and sold energy in one pilot apartment on the same day.

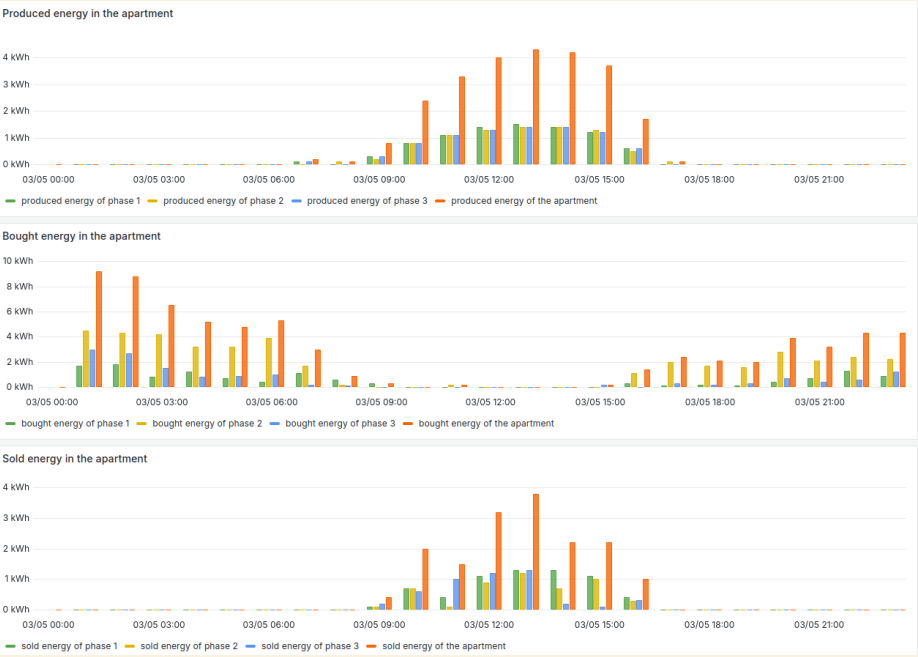


Figure 278: Produced, bought and sold energy in one day in one apartment.

Figure 279 shows the produced, bought and sold energy in one pilot apartment during the year 2024.



Figure 279: Produced, bought and sold energy in one year in one apartment

DS FI.03	
Data Element	Energy spot prices
Description of the data	This data set consists of periodic measurement in the form of time series that are done currently with a one-hour interval. In the near future, the interval with switch to 15 minutes. It includes the following data: • Energy spot price The data is identified by the following key: • Time stamp • Geographical area (example: Finland) • Unit (example: euro) This data is kept for 3 years. This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	This data is public through the Web site. https://data.nordpoolgroup.com/auction/day-ahead/prices?deliveryDate=today&currency=EUR&aggregation=DeliveryPeriod&deliveryAreas=FI,SE2
Access to data	This data is copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes.

Source of data	OptiWatti backend retrieves this information from the Web and writes it into the periodic measurements database in Timescale. https://data-api.nordpoolgroup.com/index.html
Measurement units	€
Sampling period(s)	1 hour
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	None
Graphical support	Figure 280 provides an example of spot price related data in the database.

```
data_warehouse=> SELECT mtimestamp, area, unit, pricemwh FROM energy_spot_prices
WHERE area = 'FI' AND mtimestamp::TEXT LIKE '2024-%' ORDER BY mtimestamp LIMIT 10
;
       mtimestamp       | area | unit | pricemwh
------------------------+------+------+----------
 2024-01-01 00:00:00+00 | FI   | EUR  |    28.46
 2024-01-01 01:00:00+00 | FI   | EUR  |    26.66
 2024-01-01 02:00:00+00 | FI   | EUR  |    24.48
 2024-01-01 03:00:00+00 | FI   | EUR  |    24.01
 2024-01-01 04:00:00+00 | FI   | EUR  |    21.23
 2024-01-01 05:00:00+00 | FI   | EUR  |    22.62
 2024-01-01 06:00:00+00 | FI   | EUR  |    25.04
 2024-01-01 07:00:00+00 | FI   | EUR  |    26.24
 2024-01-01 08:00:00+00 | FI   | EUR  |    32.21
 2024-01-01 09:00:00+00 | FI   | EUR  |    41.34
(10 rows)
```

Figure 280: Example of spot price related data

The plot in Figure 281 shows an example of spot price variations during a day in Finland.

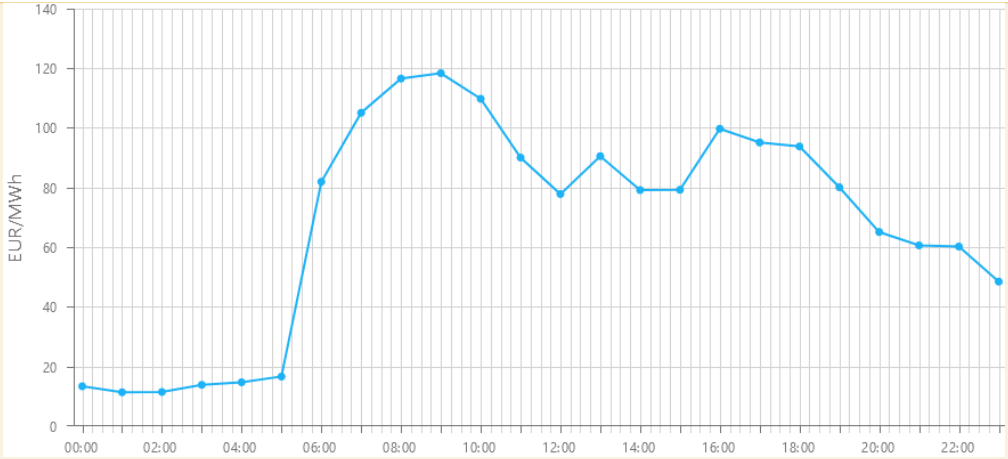


Figure 281: Plot showing an example of spot price variations during a day in Finland

DS FI.04	
Data Element	Power consumption
Description of the data	This data set consists of periodic measurement in the form of time series that are done currently with a 10-minutes interval. It includes the following data: • Calculated electric power (in Watt) consumed in the measured interval by electrical-based heating The data is identified by the following key: • Timestamp • Apartment id • Room id • Sensor id (device identifier) • Metric type This data is aggregated in hourly, daily and weekly views (count, average, standard deviation, max, min) and purged according to the defined retention policy (10 minutes measurements are kept for 1 year, hour aggregates are kept for 3 years, day aggregates are kept for 5 years, week aggregates are kept for 10 years). This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	All data owned by OptiWatti is company confidential.
Access to data	The data set consists in data related to the usage of customers' apartments and therefore it is protected by GDPR. A subset of such data, that is the data related to the 10 pilot apartments, is anonymized and copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes.

