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D7.3: Pilots' validation report

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Abstract

This report is presenting a detailed analysis of the findings from the validation of FEVER's solutions in the different pilots of the project in Spain, Germany and Cyprus. A quantitative analysis of key performance indicators (KPIs) defined in the project is presented in order to assess the performance of the developed solutions across various the different target values, complemented by an analysis of the overall impact of the project and some of its key

outcomes.

Keyword list

Renewable Energy, Energy Flexibility, Flexibility Trading, Energy Community, Energy Forecast, flexible loads, Energy storage, sector coupling

Change Log

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Executive summary

This report aims to provide analysis of the performance of FEVER's solutions and their impact in the different pilot sites, throughout the demonstration period, via quantifiable results. Towards this a set of Key Performance Indicators (KPIs) was defined at overarching level and at the level of specific Use Cases demonstrated in the pilots which are documented in deliverable *D7.2 Definition of the pilots, the validation methodology and metrics,* in which the formula for their calculation are defined. The KPIs, provide an objective basis for performance evaluation and enable a focus on the key factors contributing to the achievement of the set goals.

The report contains a short description of the pilot sites in Cyprus, Germany and Spain, detailing the business goals and flexibility assets, whereas the project's High Level Use Cases (HLUCs) relevant to the different pilot sites are briefly analyzed. The HLUCs were defined in *D1.1 Flexibility at the distribution grid: Reference usage scenarios for market and system operation services* and describe the high level concepts and functionalities related to the activation and management of flexibility as well as novel services for the distribution grid. They define the involved actors and their respective roles, outlining their responsibilities as well as their main interactions.

To facilitate the reader's understanding, the solutions of FEVER project, relevant to the pilot demonstrations, are also briefly analysed in the document:

- The different Energy Management Systems (EMSs), aiming to control various types of facilities including industrial load, building heating and cooling, EV & batteries charging and discharging, extract and manage considering individual constraints of the user;
- The solutions composing Flexibility System: flexibility offering through Flexibility Service Providing Agent, trading of flexibility through the Flexibility Trading Platform (FTP), aggregation/disaggregation of flexibility trough Flexibility Management System (FMS) as well as solution for energy trading for Energy Communities through the Peer-to-Peer Flexibility Trading Platform (P2P-FTP)
- The DSO Toolbox, a set of grid-oriented tools that complement the existing IT systems of the DSO while enabling better observability and management of the distribution network. Offering solutions for critical event prevention (CEPA), island-mode power management (IPMA), voltage compensation (VCA), grid technical loss reduction (LRA), self-healing (SHA), state estimation (Local Observability Service - LOS) as well as an Integration Platform (IP) enabling seamless integration with the control centre of the DSO, through standard and secure interfaces.

The project-level and technical solution KPIs are analysed on a pilot and Use Case (UC) basis, followed by a detailed presentation of the measured / calculated metrics and their interpretation in regards to the project's pilot overall, or the specific UC demonstration. In total 59 KPIs were calculated an assessed providing a comprehensive view of the solutions of the project. The KPI analysis is followed by an impact assessment per pilot and per HLUC, presenting the main achievements and lessons learnt.

The impact analysis is complemented by a high-level Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, concerning the developed solutions of FEVER. Strengths of the project's solutions such as diversified asset management and services and opportunities stemming from the need for energy efficiency investment deferral in distribution grid and the possible financial benefits for flexibility providers are contrasted with weaknesses such as regulatory obstacles and threats such as the prices volatility.

Towards supporting the uptake local market, the report also provides an analysis of the financial and societal gains to be expected for local flexibility providers, from the establishment of local markets, quantified by the results of FEVERs' solutions demonstrations. As reported, the industrial customers of the Spanish demonstrator have shared 2.6K €, for providing approximately 1,7MWh of activated flexibility and 68KW/6.7MWh of available capacity, over a period of 5 months. On the other hand, results from bi-directional charging scenarios, demonstrated a cost reduction of 46% for a flexible charge of approximately 4KWh in FEVER's V2G chargers. Finally, the introduction of the Real Time Market Mechanism of FEVER could provide benefits from approximately 80€/MWh to 112 €/MWh to flexibility providers as obtained from the simulations realized utilizing data from the different pilot demonstrators in Spain and Germany.

Finally, the report documents the incentive mechanism provided to flexibility providers with industrial loads in the Spanish demonstrator, capturing as well the challenges of the end users in adopting the concept of flexibility and actively participating in flexibility events, as well as gathering high level information on causes of discomfort from flexibility activation from the piloting experience.

Overall, the solutions developed and demonstrated in FEVER pilot sites provide a solid basis for marketable prototypes offering advanced distribution grid observability, extraction-aggregation-management of distributed flexibility and advanced market mechanisms enabling flexibility trading at local/regional and wholesale market levels. In all three pilot sites (Cyprus, Germany and Spain), a wide range of functionalities were deployed, fine-tuned and demonstrated and an extensive list of KPIs was compiled to assess the performance of the developed solutions under the particular conditions of the respective pilot site and its impact on the pilot operation. The challenges and constraints faced in the different pilots (e.g. technical, regulatory) that may hinder the adoption and operation of novel services were highlighted, whereas tangible benefits for the various stakeholders of the domain were quantified.

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1 Introduction

FEVER project is a response to the call *LC-SC3-ES-1-2019, entitled "Flexible Energy Production, Demand and Storage-based Virtual Power Plants for Electricity Markets and Resilient DSO Operation"*, of the Horizon 2020 program. The FEVER's project objectives lie on three keys axes:

1. To implement flexibility measures and comprehensive flexibility aggregation, management and trading solutions, in order to provide electricity grid services, such as congestion management and overvoltage avoidance, at the distribution grid.

2. To implement enhanced monitoring and automated control of the distribution grid, by developing an innovative toolbox and implementing advanced technology that leverages flexibility form distributed resources towards providing ancillary services.

3. To implement market mechanisms and tools that support and incentivize flexibility services. These mechanisms concern different market structures and time-horizons (day-ahead and continuous trading of flexibility services, centralized and local/regional markets).

In order to demonstrate the real-world applicability of the innovation concepts and to create a strong impact of the results, FEVER includes three real-world pilots in different countries, namely Cyprus, Germany and Spain. In addition to that, the project includes the design of a simulation testbed, to simulate the operation of electricity markets that incorporate novel flexibility-related services. In each demo activity, different specific objectives are set, overall contributing to the accomplishment of FEVER's high-level objectives. Different KPIs were formulated to measure, assess and validate the performance and impact of FEVER solutions across the different pilots.

1.1 Scope and objectives

This report presents a detailed analysis of the pilots' findings and validation of the overall tools. By analysing the acquired data, an assessment of the developed solutions has been conducted with regard to:

- the performance of the different solutions developed in the project,
- the flexibility calculations,
- the degree of leveraging and user satisfaction achieved,
- the impact, strengths, weaknesses, threats and opportunities, as well as
- financial and societal gains, that the establishment of local markets could produce for local flexibility providers.

1.2 Outline of the deliverable

The document can be read as a stand-alone document. However, other deliverables of FEVER offer more detailed information on specific topics relevant to this field trail which the reader may find useful as context information. The following FEVER deliverables are relevant:

- *D1.1 - Flexibility at the distribution grid* [1]: Reference usage scenarios for market and system operation services: Report describing existing solutions and examples regarding flexibility at the distribution grid (across literature and energy market press), as well as appropriately documenting the project's High Level Use Cases (HLUCs) in accordance to IEC 62559.
- *D1.2 Functional and operational requirements* [2]: Document Primary and Secondary Use Cases, decomposing the high-level functionalities of the HLUC into smaller building blocks
- *D7.2 - Definition of the pilots, the validation methodology and metrics* [3]: Report presenting the details related to the demonstration pilots of the project in terms of scenarios and use cases to be demonstrated and validated as well as the KPIs for qualitative and quantitative assessment.