	However, since this data set contains data at apartment/room level, it cannot be published as a CSV file.
Source of data	Apartment controllers are responsible for performing the calculation of the consumed power. Then, they send the information to the backend which writes into the periodic measurement database in Timescale.
Measurement units	W
Sampling period(s)	10 minutes
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	KPI FI.01, KPI FI02
Graphical support	Figure 282 contains an anonymized example of calculated consumed power in Watt for each room for one pilot apartment.

```
production_measurements=> SELECT mtimestamp, apartmentid, roomid, sensorid, metric, ROUND(mvalue, 2)
 AS value FROM periodic_measurements WHERE mtimestamp::TEXT >= '2026-04-23 00:00:00' AND apartmentid
 = 1931 AND metric = 5 AND mvalue != 0 LIMIT 10;
      mtimestamp       | apartmentid | roomid | sensorid | metric |  value
-----------------------+-------------+--------+----------+--------+---------
 2026-04-29 13:59:13+00 |        1931 |  18362 |        0 |      5 |  284.60
 2026-04-29 13:59:13+00 |        1931 |  18364 |        0 |      5 |  586.96
 2026-04-29 13:59:13+00 |        1931 |  18365 |        0 |      5 |  420.74
 2026-04-29 13:49:13+00 |        1931 |  18362 |        0 |      5 |  550.00
 2026-04-29 13:49:13+00 |        1931 |  18364 |        0 |      5 | 1125.00
 2026-04-29 13:49:13+00 |        1931 |  18365 |        0 |      5 |  800.00
 2026-04-29 13:39:13+00 |        1931 |  18362 |        0 |      5 |  550.00
 2026-04-29 13:39:13+00 |        1931 |  18364 |        0 |      5 | 1125.00
 2026-04-29 13:39:13+00 |        1931 |  18365 |        0 |      5 |  800.00
 2026-04-29 13:29:13+00 |        1931 |  18361 |        0 |      5 |  415.57
(10 rows)
```

Figure 282: Example of calculated consumed energy for each room

Figure 283 is the visualization of the electric power used for heating in one room of one pilot apartment for each hour of one day (January 22nd 2026).

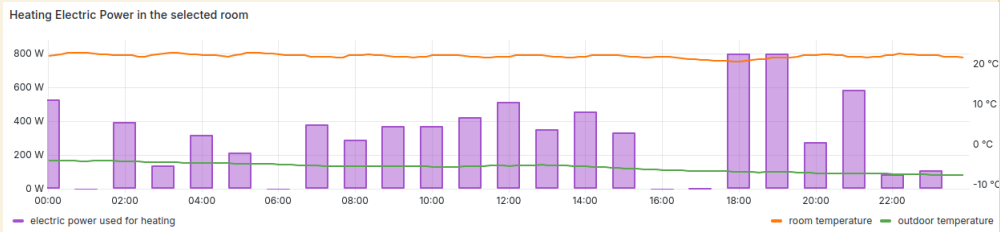


Figure 283: Visualization of the electric power used for heating in one room for each hour of one day

Figure 284 is the visualization of the electric power used for heating in one room of one pilot apartment for week of one year (2024).

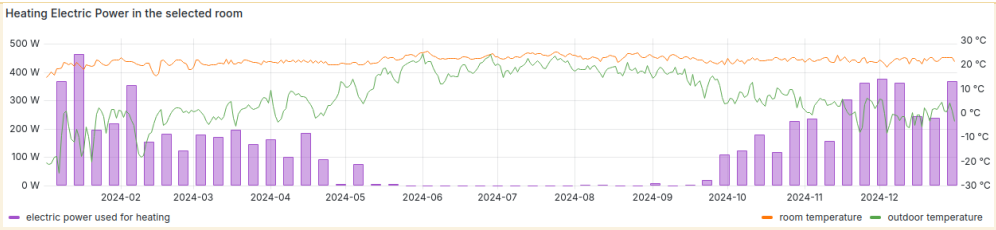


Figure 284: Visualization of the electric power used for heating in one room of one pilot apartment for week of one year

The power multiplied by the time interval (day or week) in hours gives the calculated consumed energy.

By aggregating the metric for all rooms within defined sampling intervals (like hours or days) plots like the one shown in Figure 285 can be obtained. The figure shows the cumulative energy consumed by all apartments for heating with assets that can be used for flexibility (electric radiators and electric floor heating) is a full year (2025). The data in the shown plot has been aggregated for each day.

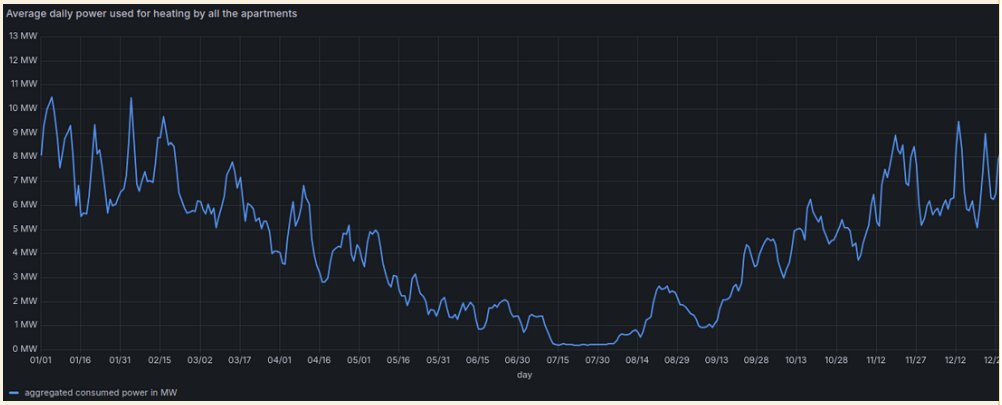


Figure 285: Average daily power used for heating cumulatively by all apartments in year 2025

The equivalent plot with aggregation done with intervals of one hour is shown in Figure 286. This data has been very useful to make accurate calculations related to the business case since it provides precious input data with hour granularity of the power that can be cut for FCR-D-up. By using the installed power theoretically usable for DR, which in the case of those plots is 25 MW, it is possible also to calculate the power that can be added for FCR-D-down.

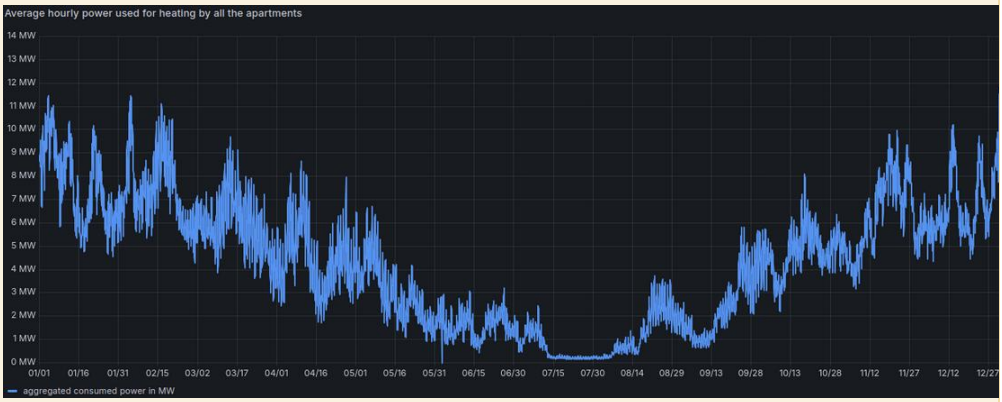


Figure 286: Average hourly power used for heating cumulatively by all apartments in year 2025

DS FI.06	
Data Element	Baseline flex power forecast output
Description of the data	This data set provides the output of the flexible power baseline forecast in the first prototype: • Temperature forecast of the room • Used electric power forecast of the room The raw data has 5 minutes granularity. Hour aggregates (average, standard deviation, max and min) are created. This data is kept for 3 years. This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	All data owned by OptiWatti is company confidential.
Access to data	The data related to the 10 pilot apartments, is anonymized and copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes. However, since this data set contains data at apartment/room level, it cannot be published as CSV file.
Source of data	The calculation is performed by the Flex Simulator component of the sFLEX and the results are written into the flex database in Timescale.
Measurement units	°C, W
Sampling period(s)	5 minutes
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	KPI FI.01, KPI FI.02
Graphical support	The Grafana dashboard in Figure 287 visualizes the data for one room (room id 18361). The line in orange colour in the plot shows the simulated temperature and the bars in purple show the simulated power. The installed power is 800 Watts and the room temperature when the simulation has started was 21.5 degrees. The set temperature is adjusted by the spot price settings since this customer does not have a fixed price contract.



Figure 287: A visualization of an example of the baseline flexible power simulation results

DS FI.09	
Data Element	FCR group bid

Description of the data	This data set contains the information that is sent to the TSO when making a bid such as:
	• Unique bid id
	• Aggregator id
	• Timestamp (when the bid has been created)
	• Bid period
	• Service type (FCR-D-up, FCR-D-down)
	• For each service: time series data
	  ○ Time interval
	  ○ Offered power
	  ○ Price in €
	The bid is done every day (bid period) for each hour of the day (time interval).
	This data is kept for 4 weeks.
	This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.

Availability of the data	A subset of this data set can be published.
Access to data	In the commercial version of the feature, this data is exchanged with Fingrid through SSL encrypted connection. Customers' data is not visible in this data set since it contains aggregate data about several apartments. However, the data set contains price information that is aggregator confidential information. If needed, this data can be shared with the Finnish partners either by encrypted file or by using the data warehouse. zenodo.org/uploads/20831281
Source of data	Bids are created by the Flex Manager component of sFLEX and the content is stored in the flex database in Timescale.

Measurement units	text, timestamp, id, W, €
Sampling period(s)	1 day (bid period); 1 hour (time interval)
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	KPI FI.02
Graphical support	The bid data is contained in the Flex database, which is a PostgreSQL relational database. An example of the most relevant tables is shown in the following tables which contain data related to the tests done with real load from the pilot customers. To enhance visibility, only the most relevant columns have been selected in the snapshot. Figure 288 contains two flex groups that have been created for the two services FCR-D-up and FCR-D-down.

```
data_warehouse=> SELECT * FROM flexdb_flexgroup;
 id |   name    | flex_market_id |                          description
----+-----------+----------------+---------------------------------------------------
  5 | pilot_up  |              1 | Pilot clients group for FCR-D Up comprising AV pilot
  6 | pilot_do  |              2 | Pilot clients group for FCR-D Down for non-AV pilot c
```

Figure 288: Flex groups

Figure 289 shows the most important input variables for the simulation for each flex group and for each market day during the test period: the amount of used rooms and the total installed power in Watt.

```
data_warehouse=> SELECT * FROM flexdb_flex_simulation;
 id  | flex_group_id | market_day | rooms_count | rooms_total | total_power_w
-----+---------------+------------+-------------+-------------+---------------
 176 |             6 | 2026-04-23 |          58 |          58 |         48070
 177 |             5 | 2026-04-23 |           7 |           7 |          8050
 178 |             6 | 2026-04-24 |          58 |          58 |         48070
 179 |             5 | 2026-04-24 |           7 |           7 |          8050
 180 |             6 | 2026-04-25 |          47 |          47 |         40875
 181 |             5 | 2026-04-25 |           7 |           7 |          8050
 182 |             6 | 2026-04-26 |          58 |          58 |         48069
 183 |             5 | 2026-04-26 |           7 |           7 |          8050
 184 |             6 | 2026-04-27 |          58 |          58 |         48069
 185 |             5 | 2026-04-27 |           7 |           7 |          8050
 186 |             6 | 2026-04-28 |          58 |          58 |         48069
 187 |             5 | 2026-04-28 |           7 |           7 |          8050
 188 |             6 | 2026-04-29 |          47 |          47 |         37364
 189 |             5 | 2026-04-29 |           7 |           7 |          8050
 190 |             6 | 2026-04-30 |          47 |          47 |         37364
 191 |             5 | 2026-04-30 |           7 |           7 |          8050
 192 |             6 | 2026-05-01 |          47 |          47 |         37364
 193 |             5 | 2026-05-01 |           7 |           7 |          8050
 194 |             6 | 2026-05-02 |          47 |          47 |         37364
 195 |             5 | 2026-05-02 |           7 |           7 |          8050
 196 |             6 | 2026-05-03 |          47 |          47 |         37364
 197 |             5 | 2026-05-03 |           7 |           7 |          8050
 198 |             6 | 2026-05-04 |          47 |          47 |         37364
 199 |             5 | 2026-05-04 |           7 |           7 |          8050
```

Figure 289: Flexible power simulation input variables

Figure 290 contains an extract of the most important results of the simulation for a certain service for 10 consecutive hours: the power baseline in Watt.

```
data_warehouse=> SELECT * FROM flexdb_flex_periodic_result LIMIT 10;
  id  |      result_start      |       result_end       | duration_s | flex_simulation_id | power_forecast_w
------+------------------------+------------------------+------------+--------------------+------------------
 2063 | 2026-04-22 22:00:00+00 | 2026-04-22 23:00:00+00 |       3600 |                176 | 7307.083333333333
 2064 | 2026-04-22 23:00:00+00 | 2026-04-23 00:00:00+00 |       3600 |                176 | 9219.666666666668
 2065 | 2026-04-23 00:00:00+00 | 2026-04-23 01:00:00+00 |       3600 |                176 | 9398.333333333332
 2066 | 2026-04-23 01:00:00+00 | 2026-04-23 02:00:00+00 |       3600 |                176 |              8937
 2067 | 2026-04-23 02:00:00+00 | 2026-04-23 03:00:00+00 |       3600 |                176 |          10139.25
 2068 | 2026-04-23 03:00:00+00 | 2026-04-23 04:00:00+00 |       3600 |                176 | 8021.833333333333
 2069 | 2026-04-23 04:00:00+00 | 2026-04-23 05:00:00+00 |       3600 |                176 |           5273.75
 2070 | 2026-04-23 05:00:00+00 | 2026-04-23 06:00:00+00 |       3600 |                176 |                 0
 2071 | 2026-04-23 06:00:00+00 | 2026-04-23 07:00:00+00 |       3600 |                176 | 6956.666666666666
 2072 | 2026-04-23 07:00:00+00 | 2026-04-23 08:00:00+00 |       3600 |                176 | 6356.083333333334
```