2 Description of the pilots

The following section introduces the three pilot sites in Cyprus, Germany, and Spain. It provides a general overview of the organizations responsible for conducting the project in each country, the opportunities they have, and the objectives they aimed to achieve within the project. A more detailed description is given in D 7.2 “Definition of the pilots, the validation methodology and metrics”.

2.1 Cyprus

The University of Cyprus (UCY) campus is located in Nicosia, Cyprus. UCY's facilities include a number of non-residential buildings as well as DERs such as PV and storage. The FOSS Research Centre for Sustainable Energy defines the energy strategy of the university with the main objective of achieving energy self-sufficiency. As a result, FOSS has a unique perspective on the energy needs of a variety of system stakeholders, including energy users and grid operators. In addition, FOSS has control over the EMS of the campus buildings and can therefore demonstrate the calculation and provision of flexibility. The University of Cyprus offered two main options for demonstrating the ability to use flexibility. Firstly, the load management of certain university buildings can be realised through the building energy management systems (BEMS) orchestrated by a central EMS. The specific infrastructure can be exploited when the flexibility is needed for congestion management in the local grid, which in the case of the actual demonstration was emulated using a real-time simulator (RTS). In addition, the UCY has implemented the converter-based assets that operated at the nanogrid level.

2.2 Germany

The German demo pilot revolved around Stadtwerk Wunsiedel GmbH (SWW) and Stadtwerk Haßfurt GmbH (SWH), which are municipal utilities and distribution system operators in Bavaria. These entities are characterized by their innovative approaches and commitment to providing affordable and environmentally friendly energy supply to urban and municipal areas. Although SWH and SWW are not neighbouring regions but more than 100 km apart from each other, for the scope of the pilot they were virtually linked through a flexibility “bridge”, enabling exchange of energy among communities in the two regions. The Energy Community formed in the grids of SWW and SWH aimed to achieve several objectives, including collective energy purchasing, energy demand and supply management, energy generation, and the provision of energy-related services. Both utilities have a significant penetration of RES, and their consumer and prosumer base cover various types of infrastructure such as industrial facilities, small and medium-sized enterprises (SMEs), professional RES sites, farms, multi-family houses with shared amenities, and individual households. Innovating trading services have been developed for these two ECs via FlexCoin, a pseudo-currency introduced by FEVER project for remunerating community members.

In detail SWH provided flexibility by the cooling house of a jam factory, by a gas and hydrogen CHP as well by six water pumps in the premises of SWH. In Schönbrunn, the energy landscape is diverse and complex. With 550 electricity customers, including 115 with electronically remote-readable meters and 435 whose readings are collected annually. Heating services cater to 80 customers, collectively consuming a significant 1,856,692 kWh of heat annually. The energy mix further diversifies with the presence of 58 PV systems, boasting a combined installed capacity of 716.58 kWp. Notably, one of these PV systems incorporates a battery with a capacity of 3.5 kVA, enhancing energy storage capabilities. A key player in the energy infrastructure is the Combined Heat and Power (CHP) unit, boasting a total rated output of 1890 kW. This unit effectively utilizes various energy sources, including an 80 kWp PV system, producing 1430 kW of heat and 380 kW of electricity. Additionally, the CHP system features a substantial heat storage tank with an 80,000-liter capacity, alongside a heating rod with a nominal output of 1.1 MW. Although the installation of the heating rod is pending, plans are in place for its operation for half of the year, amounting to approximately 4380 hours annually. The energy generation and consumption figures underscore the importance of managing resources efficiently. With a power availability of 4,818,000 kWh and power generation of 5,924,126 kWh, alongside heat generation reaching 4,643,460 kWh, the need for flexibility in energy management becomes apparent. This flexibility is provided by SWW allowing strategic choices regarding the operation of energy units. SWW can opt to utilize the pellet boiler and heating rod concurrently, rely solely on the pellet boiler, or operate solely with the heating rod. Such flexibility enables SWW to adapt to varying demand patterns and optimize energy utilization effectively, ensuring the reliable and sustainable provision of energy services to the residents of Schönbrunn.

In the German pilot project, the DSOs have set a goal to demonstrate, how providers of balancing energy for higher grid levels and external supply areas can be connected and acting as an energy community by the use of a so called “flexibility bridge”.

2.3 Spain

The Spanish pilot, conducted by Aněll, focused on showcasing enhancement of observability and controllability of the distribution network as well as the utilization of aggregated local flexibility for ancillary services, specifically in response to congestions faced due to the increasing penetration of distributed PV generation. The pilot aimed to demonstrate the feasibility and impact of combining various flexibility technologies with different availability and dynamics. Flexibility sources in the pilot project include stationary and electric vehicle (EV) batteries for flexible electricity storage. Moreover, two power electronic devices (PED and IDPR), responsible for managing battery arrays, will leverage their unique features to offer ancillary services such as voltage control, reactive power control, distribution line harmonic compensation, phase balancing, and loss reduction. T The positive impacts of these services were expected at both the substation and consumer levels.

The pilot project was conducted within the subsidiary of Estabanell within the electrical network of the distribution company of Estabanell known as Aněll. Aněll is a Catalonia-based DSO, operating over 120 km of 40 kV sub-transmission network and more than 1000 km of medium and low voltage network, serving 31 towns. The Pilot assets are distributed in three different sites: L’esquirol, Granollers and Vallfogona. Granollers is an urban town near Barcelona and the place in which the V2G chargers will be installed in Estabanell’s premises. In contrast, L’esquirol and Vallfogona are rural areas in which the PEDs are installed to improve grid service. In order to measure the combined impact of the project’s solution on the combination of the three sites, a Virtual Grid of the distribution network was also formulated leveraging GIS data. The model was created using Python programming language and composes the LV network of the three sites mentioned and also the transmission network connected them. The Virtual Grid plays a crucial role and is the basis of many flexibility services as it enables the usage of power flow analysis to assess the project’s results.

2.4 Use Cases mapping

The following table gives an overview, of which High Level Use Cases (HLUCs) have been defined and selected to be demonstrated in each pilot site. Detailed information on HLUCs can be accessed from D1.1. [1].

Table A: High Level Use Cases per pilot

#	HLUC Name	ES	DE	CY
1	Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc)	x	x	
2	Voltage compensation via reactive power procurement	x	x	x
3	Real time detection of uncontrolled islanding by leveraging storage flexibility	x		
4	Self-healing operation after critical event considering DER & grid flexibility	x	x	
5	Flexibility exploitation for islanded microgrid operation			x
6	Leveraging DER flexibility towards enhancing network operational efficiency	x	x	
7	Improving power quality & reducing losses through local storage utilization	x		

8	Economically optimised flexibility leveraging for a connected microgrid		x
12	Creating dynamic tariffs based on flexibility use in the actual regulatory framework	x	
13	Improving the outcome in flexibility by introducing sector coupling	x	
14	Form a first example of a regional flexibility exchange model	x	
15	P2P flexibility trading	x	

It must be noted that early results from laboratory tests of HLUC03 proved that most of the commercial inverters already have mechanisms of real-time detection of uncontrolled island, hence the HLUC was repurposed to HLUC05 since during the project.

3 FEVER Solutions

In this chapter, the solutions developed during the project are briefly presented. These include the different Energy Management Systems, the Flexibility Management and Trading solutions, and the DSO Toolbox. Another set of solutions developed in the context of FEVER, implementing different market mechanisms is described in deliverable D4.4 [4].

The following figure briefly presents the project’s solutions on the overall ecosystem.

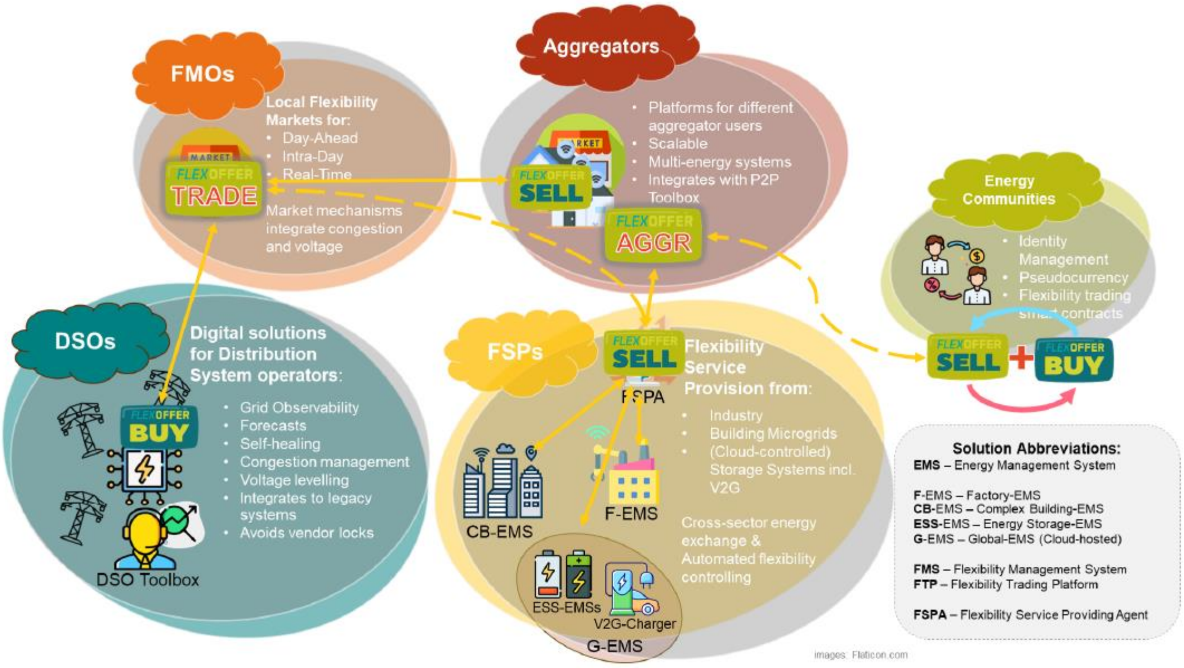


Figure A: FEVER Ecosystem

3.1 Energy Management Systems

FEVER project developed an ensemble set of Energy Management Systems, enabling the management and extraction of flexibility from diverse type of assets. These EMS are briefly described below:

- The Factory Energy Management System (FEMS) which incorporate broad applicability across diverse industrial loads and production units. FEVER pilots involve the control of various types of assets within an industrial environment, hence the FEMS must account for their specific characteristics while also aligning them on a common stage. To achieve this, a core algorithm was developed based on the identified common characteristics of 'availability,' 'adaptation capacity,' and 'intervention.' This core algorithm describes the adaptation are comprising characteristics. The asset types described as 'controlling setpoint,' 'production asset,' and 'operation block asset' are designed to meet the requirements of the FEVER project, but the list can be expanded in the future to accommodate additional asset types that may arise.
- The Microgrid Energy Management System (mgEMS) was implemented to optimize the operation of Distributed Energy Resource (DER) assets within a microgrid. A microgrid scheduler aggregates flexibility from flexible assets to be utilized for an internal objective function based on day-ahead energy forecasts, while a local EMS aggregates the extracted flexibility from the assets for providing services to the grid.
- Energy Storage Management Systems (ESMS) were deployed in the Spanish pilot. These EMSs are responsible for extracting energy flexibility from various types of Energy Storage Systems (ESS) for the day-ahead flexibility market, while also providing some services directly to the Distribution System Operator (DSO). The EMSs consist of a Vehicle-to-Grid (V2G) EMS and two Battery EMSs. The V2G EMS handles bidirectional charging stations in an aggregated manner, capable of managing both active and reactive power. On the other hand, the Battery

EMSs manage two sets of stationary batteries through two power devices. All three EMSs are integrated into a single cloud-based solution in the Global Energy Management System (GEMS), which aims to mitigate integration issues.

3.2 Flexibility System

3.2.1 Flexibility Trading Platform

The Flexibility Trading Platform (FTP) serves as a connection between prosumers who can provide flexibility through their Energy Management Systems (EMS) and external systems. The FTP consists of a control center responsible for performing scenarios, as well as Flexibility Service Providing Agents (FSPA) and Flexibility Service Consuming Agents (FSCA). FSPA facilitates the exchange of prosumer information, while FSCAs handle the exchange of information with external entities related to adaptation requests. These agents are designed for the exchange of flexibility and adaptation control.

Furthermore, the FTP provides several APIs for data exchange with external components, enhancing interoperability and enabling seamless integration with other systems.

The FTP supports various flexibility extraction scenarios, including:

- Extracting flexibility from processes: This involves identifying and utilizing flexibility available within different industrial processes or energy-consuming systems
- Linking energy vectors: The FTP enables the integration and coordination of multiple energy vectors, such as electricity, heat, and transport, to leverage flexibility across these domains
- Dynamic grouping of different storage devices: The platform allows for the flexible grouping of various storage devices, such as batteries or electric vehicles, to optimize their collective contribution to the overall flexibility of the system

Overall, the FTP acts as a central hub for exchanging flexibility and adaptation control, facilitating the efficient utilization of flexibility resources and enabling seamless interaction between prosumers and external systems.

3.2.2 Flexibility service providing agent

The Flexibility Service Providing Agent (FSPA) has the following functionalities:

- It provides an interface for communication with FTP, to exchange information about energy flexibility available and demands
- It provides an interface for communication with EMS. The interface is implemented as a listener for the reception of the EMS data
- It controls message flow and generates flexibility offers (FOs):
  - It forms FOs based on flexibility data offered from EMS including consideration of prices defined by the FSPA user and transmits them to the FTP
  - In case of accepted FO, FSPA receives an execution schedule from the FTP
  - It optionally forms execution schedules toward EMS

3.2.3 Flexibility Management System

The Flexibility Management System (FMS) is a software component that provides advanced functionalities for managing and trading flexibility assets in a smart energy system. Key features are:

- Aggregator Management: The FMS enables aggregator users to efficiently handle a large number of prosumers with diverse types of flexibility. Aggregators can effectively oversee and coordinate these prosumers within their portfolio,
- Flexibility Aggregation: The FMS aggregates the flexibility assets of individual prosumers, taking into account their geographical location. By consolidating these assets, the FMS optimizes their utilization and enhances the overall flexibility within the system,

- Demand and Supply Disaggregation: The FMS disaggregates the demand and supply schedules associated with the flexibility assets. This process allows for a detailed analysis of the available flexibility, providing insights into its distribution and availability,
- Trading on FTP: The FMS facilitates the trading of aggregated flexibility assets on the FTP
- Trading on P2P-FTP: The FMS also enables the trading of flexibility assets, including both flexibility and electricity, on the Peer-to-Peer Flexibility Trading Platform (P2P-FTP). The P2P-FTP allows direct trading between prosumers, enabling them to engage in the buying and selling of flexibility and electricity resources,
- User Control: Prosumer users are empowered with control over the level of flexibility they offer to aggregators and the extent of their engagement in trading on the P2P-FTP. This feature allows prosumers to actively participate in the market and make decisions regarding their flexibility assets and electricity trading activities,

In summary, the FMS serves as a comprehensive software solution for managing and trading flexibility assets. It enables aggregators to handle diverse prosumer portfolios, aggregates and disaggregates flexibility assets, facilitates trading on both FTP and P2P-FTP platforms, and provides prosumer users with control over their flexibility resources and trading activities.