Figure 290: Flexible power simulation output variables

Figure 291 contains information about the prepared bids, including the id, the used Flex Group, the Flex Group name, the market, the market day and fields containing the status such as time of submission and time of acceptance.

```
data_warehouse=> SELECT * FROM flexdb_flex_bid;
 id  | flex_group_id | flexgroup_name | market | market_day |        ready_at        |      submitted_at      |         ack_at
-----+---------------+----------------+--------+------------+------------------------+------------------------+------------------------
 184 |             6 | pilot_do       | FcrdDo | 2026-04-23 | 2026-04-22 12:30:06+00 | 2026-04-22 13:00:02+00 | 2026-04-22 13:00:38+00
 185 |             5 | pilot_up       | FcrdUp | 2026-04-23 | 2026-04-22 12:30:12+00 | 2026-04-22 13:00:05+00 | 2026-04-22 13:00:41+00
 186 |             6 | pilot_do       | FcrdDo | 2026-04-24 | 2026-04-23 12:30:06+00 | 2026-04-23 13:00:02+00 | 2026-04-23 13:00:38+00
 187 |             5 | pilot_up       | FcrdUp | 2026-04-24 | 2026-04-23 12:30:12+00 | 2026-04-23 13:00:05+00 | 2026-04-23 13:00:41+00
 188 |             6 | pilot_do       | FcrdDo | 2026-04-25 | 2026-04-24 12:30:05+00 | 2026-04-24 13:00:02+00 | 2026-04-24 13:00:38+00
 189 |             5 | pilot_up       | FcrdUp | 2026-04-25 | 2026-04-24 12:30:11+00 | 2026-04-24 13:00:05+00 | 2026-04-24 13:00:41+00
 190 |             6 | pilot_do       | FcrdDo | 2026-04-26 | 2026-04-25 12:30:06+00 | 2026-04-25 13:00:02+00 | 2026-04-25 13:00:38+00
 191 |             5 | pilot_up       | FcrdUp | 2026-04-26 | 2026-04-25 12:30:12+00 | 2026-04-25 13:00:05+00 | 2026-04-25 13:00:41+00
 192 |             6 | pilot_do       | FcrdDo | 2026-04-27 | 2026-04-26 12:30:06+00 | 2026-04-26 13:00:02+00 | 2026-04-26 13:00:38+00
 193 |             5 | pilot_up       | FcrdUp | 2026-04-27 | 2026-04-26 12:30:12+00 | 2026-04-26 13:00:05+00 | 2026-04-26 13:00:41+00
 194 |             6 | pilot_do       | FcrdDo | 2026-04-28 | 2026-04-27 12:30:05+00 | 2026-04-27 13:00:02+00 | 2026-04-27 13:00:38+00
 195 |             5 | pilot_up       | FcrdUp | 2026-04-28 | 2026-04-27 12:30:12+00 | 2026-04-27 13:00:05+00 | 2026-04-27 13:00:41+00
 196 |             6 | pilot_do       | FcrdDo | 2026-04-29 | 2026-04-28 12:30:06+00 | 2026-04-28 13:00:02+00 | 2026-04-28 13:00:39+00
 197 |             5 | pilot_up       | FcrdUp | 2026-04-29 | 2026-04-28 12:30:12+00 | 2026-04-28 13:00:06+00 | 2026-04-28 13:00:42+00
 198 |             6 | pilot_do       | FcrdDo | 2026-04-30 | 2026-04-29 12:30:05+00 | 2026-04-29 13:00:02+00 | 2026-04-29 13:00:39+00
 199 |             5 | pilot_up       | FcrdUp | 2026-04-30 | 2026-04-29 12:30:11+00 | 2026-04-29 13:00:06+00 | 2026-04-29 13:00:42+00
 200 |             6 | pilot_do       | FcrdDo | 2026-05-01 | 2026-04-30 12:30:06+00 | 2026-04-30 13:00:02+00 | 2026-04-30 13:00:39+00
 201 |             5 | pilot_up       | FcrdUp | 2026-05-01 | 2026-04-30 12:30:12+00 | 2026-04-30 13:00:05+00 | 2026-04-30 13:00:42+00
 202 |             6 | pilot_do       | FcrdDo | 2026-05-02 | 2026-05-01 12:30:06+00 | 2026-05-01 13:00:02+00 | 2026-05-01 13:00:37+00
 203 |             5 | pilot_up       | FcrdUp | 2026-05-02 | 2026-05-01 12:30:12+00 | 2026-05-01 13:00:04+00 | 2026-05-01 13:00:40+00
 204 |             6 | pilot_do       | FcrdDo | 2026-05-03 | 2026-05-02 12:30:05+00 | 2026-05-02 13:00:02+00 | 2026-05-02 13:00:38+00
 205 |             5 | pilot_up       | FcrdUp | 2026-05-03 | 2026-05-02 12:30:12+00 | 2026-05-02 13:00:05+00 | 2026-05-02 13:00:41+00
 206 |             6 | pilot_do       | FcrdDo | 2026-05-04 | 2026-05-03 12:30:06+00 | 2026-05-03 13:00:02+00 | 2026-05-03 13:00:38+00
 207 |             5 | pilot_up       | FcrdUp | 2026-05-04 | 2026-05-03 12:30:13+00 | 2026-05-03 13:00:05+00 | 2026-05-03 13:00:41+00
```

Figure 291: Bids

Figure 292 contains the details of a one of such bids. It includes the offered flexible capacity and the price in euro for each service and for each hour.

```
data_warehouse=> SELECT COUNT(*) FROM flexdb_flex_bid_period;
 count
-------
   576
(1 row)

data_warehouse=> SELECT * FROM flexdb_flex_bid_period LIMIT 10;
  id  | bid_id |      period_start      |       period_end       | duration_s | scaling_factor |   raw_capacity_w   |     capacity_mw      | unit_price | amount_price_eur
------+--------+------------------------+------------------------+------------+----------------+--------------------+----------------------+------------+------------------
 4392 |    184 | 2026-04-22 22:00:00+00 | 2026-04-22 23:00:00+00 |       3600 |              1 |  40762.916666666664 |  0.040762916666666666 |        100 |             4.08
 4393 |    184 | 2026-04-22 23:00:00+00 | 2026-04-23 00:00:00+00 |       3600 |              1 |   38850.33333333333 |  0.038850333333333333 |        100 |             3.89
 4394 |    184 | 2026-04-23 00:00:00+00 | 2026-04-23 01:00:00+00 |       3600 |              1 |   38671.66666666667 | 0.038671666666666674 |        100 |             3.87
 4395 |    184 | 2026-04-23 01:00:00+00 | 2026-04-23 02:00:00+00 |       3600 |              1 |              39133 |             0.039133 |        100 |             3.91
 4396 |    184 | 2026-04-23 02:00:00+00 | 2026-04-23 03:00:00+00 |       3600 |              1 |            37930.75 |           0.03793075 |        100 |             3.79
 4397 |    184 | 2026-04-23 03:00:00+00 | 2026-04-23 04:00:00+00 |       3600 |              1 |  40048.166666666664 |  0.040048166666666666 |        100 |                4
 4398 |    184 | 2026-04-23 04:00:00+00 | 2026-04-23 05:00:00+00 |       3600 |              1 |            42796.25 |           0.04279625 |        100 |             4.28
 4399 |    184 | 2026-04-23 05:00:00+00 | 2026-04-23 06:00:00+00 |       3600 |              1 |              48070 |              0.04807 |        100 |             4.81
 4400 |    184 | 2026-04-23 06:00:00+00 | 2026-04-23 07:00:00+00 |       3600 |              1 | 41113.333333333336 | 0.041113333333333335 |        100 |             4.11
 4401 |    184 | 2026-04-23 07:00:00+00 | 2026-04-23 08:00:00+00 |       3600 |              1 |  41713.916666666664 |  0.041713916666666666 |        100 |             4.17
```

Figure 292: Bid details

Figure 293 is a visualization of the bid data for FCR-D-down for one day. The bar in green shows the baseline and the bar in purple shows the offered flexible capacity. The horizontal blue line indicated the installed power.

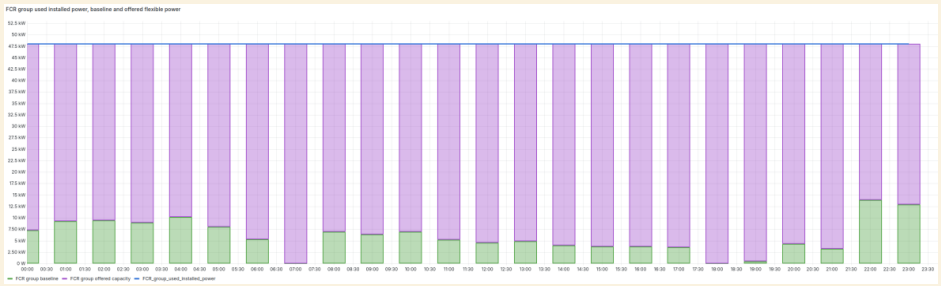


Figure 293: Bid data visualization: FCR-D-down case

Figure 294 is a similar visualization for the FCR-D-up case. In both examples, a scaling factor of 1 has been used and this is the reason why the whole baseline can be used for FCR-D-up.

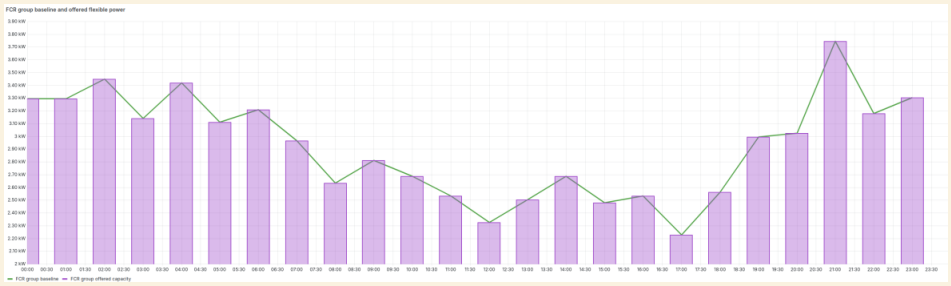


Figure 294: Bid data visualization: FCR-D-up case

DS FI.11	
Data Element	FCR log
Description of the data	This data set contains the information that is collected during an active bid such as: • Timestamp • Grid frequency • Power baseline • Max power of the reserve • Min power of the reserve • Instantaneous active power injection • Service type (FCR-D-up, FCR-D-down). For each service: ○ Maintained flexible capacity (reserved capacity)

- Reserve activation ratio (from 0 to 1): how much maintained capacity has been activated
- Activated power
- Regulating strength

Figure 295 contains a more formal description of the fields including the differences between ETSOE specifications and Fingrid specifications:

Field name	Description
DateTime	Timestamp in the format yyyymmddThhmmss,xxx
ContStatus_FcrdUp, ContStatus_FcrdDo	Status FCR-D up / FCR-D down [on/off] – It is triggered on when the system starts to monitor the frequency
Contmode_FcrdUp, Contmode_FcrdDo	Alphanumeric identifier containing the used flex group name
Baseline	Power baseline in MW (negative value for consumption) - Called CalcBaseline in ETSOE specs
Pmax	Maximum power of the reserve (0 MW if all heaters can be turned off)
Pmin	Minimum power of the reserve in MW (total consumption if all the controllers and all the heaters are "online")
GridFreq	Grid frequency
ApplFreqSig	Applied frequency (used only during testing when using simulated frequency sources) - Not in Fingrid specs
Cap_FcrdUp, Cap_FcrdDo	Maintained flexible capacity (reserved capacity) in MW: it can be different from the sold capacity in the bid due to incorrect baseline calculation
ContOutSig	Reserve activation ratio (from 0 to 1): how much maintained capacity has been activated - Not in Fingrid specs
InsAcPow	Instantaneous active power injection in MW (negative value for absorbed power)
ContSetP	Setpoint before FCR [MW] - The value of InsActPow before FCR activation - Not in Fingrid specs
Act_FcrdUp, Act_FcrdDo	Activated power (the difference between the current instantaneous active power and the instantaneous active power just before FCR activation: InsAcPow – ContSetP)
RegStr_FcrdUp, RegStr_FcrdDo	Regulating strength (maintained capacity / frequency range)
Pavailable	The maximum active power that could be consumed under the current conditions (Pmin minus heaters which are not allowed to be used in flex at the moment minus heaters which cannot be controlled currently). Calculated value. – Not in ETSOE specs

Figure 295: FCR Log fields

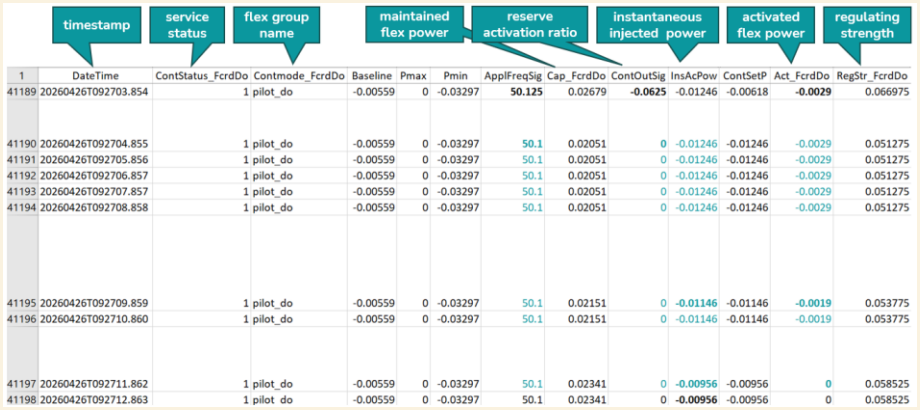
This data set is kept for 4 weeks.

Note that, even though the sampling interval is very small, the amount of data is not huge because it is aggregated data for all the assets that belong to a flexibility group.

This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.