In the FEVER project, the FMS plays a complementary role to the FTP by enhancing the capabilities for aggregating flexibility. FMS is specifically designed to handle the aggregation of smaller flexibility assets and prosumers, which would be impractical or infeasible to manage individually using the flexibility cost models required by the FSPAs in FTP.

Unlike FTP, FMS does not necessitate prosumers to determine a flexibility price for each flexibility offer submitted to FTP through their respective FSPAs. Instead, FMS employs the concept of flexibility contracts to estimate the weekly or monthly remuneration that aggregators need to pay prosumers for the offered flexibility. This approach simplifies the integration of new flexibility assets by utilizing significantly less complex FSPAs.

Moreover, FMS utilizes these flexibility contracts to estimate the flexibility price when providing aggregated flexibility to FTP, effectively functioning as a standard FSPA towards FTP. This integration ensures the smooth coordination and operation between FMS and FTP.

3.3 DSO Toolbox

The DSO Toolbox is a suite of grid-oriented tools complementing the DSO's legacy IT systems whilst enabling more advanced observability and management of the distribution grid. The main components of this solution are the following:

- Business Applications & Services: Applications offering advanced grid operations such as critical event prevention (CEPA), island-mode power management (IPMA), voltage compensation (VCA), grid technical loss reduction (LRA) and self-healing (SHA). Services such as energy forecasting (EF), grid operation planning (GOP), prediction of voltage violations and grid congestions (CEF), detection of grid faults (FDA), state estimation (Local Observability Service - LOS) acting as an integral part of the applications.

- Integration Platform (IP): The IP facilitates the interactions among the different grid observability and control components of the DSO Toolbox and the legacy applications and services of the DSO through standard and secure interfaces (through Integration Middleware, Data Store and Switchgear Dispatch Scheduler - SDS). Moreover, it enables performing an impact assessment of active grid management operations and exposes a mash-up of the presentation layer of the tools to be implemented. Finally, it enables the exchange and management of flexibility signals via flexibility service agents.

3.3.1 Generation and load forecasting tools

The Energy Forecasting tool encompasses two distinct modules dedicated to the prediction of energy generation and energy consumption, developed by University of Cyprus and University of Girona respectively. The development of this forecasting tool necessitates a meticulous spatiotemporal resolution, as its purpose is to streamline the operations of DSOs and enhance their ability to anticipate potential grid issues, thus enabling proactive measures to prevent them through effective grid management. Moreover, energy forecasting, encompassing both generation and consumption aspects, contributes to the optimization of flexibility measures and the formulation of local optimization strategies. The forecasting tools operate in two modes: training and forecasting. During the training phase, the models are trained using historical data and machine learning techniques. Specifically, the historical data for the energy generation forecasting module comprise photovoltaic (PV) generation data, while the energy demand forecasting module relies on electrical consumption data. Both modules necessitate past weather data during the training period, as weather conditions exert a direct impact on PV generation and exert a strong influence on electrical consumption patterns. To generate forecasted values for energy generation and consumption, the models also rely on weather prediction data as an input. The outputs generated by the forecasting modules exhibit the same level of granularity and forecasting horizon as the data used for training. Continuous training at regular intervals ensures improved accuracy of the forecasting models. Consequently, the trained models, which are the outputs of the training phase, are employed during the forecasting operation mode of the tools. The Energy Forecasting tool is a component of the DSOs' Toolbox, and its forecasted values serve as inputs for other tools that augment and optimize grid operations for DSOs.

For accessing past weather data and weather prediction Meteoblue service (www.meteoblue.com) was utilized.

3.3.2 Tools for optimum distribution grid monitoring

Two tools provide enhanced grid monitoring capabilities implementing fault detection methods.

The first tool – developed by University of Girona – is based on the theoretical foundations of Principal Component Analysis. This method utilizes multivariate statistical analysis to explore the correlation among measured variables and represent them in a lower-dimensional space. By creating a reference model based on data collected during normal operating conditions, any deviations from this model can be considered abnormal or potential faults. Two statistical metrics are employed for fault detection: Hotelling T2, which measures the Mahalanobis distance of observations from the centre of the model, and Square Prediction Error (SPE or Q), which quantifies the squared distance of samples from the projection hyperplane. When a fault candidate is identified, a detailed analysis of the fault magnitude and the contributions of measured variables can help isolate the variable or set of variables most likely responsible for the abnormal behaviour.

The second tool – developed by University of Patras – is a fault detection approach based on Recurrent Neural Networks (RNN), which leverages the power of machine learning. The RNN is trained to recognize various types of faults occurring at different locations within the grid. The training process involves feeding of the neural network with a large dataset comprising records of the faults that need to be detected. This method encompasses four main functionalities:

- Faulty feeder detection: The model can detect the specific feeder where the fault occurred and differentiate it from the healthy feeders,
- Faulty branch detection: The model can precisely identify the branch from which the fault originated,
- Fault class identification: The model can determine the type of fault that occurred in the grid,
- Fault distance from the root node calculation: The model can estimate the distance from the root node of the grid assuming a radial topology.

Both of these methods are designed to be independent of the specific topology characteristics of each distribution grid, making them adaptable and applicable to various grid configurations.

3.3.3 Power quality and local observability services

The Power Quality Service (PQS) operates an algorithm that calculates optimal operational setpoints for assets capable of mitigating the impacts of harmonics and phase unbalances. These power quality issues have a significant effect on technical losses in the distribution grid, with extreme cases of phase unbalances resulting in potential losses of several thousand euros per hour and harmonics increasing losses by up to 1600 euros per hour in specific instances. The PQS consists of two main processes: forecasting harmonics and unbalances and estimating asset capacity reserve. These processes utilize a machine learning model trained with local experimental data to learn and autonomously perform these tasks in the future. Once the forecasting is completed, the PQS estimates the asset capacity reserve based on historical measurements that establish the relationship between asset power injection and the distortion power present in the grid. The outcome is the asset capacity reservation, which represents the maximum apparent power required to mitigate harmonics and phase unbalances. This information is communicated to the asset owners, enabling them to provide other flexibility services while knowing in advance the available apparent power of their equipment.

The Voltage Compensation Application (VCA) aims to leverage any asset capable of providing reactive power to the distribution system to assist DSOs in maintaining voltage levels within regulatory and standard thresholds. This is achieved through flexibility requests traded in a local market facilitated by the FTP. The VCA utilizes algorithms developed in the Python programming language to create a network model of the distribution grid, encompassing all its elements, and enabling the computation of time-series power flow. By incorporating demand and generation forecasting services through the integration middleware of the DSO Toolbox, the VCA computes a set of power flows and assesses voltage deviations in the distribution grid. This information is used to communicate with the FSCA, generating flexibility requests to address these deviations.

The Local Observability Service focuses on observability and is divided into two levels: localized data acquisition and observability services. Localized data acquisition involves integrating various equipment capable of providing sensing capabilities. The second level is grid observability, which involves the continuous monitoring of the distribution grid by the DSO. Traditionally, grid monitoring has been performed at the transmission level using power grid state estimation. However, with the increasing complexities and new paradigms such as electric vehicles, distributed generation, battery systems, vehicle-to-grid (V2G) technologies, and demand response, current research efforts are focused on efficiently performing power grid monitoring at the distribution level, particularly at the low-voltage (LV) level, to ensure the required grid observability. By aggregating and integrating data from various sources, it becomes possible to apply state estimation techniques and provide accurate status information for all feeders in the grid, even in areas with limited communication capabilities. The service aim to offer an accurate diagnosis of the status of each medium-voltage (MV) and LV feeder, complementing traditional Supervisory Control and Data Acquisition (SCADA) systems and enabling additional services within the DSO Toolbox.

3.3.4 Tools for optimum distribution grid control

A modular implementation has been developed for the DSO Toolbox, consisting of a set of components and applications designed to assess and support the operation of distribution grids by leveraging flexibility. The objective is to empower DSOs in enhancing the controllability of the distribution grid. The following applications were developed as part of this implementation:

- Critical Event Prevention Application (CEPA) and Loss Reduction Application (LRA): These two applications, sharing input and output data, were combined into a single application with two modalities. In the case of a diagnosed critical event, flexibility is requested to mitigate the problem. In the absence of a critical event, flexibility is requested to optimize losses through peak shaving.
- Self-Healing Application (SHA): The SHA aims to identify abnormal behavior within the monitored area, analyze the involved variables, and determine the extent of the impact. Based on this information, a mitigation plan is proposed to minimize the impact, such as reconfiguring the network to reduce the number of affected users or the duration of the disturbance.
- Island-mode Power Management Application (IPMA): The IPMA serves two main objectives. Firstly, it maintains continuous communication with monitoring assets, SCADA, and other DSO Toolbox services to improve the detection of unwanted islanding situations and propose a forced disconnection strategy. Secondly, it offers a grid reconfiguration strategy that enables the provision of energy to a set of loads when the main grid is unavailable due to a fault or maintenance.

In addition to the applications mentioned above, several associated components, known as advanced operations, are utilized to provide operational capabilities:

- Power Flow Simulator (PFS): This external component, not developed within FEVER, is essential for obtaining a complete understanding of the steady-state behaviour of the grid. PandaPower[1] software is used to calculate the values of electrical variables (voltage, currents, powers) throughout the grid based on given variables such as consumption, generation, and the grid model.
- Grid Operation Planner (GOP): This component is responsible for generating a grid schedule that considers different objectives and available resources. It provides schedules for flexibility utilization and switchgear operation.
- Critical Event Forecaster (CEF): This component can predict critical event situations within a certain margin of error by utilizing forecasted data on generation and demand within the grid.

These components and applications collectively enhance the operational capabilities of the DSO Toolbox and contribute to the effective management of distribution grids.

3.3.5 Integration platform

The Integration platform facilitates the interactions through standard and secure interfaces among the different grid observability and control components of the DSO Toolbox, the legacy applications of the DSO and external services. Information flows through the platform follow a canonical data model based on IEC Common Information Model (CIM) series whereas it also enables interfacing Flexibility Management & Trading solutions for requesting and managing flexibility with the use of FlexOffer protocol [5]. The platform also provides a graphical user interface (GUI) to the end-user to monitor and control various operations such as: detection of congestions events and voltage issues, application of mitigation actions (i.e. flexibility requests), metrics for assessing the impact of mitigation actions (amongst other).

[1] http://www.pandapower.org/

4 Impact Measurement

In this chapter, we first present the mapping of High-level Use Cases (HLUCs) with Key Performance Indicators (KPIs) following the initial documentation reported in D7.2 [3]. Project are presented on a project-level or at technical (i.e. Use Case) Level. The chapter also present the actual measured or calculated KPIs and an assessment of the whether the relevant target was reached.

4.1 Project-level KPIs

The following section presents the key performance indicators (KPIs) relevant to various HLUCs and the corresponding pilot sites at which they are measured.

Table B: Key Performance Indicators (Project-level)

KPI	Description	HLUC	GER	ESP	CYP
DOA_01	Distributed storage integration	Overarching	x	x	x
DOA_02	Reduction of peak active power from V2G/EV	HLUC13		x	
DOA_03	Power-2-X flexibility aggregated	HLUC01, HLUC13	x		
DOA_04	Distribution grid stability through responsiveness of flexibility services	HLUC01	x		
DOA_05	Flexibility of virtual energy storage	Overarching	x	x	x
DOA_06	Critical event prediction	HLUC01	x	x	
DOA_07	Losses reduction	HLUC06, HLUC07		x	
DOA_08	Short term spatio-temporal forecasting errors	HLUC01, HLUC02, HLUC04, HLUC05, HLUC06, HLUC08	x	x	x
DOA_09	Peak demand reduction	HLUC01, HLUC06	x	x	
DOA_10	Fault detection and localization	HLUC04	x	x	
DOA_11	Peak demand reduction (MV/LV transformer)	HLUC01, HLUC06	x	x	
DOA_12	Increasing the RES hosting capacity at the distribution grid	Overarching		x	
DOA_13	Maximization of the use of infrastructures	Overarching		x	
DOA_14	Increase power quality	HLUC02, HLUC07		x	
DOA_18	CO2 emissions reduction	Overarching	x	x	x
DOA_19	Secure information and communication technologies	Overarching	x	x	x
DOA_20	Integration performance	Overarching		x	x

4.2 Technical solution level KPI

The following section presents the key performance indicators (KPIs) relevant to various Primary or Secondary UCs (see D1.2 [2]) and the corresponding pilot sites at which they are measured. A mark in parenthesis means inability to measure, whereas the reasons are explain in the detailed analysis of section 4.3.2.

Table C: Key Performance Indicators (Technical solution level)