Availability of the data	A subset of this data set can be published.
Access to data	If needed, this data can be shared with the Finnish partners by an encrypted file. zenodo.org/uploads/20743826
Source of data	This data is stored in sDATA in the flex database.
Measurement units	timestamp, MW, Hz, text, MW/Hz
Sampling period(s)	1 second
Related experiment(s)	FI-UC.01.01, FI-UC.01.02
Related Products	sFLEX

Related KPIs	KPI FI.01, KPI FI.02
Graphical support	Figure 296 shows an example of FCR Log. The selected entries correspond to an FCR-D-down deactivation event during tests with real load from pilot customers.



1	DateTime	ContStatus_FcrdDo	Contmode_FcrdDo	Baseline	Pmax	Pmin	ApplFreqSig	Cap_FcrdDo	ContOutSig	InsAcPow	ContSetP	Act_FcrdDo	RegStr_FcrdDo
41189	20260426T092703.854	1	pilot_do	-0.00559	0	-0.03297	**50.125**	0.02679	**-0.0625**	-0.01246	-0.00618	**-0.0029**	0.066975
41190	20260426T092704.855	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41191	20260426T092705.856	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41192	20260426T092706.857	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41193	20260426T092707.857	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41194	20260426T092708.858	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02051	0	-0.01246	-0.01246	-0.0029	0.051275
41195	20260426T092709.859	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02151	0	-0.01146	-0.01146	-0.0019	0.053775
41196	20260426T092710.860	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02151	0	-0.01146	-0.01146	-0.0019	0.053775
41197	20260426T092711.862	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02341	0	-0.00956	-0.00956	0	0.058525
41198	20260426T092712.863	1	pilot_do	-0.00559	0	-0.03297	50.1	0.02341	0	**-0.00956**	-0.00956	0	0.058525

Figure 296: Example of FCR Log

DS FI.12	
Data Element	FCR bid acceptance rate (KPI)
Description of the data	This data set contains the information that is needed to calculate the KPI FI.05 bid acceptance rate: • Service type • Reserved power • Offered power • KPI value This KPI is a measure of how many aggregator's bids are accepted by the TSO. The reserved power might be smaller than the offered power since the TSO might not accept all the bids. This KPI is the percentage of the ratio between the reserved power (MW) and the offered power (MW). There are separate values for FCR-D-up and FCR-D-down. We keep this data for 1 year. This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	A subset of this data set can be published.
Access to data	This data can be shared with the Finnish partners.
Source of data	The information is taken from the bid data (data set FI01_09 "FCR group bid"). The bid data is available with 1 hour interval. Data can be then aggregated into day intervals. This data is calculated by sFLEX and is stored in sDATA in the flex database in Timescale.

Measurement units	text, count, %
Sampling period(s)	1 day
Related experiment(s)	FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	Not applicable.
Graphical support	During the time of the STREAM project, this KPI can be calculated only with estimations since the real connection to the TSO is not part of the prioritized content. The price of flexibility services is driven by assets such as batteries. So, an aggregator which controls just electric radiators as flexible assets might offer bids for a very low price. Still, Fingrid rules state that, if the bid is accepted (and at very low price the probability that this happens is clearly higher), the aggregator is compensated with the price of the most expensive accepted bid for that hour. Hence the target value is set at **90%**.

DS FI.13	
Data Element	Flexibility estimation accuracy (KPI)
Description of the data	This data set contains the information that is needed to calculate the KPI FI.02 Flexibility estimation accuracy: • Service type • Maintained flexible power • Reserved flexible power • KPI value We keep this data for 3 years. The Flexibility estimation reliability measures how accurate the calculation of the flexible power has been. It is the percentage of the ratio between the actual maintained flexibility (MW) and the reserved/allocated flexibility (MW). There are separate values for FCR-D-up and FCR-D-down. The maintained power may be smaller than the reserved power when the baseline calculation in not accurate enough. This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	A subset of this data set can be published.
Access to data	This data can be shared with the Finnish partners.

	zenodo.org/uploads/20749336
Source of data	This data is calculated by sFLEX and is stored in sDATA in the flex database in Timescale. The source of the data to calculate this KPI is the bid data and the FCR Log. The source information is available with a sampling interval of 1 hour in bid data and of 1 second in the FCR Log. Hour based data is be calculated.
Measurement units	text, MW, %
Sampling period(s)	1 day
Related experiment(s)	FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	Not applicable
Graphical support	This data set is a KPI that will be calculated as part of Work Package 6. Its results will be documented in the deliverable D6.1.

DS FI.14	
Data Element	FCR activation speed (KPI)
Description of the data	This data set contains the KPI FI.01 Activation speed. Each service has its own KPI. The KPI is calculated by using the information contained in the FCR Log. This information is available with 1 second sampling interval. The FCR activation speed is a measure on how well the system complies with the tight requirements related to linearity and response time when activating a reserve containment reserve. Its calculation requires a complex algorithm. The reserve activation ratio is a measure of how much flexible capacity has been activated. It tells how much the frequency has deviated within the FCR frequency range because the amount of reserved power to use shall be proportional to the frequency deviation. When it is different than zero, there is some activated flexible capacity (1 means that the full maintained flexible capacity has been activated). After 5 seconds 50% of the necessary reserved power shall be activated. After 7,5 seconds 86% of the necessary reserved power shall be activated. After 30 seconds 100% of the necessary reserved power shall be activated. Therefore, there are 3 aggregate results for each of the services (FCR-D-up and FCR-D-down).

	The calculation requires few hundred lines of python scripts. The result is **a triplet of integers for each service** with possible values from 0 to 1. The logic can be summarized as follows: • Monitor the reserve activation ratio (ContOutSig), which tells if FCR-D is activated, how much and in which direction • When ContOutSig != 0, count time & monitor the activated flexible power (Act_x) till ContOutSig deviates in the opposite direction • If after 5 seconds, Act_x >= 50%*Cap_x*ContOutSig, then 50%actKPI = 1 (Cap_x is the reserved capacity, the values are compared by using absolute values*; Cap_x*ContOutSig tells how much reserved capacity shall be activated based on the actual frequency deviation*) • If after 7 seconds, Act_x >= 86%*Cap_x*ContOutSig, then 86%actKPI = 1 • If after 30 seconds, Act_x >= 86%*Cap_x*ContOutSig, then 100%actKPI I = 1 • Calculate the average of the events KPIs within one Log file (one day) • Calculate the average of the Log file KPIs for the selected group of logs (spanning, for example, through a week) We keep this data for 3 years. This data set is used in the use case FI_01 Using apartments' explicit flexibility for FCR-D ancillary services.
Availability of the data	A subset of this data set can be published.
Access to data	This data can be shared with the Finnish partners. zenodo.org/uploads/20749776
Source of data	The information is taken from the FCR log (data set FI01_11). The FCR Log has data with 1 second observation interval. This data is aggregated into day aggregates. This data is calculated by sFLEX and is stored in sDATA in the flex database in Timescale.
Measurement units	text, count, %
Sampling period(s)	1 day
Related experiment(s)	FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	Not applicable.
Graphical support	Figure 297 provides an example of calculation of this KPI for FCR-D-down and Figure 298 provides an example for FCR-D-up. In both examples the