KPI	Description	HLUC	GER	ESP	CYP
KPI_PUC01_1	Responsiveness of close-to real time prevention	HLUC01		x	
KPI_PUC01_2	Performance of critical event forecasting	HLUC01	x	x	
KPI_PUC02_1	Responsiveness of grid Reconfiguration planning	HLUC01, HLUC04		x	
KPI_PUC02_2	Efficiency of grid Reconfiguration planning	HLUC01, HLUC04		(x)	
KPI_PUC03_1	Amount of requested energy flexibility	HLUC01, HLUC05, HLUC08		x	
KPI_PUC03_2	Amount of delivered energy flexibility	HLUC01, HLUC05, HLUC08	x	x	
KPI_PUC03_3	Total flexibility request cost	HLUC01, HLUC05, HLUC08	x	x	
KPI_PUC04_1	Amount of offered energy flexibility	HLUC04, HLUC05, HLUC06, HLUC08, HLUC09, HLUC12, HLUC13, HLUC14	x	x	x
KPI_PUC04_2	Amount of delivered energy flexibility	HLUC04, HLUC05, HLUC06, HLUC08, HLUC09, HLUC12, HLUC13, HLUC14	x	x	
KPI_PUC04_3	Total reward	HLUC04, HLUC05, HLUC06, HLUC08, HLUC09, HLUC12, HLUC13, HLUC14		x	
KPI_PUC05_1	Prosumer reliability	HLUC01, HLUC04, HLUC05, HLUC06, HLUC08, HLUC09, HLUC12, HLUC13, HLUC14, HLUC15	x	x	
KPI_PUC06_1	Congestion management effectiveness	HLUC01, HLUC02, HLUC04, HLUC06		x	
KPI_PUC06_2	Voltage compensation effectiveness	HLUC01, HLUC02, HLUC04, HLUC06		(x)	
KPI_PUC06_3	Loss compensation effectiveness	HLUC01, HLUC02, HLUC04, HLUC06		x	
KPI_PUC06_4	Self-healing effectiveness	HLUC01, HLUC02, HLUC04, HLUC06		(x)	
KPI_PUC06_5	Faulty feeder detection accuracy	HLUC01, HLUC02, HLUC04, HLUC06	(x)		
KPI_PUC06_6	Faulty branch identification accuracy	HLUC01, HLUC02, HLUC04, HLUC06	(x)		
KPI_PUC06_7	Distance error of fault detection	HLUC01, HLUC02, HLUC04, HLUC06	(x)		
KPI_PUC07_1	Responsiveness of close-to real time prevention	HLUC02		(x)	
KPI_PUC08_1	Island´s detected	HLUC03		x	

KPI_PUC09_1	Responsiveness of close-to real time mitigation	HLUC03		(x)	
KPI_PUC09_2	Islands mitigated	HLUC03		(x)	
KPI_PUC10_1	Power Quality Indicator	HLUC07		x	
KPI_PUC11_1	Improvement of power quality	HLUC07		x	
KPI_PUC12_1	Responsiveness of self-healing	HLUC04		x	
KPI_PUC13_1	Loss reduction	HLUC06		x	
KPI_PUC22_1	Target SoC reach	HLUC06, HLUC13		x	
KPI_PUC22_2	Economic benefit of using FEVER EV charging	HLUC06, HLUC13		x	
KPI_PUC27_1	Daily Number of interventions	HLUC13	(x)		
KPI_PUC27_2	Amount of needed energy flexibility	HLUC13	(x)		
KPI_PUC27_3	External procurement	HLUC13	x		
KPI_PUC29_1	Critical loads connectivity	HLUC05			x
KPI_PUC29_2	Frequency regulation	HLUC05			x
KPI_PUC29_3	Voltage regulation	HLUC05			x
KPI_PUC29_4	Power supply continuity	HLUC05			x
KPI_PUC29_5	Flexible loads	HLUC05			x
KPI_PUC29_6	Trading flexibility	HLUC05, HLUC08			x
KPI_PUC29_7	Operation cost	HLUC08			x
KPI_PUC31_1	External procurement	HLUC14	x		
KPI_PUC32_1	Transaction processing throughput	HLUC15	x		
KPI_PUC32_2	Number of peers	HLUC15	x		
KPI_SUC01_1	Performance of forecasting	HLUC01, HLUC02, HLUC04, HLUC05, HLUC06, HLUC08	x	x	x
KPI_SUC02_1	Data received	HLUC01, HLUC02, HLUC03, HLUC04, HLUC06, HLUC07	x	x	x
KPI_SUC02_2	Frequency of data received	HLUC01, HLUC02, HLUC03, HLUC04, HLUC06, HLUC07	x	x	x
KPI_SUC02_3	Consistency of data received	HLUC01, HLUC02, HLUC03, HLUC04, HLUC06, HLUC07	x	x	x
KPI_SUC04_1	Performance of planning	HLUC01, HLUC02, HLUC04, HLUC06	x	x	x
KPI_SUC05_1	Asset state response time	HLUC04, HLUC05, HLUC06	x	x	
KPI_SUC05_2	Asset control reaction time	HLUC04, HLUC05, HLUC06	x	x	
KPI_SUC06_1	Number of Flex-Offers per time unit	HLUC04, HLUC05, HLUC06, HLUC08, HLUC09, HLUC12, HLUC13, HLUC14	x	x	
KPI_SUC06_2	Flexoffer accuracy	HLUC09	x	x	
KPI_HLUC03	Reduction of interruption duration/ frequency	HLUC03		x	

4.3 KPI Calculations

The calculations of the individual KPIs are presented in detail in the following section. The presentation includes a short description of the KPI, the responsible party, the calculation, the unit, and the results/measurements. Finally, there is a brief interpretation of the success of the pilot project/HLUC. A detailed explanation of the individual KPIs, calculation methods and terms is provided in the document D 7.2 "Definition of the pilots, the validation methodology and metrics" [3].

4.3.1 Project-level KPIs

KPI	DOA_01: Distributed storage integration
Short Description	Distributed storage integration in the grid (per pilot): Capacity Energy
Responsible Party	SWW, SWH, EST, UCY
Results/ Measurement	The following tables (Table D, Table E) present the calculated flexibility for the German pilot on an asset basis and in total.

Table D: Calculations available Flexible Energy (SWH)

Storage Type	**Capacity (kW)**	**Annual Operation (Hours)**	**Annual Capacity (kWh)**	**Available Flexibility[2] (kWh)**
Jam Factory	300	8,760	2,628,000	300.00
Water Pump 1	45	1,882	84,690	9.67
Water Pump 2	45	1,955	87,975	10.04
Water Pump 3	45	1,918	86,310	9.85
Water Pump 4	32	3,344	107,008	12.22
Water Pump 5	32	3,460	110,720	12.64
Water Pump 6	32	3,470	111,040	12.68
CHP (natural gas)	400	2,200	880,000	100.46
CHP (natural gas & hydrogen)	340	1,500	510,000	58.22
SUM	**1,271**	**-**	**4,605,743**	**525.77**

Table E: Calculations available Flexible Energy (SWW)

Storage Type	**Capacity (kW)**	**Annual Operation (Hours)**	**Annual Capacity (MWh)**
Electrolyser	9,350	7,000	65,450
Heating Rod	1,100	4,380	4,818

[2] The available flexibility is calculated considering one hour availability for flexibility interventions per asset per day.

<table>
<tr><td></td><td>
<table><tr><td>SUM</td><td>10,450</td><td>-</td><td>70,268</td></tr></table>
In the case of the Spanish pilot, the total storage integration is approximately 1,700kWh offered from over 640kW of flexible distributed storage assets per month. This was calculated considering the following assets:

<u>Electric Vehicles</u>: The V2G charging demonstration was done with an EV emulator that has an infinite capacity, hence for the calculation we have taken an average 22kWh capacity from average V2G vehicles from the IEA global EV outlook 2020 report [6].
<u>Stationary batteries</u>: 10kVAh from the battery installed in the rural town of Vallfogona de Ripollès.
<u>Flexible loads</u>: Total flexible installed capacity 567.09kW from 5 industrial clients (see Annex A).