aggregate data for each day is first printed and then the aggregate data for all the test period is calculated.

```
ubuntu@ip-172-31-32-81:~/measurements-mgmt/kpi_calculation$ python3 FCR_D_activation_KPIs.py

Script start time (UTC): 2026-05-13 19:34:08

This script loops through all the FCR logs contained in a defined directory and for each of them collects a summary of the results of the activation KPIs.
Then, it calculates the overall amount of source entries, the overall amount of activation events and the average values of the activation KPIs.
It shall be run only on Logs related to the same service.

Summary of each single Log file

| file_name                          |   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|:-----------------------------------|-----------------:|--------------------:|-------------:|-------------:|--------------:|
| pilot_do_FcrdDo_FI_UTC_20260423.csv |            47565 |                   0 |          nan |          nan |           nan |
| pilot_do_FcrdDo_FI_UTC_20260424.csv |            86300 |                   2 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260425.csv |            86323 |                  20 |         0.95 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260426.csv |            86324 |                  11 |         0.91 |         0.91 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260427.csv |            86234 |                   2 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260428.csv |            86323 |                  12 |         0.83 |         0.92 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260429.csv |            86324 |                 140 |         0.92 |         0.93 |          0.99 |
| pilot_do_FcrdDo_FI_UTC_20260430.csv |            86324 |                   6 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260501.csv |            86323 |                   9 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260502.csv |            86324 |                   4 |            1 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260503.csv |            86324 |                  12 |         0.92 |            1 |             1 |
| pilot_do_FcrdDo_FI_UTC_20260504.csv |            86323 |                  12 |         0.92 |         0.92 |             1 |

Summary of the all time period

|   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|-----------------:|--------------------:|-------------:|-------------:|--------------:|
|           997011 |                 230 |         0.95 |         0.97 |             1 |

Script end time (UTC): 2026-05-13 19:34:31
Script duration: 0:00:23
```

Figure 297: Example of calculation of the activation KPIs for FCR-D-down

```
ubuntu@ip-172-31-32-81:~/measurements-mgmt/kpi_calculation$ python3 FCR_D_activation_KPIs.py

Script start time (UTC): 2026-05-18 07:06:34

This script loops through all the FCR logs contained in a defined directory and for each of them collects a summary of the results of the activation KPIs.
Then, it calculates the overall amount of source entries, the overall amount of activation events and the average values of the activation KPIs.
It shall be run only on Logs related to the same service.

Summary of each single Log file

| file_name                          |   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|:-----------------------------------|-----------------:|--------------------:|-------------:|-------------:|--------------:|
| pilot_up_FcrdUp_FI_UTC_20260423.csv |            47595 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260424.csv |            86324 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260425.csv |            86323 |                   7 |         0.86 |         0.86 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260426.csv |            86323 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260427.csv |            86231 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260428.csv |            86324 |                   5 |          0.6 |          0.6 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260429.csv |            86324 |                  36 |         0.92 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260430.csv |            86324 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260501.csv |            86324 |                   1 |            1 |            1 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260502.csv |            86323 |                   0 |          nan |          nan |           nan |
| pilot_up_FcrdUp_FI_UTC_20260503.csv |            86325 |                   5 |          0.8 |          0.8 |             1 |
| pilot_up_FcrdUp_FI_UTC_20260504.csv |            86324 |                   3 |            1 |            1 |             1 |

Summary of the all time period

|   source_entries |   activation_events |   50%act_KPI |   86%act_KPI |   100%act_KPI |
|-----------------:|--------------------:|-------------:|-------------:|--------------:|
|           997064 |                  59 |          0.9 |         0.91 |             1 |

Script end time (UTC): 2026-05-18 07:06:57
Script duration: 0:00:23
```

Figure 298: Example of calculation of the activation KPIs for FCR-D-up

DS FI.16	
Data Element	Customer profitability output
Description of the data	This data set contains the information that is obtained as a result of calculating the profitability for the customer: • Extra cost for the customers due to the usage of the heating assets for FCR-D-down • Savings for the customer due to the usage of the assets for FCR-D-up • Extra costs due to re-heating of the rooms after a load cut due to FCR-D-up • Customer compensation (if any) Week and year aggregates are created. The data is retained 3 years. This data set is used in the use case FI_05 Evaluating the flexibility profitability for the customer.
Availability of the data	All data owned by OptiWatti is company confidential.

Access to data	Data related to the pilot apartments is anonymized and copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes. zenodo.org/uploads/20743597
Source of data	The Flex Analyzer component of sFLEX performs such calculations and stores the result into the flex database in Timescale.
Measurement units	€
Sampling period(s)	1 day
Related experiment(s)	FI-UC.05.01
Related Products	sFLEX, sDATA
Related KPIs	Not applicable
Graphical support	**Extra cost for the customers due to the usage of the heating assets for FCR-D-down** Figure 299 shows an extract of the data set produced with data obtained during the tests with real assets from the apartments of the pilot customers. Each entry is related to one hour. Each Flex Client (apartment) has 3 columns identified by the apartment id (id) in brackets: • Column “no.Act (id)”: Number of 10 min time slots within an hour during which any activations took place in the specified apartment. If it is 0, no activations were done during this hour in this apartment • Column “E[Wh] (id)”: Approximated activation energy (as described earlier) in Wh (watt hours) during this hour for the specified apartment. If no activation occurred, no power was activated, and thus, activation energy is 0. Otherwise, the activation energy is greater than 0 irrespective of the activation direction (FCR-D-up or FCR-D-down) • Column “cents (id)”: Corresponding monetary value in euro cents (as all pilot customers use euros) during this hour for the specified apartment. If no activations occurred, the corresponding monetary value is 0. Whereas in case of activations, the corresponding monetary value is the period’s activation energy in kWh times the corresponding price according to customer’s contract. Note that customers have different types of contracts: some use periodic (hourly) pricing, other have fixed pricing. Either way, it all have been taken into account.

1	DateTime	no.Act (4)	E[Wh] (4)	cents (4)	no.Act (1931)	E[Wh] (1931)	cents (1931)	no.Act (2061)	E[Wh] (2061)	cents (2061)	no.Act (2082)	E[Wh] (2082)	cents (2082)	no.Act
27	2026-04-24T23:00:00+00:00	1	12,3	0	1	2,54	0,03	1	16,84	0,15	0	0	0	
28	2026-04-25T00:00:00+00:00	1	97,14	0	0	0	0	1	16,37	0,12	1	4,13	0,03	
29	2026-04-25T01:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
30	2026-04-25T02:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
31	2026-04-25T03:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
32	2026-04-25T04:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
33	2026-04-25T05:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
34	2026-04-25T06:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	
35	2026-04-25T07:00:00+00:00	0	0	0	0	0	0	0	0	0	1	0,79	0,01	
36	2026-04-25T08:00:00+00:00	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 299: Customer profitability calculation for the pilot customers: extract

By summing up the totals of the columns related to the costs, the result is 53,53 cents of costs for 5 apartments for 7 days as shown in Figure 300. By normalizing this result to one year, we obtain for each apartment on average: 0,5353 / 7 *365 / 5 = 5,58 €

1	DateTime	no.Act (4)	E[Wh] (4)	cents (4)	no.Act (1931)	E[Wh] (1931)	cents (1931)	no.Act (2061)	E[Wh] (2061)	cents (2061)	no.Act (2082)	E[Wh] (2082)	cents (2082)	no.A
170	Col totals	31	1778,71	17,95	28	601,9	7,19	37	1151,73	12,93	34	350,6	3,52	

Figure 300: Customer profitability calculation for the pilot customers: totals

Savings for the customer due to the usage of the assets for FCR-D-up

By using an identical process for FCR-D-up, the result is a saving for 3 apartments in 12 days of 0.38 cents. This means an average yearly saving on average for each apartment of 0.38 / 7 * 365 / 3 = 6,6 cents.

Extra costs due to re-heating of the rooms after a load cut due to FCR-D-up

Most of the frequency deviations last less than a minute and in such short time the temperature sensors in the rooms will not notice any difference. So, the extra costs of re-heating after load cut are estimated to be null.

Customer compensation

No monetary customer compensation is considered in the business model.

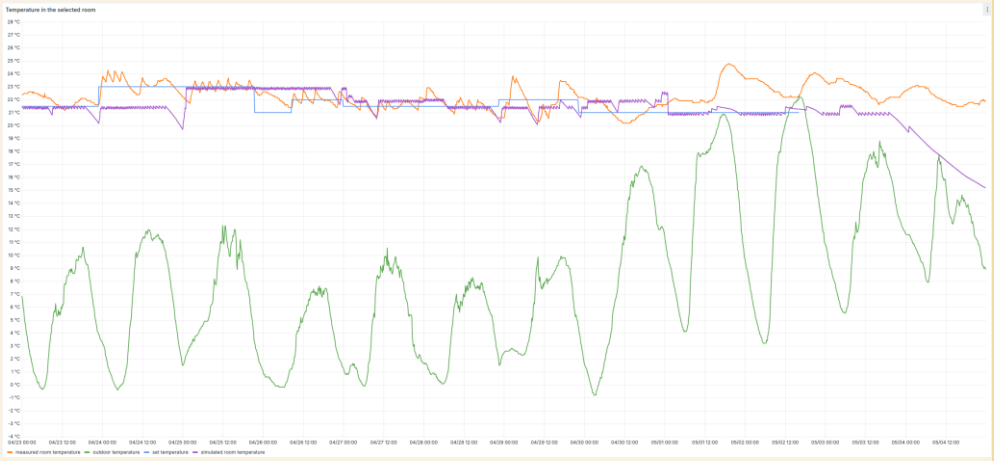
Since a load cut FCR-D-up will happen on not more than 25% of the cases and since the value of the saving is so low, the conclusion is an average annual cost of 5,5 € for an apartment which has an installed power usable theoretically for flexibility of 5,6 kW.

By normalizing this value to an apartment with 10 kW of installed load theoretically usable for flexibility, the result is an extra annual cost of 10 €.

This value is in the same range of the value that has been calculated based on statistical data from Fingrid. The small difference could be explained by the fact that during the testing period there has been a slight lower number than usually of frequency deviations.

DS FI.20	
Data Element	Temperature variations' calculations results
Description of the data	Based on the statistics provided by the TSO, disturbances leading to power cuts are most often very short (lasting just few seconds) and in such time there's no noticeable difference in room temperature. However, it may be useful to estimate the temperature changes due to longer disturbances, even though such disturbances are expected to be rare.

	Such estimation helps in understanding how important it would be to have room-level user settings for the max deviations of the temperature from the set temperature when using explicit flexibility. This data set contains the result variables: • Temperature measurements for each room without usage of flexibility • Temperature measurements for each room when using flexibility The raw data is retained for 3 years.
Availability of the data	All data owned by OptiWatti is company confidential.
Access to data	The data set consists in data related to the usage of customers' apartments and therefore it is protected by GDPR. A subset of such data, that is the data related to the 10 pilot apartments, is anonymized and copied into a separate data warehouse. Such data is accessible by the Finnish partner VTT (a selected list of persons with own credentials) through an SSL encrypted connection only for research and analysis purposes.
Source of data	The source of this data is the Analyzer component of sFLEX. The data is then written in the flex database in Timescale.
Measurement units	°C
Sampling period(s)	10 minutes
Related experiment(s)	FI-UC.01.02
Related Products	sFLEX, sDATA
Related KPIs	None
Graphical support	Figure 301 shows the temperature of the room of one pilot apartment for 12 days, which is the interval that has been used to test FCR with real load from pilot customers. The line in blue is the set temperature, the line is green is the outdoor temperature, the line is orange is the measured temperature during the tests when heating assets were used for flexibility. All those metrics are part of the data sets FI01_02 “Periodic measurements”. The line in purple is the simulated room temperature that has been calculated when estimating the flexible power baseline. It is part of the data set FI01_06 “Baseline flex power forecast output”. This value is not affected by usage of flexibility. Therefore, the difference with the measured temperature is the closest measurement that is currently available of the deviation in room temperature due to usage of heating assets for flexibility.

	However, it should be noted the simulation does not consider issues like energy radiated by the sun, effect of the wind, etc. Therefore. the actual difference in temperature due only to demand-response is much smaller than what shown in this plot.  *Figure 301: Example of measured room temperature vs. simulated temperature*

DS FI.21	
Data Element	Customer feedback
Description of the data	This data set contains the information related to the mechanism to gather customer feedback about the usage of explicit flexibility: • Sent questionaries • Customer answers The feedback includes a customer satisfaction index (from 1 to 5) which is measured in the KPI FI04_02 Customer satisfaction. This data set is used in the use case FI_04 User experience when using flexibility.
Availability of the data	This data set can be shared inside the STREAM project.
Access to data	This data can be shared with the Finnish partner by encrypted file. zenodo.org/uploads/20750087
Source of data	This data has been written on a file.
Measurement units	text
Sampling period(s)	One time data.
Related experiment(s)	FI-UC.04.01
Related Products	sFLEX, sDATA

Related KPIs	KPI FI.06
Graphical support	This data set is a KPI that will be calculated as part of Work Package 6. Its results will be documented in the deliverable D6.1.

DS FI.22	
Data Element	Customer answer rate percentage
Description of the data	This data set contains the information that is needed to calculate the KPI FI.04 Answer rate percentage: • Number of answered questionaries • Number of sent questionaries • KPI value The KPI is calculated as follows: count of answered questionnaires / count of sent questionnaires * 100. The retention policy is 3 years. This data set is used in the use case FI_04 User experience when using flexibility.
Availability of the data	All data owned by OptiWatti is company confidential.
Access to data	This data can be shared with the Finnish partner. zenodo.org/uploads/20750036
Source of data	This data will be probably stored in the flex database in Timescale.
Measurement units	Count, %
Sampling period(s)	One time data.
Related experiment(s)	FI-UC.04.01
Related Products	sFLEX, sDATA
Related KPIs	KPI FI.04
Graphical support	Not applicable.