In Cyprus pilot, the aggregated distributed storage integration was 350KWh per day, providing by building cooling (Power2cold) and the batteries installed in the nanogrid.
</td></tr>
<tr><td>Target Value</td><td>Distributed storage integration in the grid (per pilot):
Capacity: 750 kW
Energy: 350 kWh</td></tr>
<tr><td>Interpretation regarding pilot</td><td>
<u>SWH</u>
Stadtwerk Haßfurt was able to provide a daily total available capacity of 525.77 kWh, slightly exceeding the target value of 350 kWh. This capacity was supplied by water pumps, CHPs and the jam factory's cooling system.
<u>SWW</u>
Two additional storage systems were integrated into the SWW system: the electrolyser can be used as a flexibility asset for the entire area; the Heating rod on the other hand is installed in the CHP located in Schönbrunn and is connected to an 80,000L water tank. The utilization of the heating rod can supply flexibility in both deficit and excess of energy generation/demand, allowing cross-sector integration.
<u>EST</u>
The achieved energy flexibility is above the target value whereas the capacity is a bit below. Even though there was less available capacity than targeted – which can be also attributed to problems in using the PED battery in the pilot - there has been a very positive response from the industrial clients offering a significant amount of flexibility.
<u>UCY</u>
The storage systems were successfully installed and operated under the requirements of FEVER. The target was not reached due to the scope and size of the pilot, but all relevant use cases were successfully demonstrated.
</td></tr>
</table>

KPI	DOA_02: Reduction of peak active power from V2G/EV
Short Description	V2G and EV management: Reduction of peak active power consumption of the grid

Responsible Party	UPC
Results/ Measurement	The maximum aggregated power the V2G chargers can provide is P'=7.2kW. Given the demand values measured during one month at the secondary substation CT0980, an average P = 53.39kW is used. Hence DOA_02 = 13.49%
Target Value	10 %
Interpretation regarding pilot	This KPI has been readjusted to fit in the ES pilot HLUC06 (Leveraging DER flexibility towards enhancing network operational efficiency), included in the LRA validation. Since the impact of two EVs in Granollers city would be imperceptible, it has been de-escalated to the consumption of a single transformation centre and its loads. The results are based on the validation tests performed on the two V2G chargers installed on site, using an EV emulator.

KPI	DOA_03: Power-2-X flexibility aggregated
Short Description	Power-2-cold flexibility steps power Maximum aggregated power2cold flexibility
Responsible Party	SWH
Results/ Measurement	The amount of energy required to move the refrigeration unit from the lowest operating point to the optimal operating point is 92.5 kWh, and the time required for this is 0.5 hours. $P_i = \frac{92.5\ kWh}{0.5h} = 185\ kW$
Target Value	Power-2-cold flexibility steps power: 200 kW Maximum aggregated power2cold flexibility: 1000 kW
Interpretation regarding pilot	Stadtwerk Hassfurt can provide a maximum aggregated Power2cold flexibility of 185 kW, which is well below the ambitious target value of 1000 kW. Unforeseen retrofitting of the cooling facilities in the pilot site of SWH have affected the size of controllable loads offered for FEVER demonstrations.

KPI	DOA_04: Distribution grid stability through responsiveness of flexibility services
Short Description	Time required to activate portion of load flexibility through DR services
Responsible Party	SWW
Results/ Measurement	The FEMS communicates every 1 minute. In this context there are two facts to consider: when the prosumer gets the schedule, the schedule is assigned

up to one minute earlier; when the prosumer gets the schedule, it takes until the next sending interval to report how the FEMS responded to that schedule.

Some possible sources of delay are: frequency of reading the power measurement from the power meter, sampling frequency of power meter, response time of the control system on site, "Inertia" of the equipment on site (either rotary or ramping limit of power change)

Table F: Examples of DOA_04 calculations

Time	Example 1	Example 2
Offer creation time	2023-11-09 07:45:05	2023-11-23 07:08:04
Offer received	2023-11-09 07:45:05	2023-11-23 07:08:04
Schedule assignment time	2023-11-09 07:45:49	2023-11-23 07:08:19
Prosumer status changed to "in activation"	2023-11-09 07:49:05	2023-11-23 07:11:04
Prosumer power measurement "jump"	2023-11-09 07:50:00	2023-11-23 07:10:00
Time to activate (power change)	4 min and 11 s	1 min and 41 s
Time to activate (status change)	3 min and 16 s	2 min and 45 s

Target Value	30min (>25% of DR) - 1hr (>50% of DR) - 24hrs (100% of DR)
Interpretation regarding pilot	Testing was performed to get both 'responsiveness' elements by assigning in real time to the adaptation start on the FTP. The communication frequency was set to 1 minute period, what resulted in 2min-3min responsiveness delay (responsiveness element 1)) and up to 1min delay to asset activation (responsiveness element 2)).

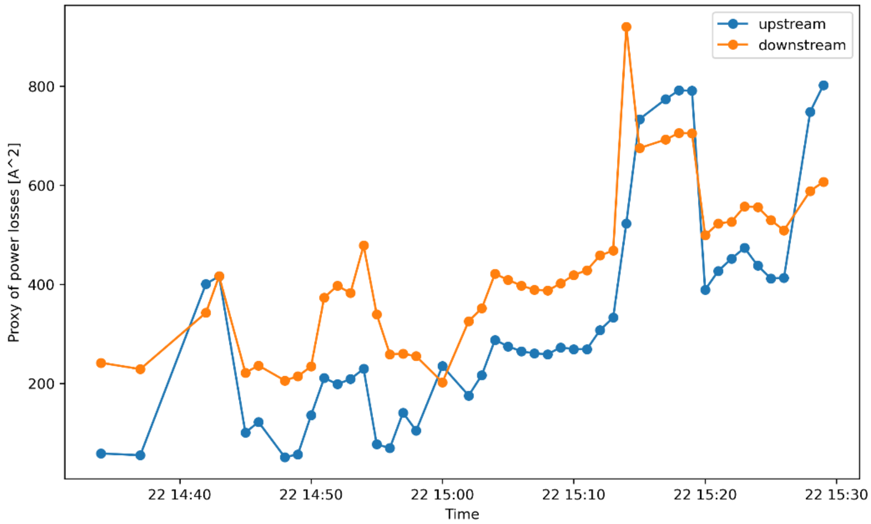
KPI	DOA_05: Flexibility of virtual energy storage
Short Description	Flexibility generated by virtual energy storage in demonstrated use cases (energy demand variation (delta MWh /h) with respect to peak demand (MWh/h)). It reflects the reduction of the peak demand.
Responsible Party	INEA
Results/ Measurement	**Pilot: Germany- SWW** All prosumers: 100% **Pilot: Germany- SWH** Jam Factory: 25% Water pumps: 4%

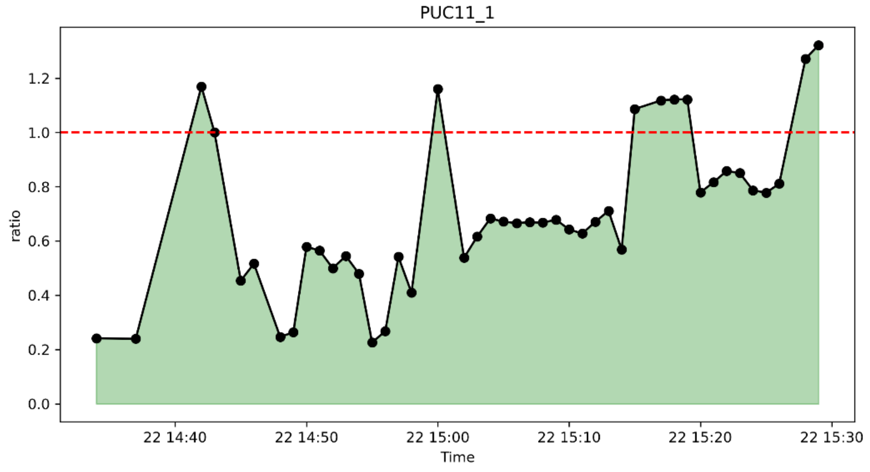
<table>
<tr><td></td><td>
CHP H2: 100%
CHP NG: 100%
<u>Pilot: Spanish- EST</u>
Table G: Flexibility of virtual energy storage
<table>
<tr><th>Flexibility Provider</th><th>DOA_05</th></tr>
<tr><td>Industry 1</td><td>77% +/- 45%</td></tr>
<tr><td>Industry 2</td><td>13% +/- 10%</td></tr>
<tr><td>Industry 3</td><td>40% +/- 30%</td></tr>
<tr><td>Industry 4</td><td>59% +/- 50%</td></tr>
<tr><td>Industry 5</td><td>52% +/- 30%</td></tr>
</table>
<u>Pilot Cyprus – UCY</u>
CBEMS: 30%
</td></tr>
<tr><td>Target Value</td><td>>15%</td></tr>
<tr><td>Interpretation regarding pilot</td><td>
All pilots achieve the envisioned target. More specifically:
SWW:
At the installation at demo site it was not possible to include the accounting meter, therefore the sum of controlled assets was used as a reference total. Since all consumption or production is assigned for flexibility, it results in a KPI value of 100%.
SWH:
25% comes from Jam factory which offers approx. 15kwh for 1h, while the total average daily consumption is around 60kW.
The water pumps are allowed to go to intervention max for 1 hour per day due to operation constraints.
The rest are in standby position and the flexibility also represents their consumption.
EST:
Harvesting flexibility from industrial processes, it was impossible to switch off all loads. The offered capacity was set to match consumption based on actual data acquired during sample adaptation periods.
Every prosumer offered flexibility every second day for 1 hour of the day to reduce intrusion of flexibility services participation with the business as usual operation. Loads under our control could be switched off for a period of 1h, but the total consumption did not drop to 0 due to loads not under our control.
KPI value was calculated for every prosumer for every hour which is the time duration of a single adaptation. The analysis concerns the period of flexibility activation between 01/09/2023 and 15/12/2023 and the average value of all prosumers was above target 15%.
</td></tr>
</table>

	UCY: For Cyprus, the KPI is large because provided flexibility is from the chillers, which represent the majority of consumption from the referenced energy center.

<table>
<tr><td>KPI</td><td>DOA_06: Critical event prediction (missed incidents)</td></tr>
<tr><td>Short Description</td><td>Critical event prediction (missed incidents)</td></tr>
<tr><td>Responsible Party</td><td>UdG</td></tr>
<tr><td>Results/
Measurement</td><td>False Negative Rate (FNR), or missed incidents, is a measure that measures the proportion of critical events that were inaccurately predicted as negative by our trained model.
Table H: False Negative Rate
<table>
<tr><th>Pilot</th><th>FNR</th></tr>
<tr><td>Spanish pilot - EST</td><td>6.98%</td></tr>
<tr><td>German pilot - SWW</td><td>16.55%</td></tr>
<tr><td>German pilot - SWH</td><td>12.76%</td></tr>
</table></td></tr>
<tr><td>Target Value</td><td><5%</td></tr>
<tr><td>Interpretation regarding pilot</td><td>This KPI is computed daily for the whole grid assessing the results of the Critical Event Prevention Application (CEPA) across different pilots.
The interest of the CEPA is predicting events that rarely occur. That means we want to be able to focus on predicting critical events but most of the time there is no critical event. This is called class imbalance and can be solved by using other metrics to complement it. In this sense, KPI_PUC01_2 shows other indicators about the performance of critical event forecasting while this KPI focuses on FNR.
<u>Pilot: Spanish Pilot- EST</u>
The pilot has oversized feeder lines, so the threshold for considering a Critical Event (congestion) has been fixed at 17% of the thermal limit of the lines (same for all the lines in the pilot’s grid).
The mean value obtained in the evaluated period is 6.98%, slightly above the established value. This deviation is mainly due to the error introduced by the energy forecasting models and the aforementioned reduction of the grid capacity, which causes to be working around that limit. The same situation will be repeated for the other pilots.
<u>Pilot: German Pilot - SWH</u>
The pilot has oversized feeders, so the threshold for considering a Critical Events (congestions) has been fixed in a 2% of the thermal limit of the lines (same for all the lines in the pilot’s grid).</td></tr>
</table>

	The mean value obtained in the evaluated period for the FNR is 12.76%. Although this is apparently a high value, this is due to the fact that the capacity has had to be artificially reduced to 2% of the maximum capacity because the grid is oversized. Therefore, we are faced with balanced consumption in the grid that oscillates around the established limit, which means that events can easily be detected or not. For example, using a 2.1% limitation, events are no longer detected. **Pilot: German Pilot - SWW** As in previous cases, this pilot has oversized feeders, so the threshold for considering a Critical Events (congestions) has been fixed in a 4% of the thermal limit of the lines (same for all the lines in the pilot's grid). The mean value obtained in the evaluated period for FNR is 16.55%. This apparently high value is due to the same reason as stated for the SWH pilot.

KPI	DOA_07: Losses reduction
Short Description	Losses reduction due to local use of energy (shift towards the "zero km" paradigm) and the optimal operation of storage converters (harmonic compensation, reactive power compensation, balancing).
Responsible Party	UPC
Results/ Measurement	During the time frame considered, the intensity of total current in each phase a,b and c, were measured upstream and downstream of the PED, during its compensation operations. The chart shows the behaviour of the KPI numerator (upstream-blue line) and the KPI denominator (downstream-orange line)  **Figure B: Index of power losses upstream and downstream the PED** That's the behaviour of the KPI.

	 **Figure C: Behaviour of DOA_07** $\bar{P}_{upstream} = 323.24\ [A^2]$ $\bar{P}_{downstream} = 425.75\ [A^2]$ $\overline{PUC11\_1} = 69.4\ \%$ On average, the mitigation action of PED is able to reduce by a 40% the intensity of total currents and therefore of the active power losses related to these currents. Please note that peaks of the KPI over 100% are due to PED setpoints being changed for active or reactive power injections. This causes new currents to be injected in the three phases by the PED which causes the increase of the upstream current with respect to the downstream current.
Target Value	>25%
Interpretation regarding pilot	The previous numbers and KPI calculations were taken and performed during an internal test day on the 22nd of November 2023. The test time window spans approximately between 2:00 PM and 4:00 PM. During these tests, the different operating conditions of the PED, present in the l'Esquirol site were tested and electrical quantities were measured thanks to the installed CVMs. Particularly, a CVM was placed upstream of the PED with the aim of measuring the output of PED operations (called "mitigated state") and another CVM, was placed downstream of the PED, intending to measure the grid in non-mitigated conditions. Please be aware that the l'Esquirol pilot does not present high levels of harmonics formation. The measuring equipment actually struggles in recording data of harmonics formation because of the low intensity of typical currents. This turns into a minor effect of harmonics on power quality, which is instead mainly affected by unbalances.

KPI	DOA_08: Short-term spatiotemporal forecasting errors
Short Description	Short-term spatiotemporal forecasting errors (RMSE)
Responsible Party	UCY, UdG

Results/ Measurement	**UCY**

UCY

For PV production the following error metrics were calculate:

RMSE = 7.5% and MAPE = 6.4%

UdG

Pilot: Spanish

In the case of the Spanish pilot, forecasting models have been created for 3 different localities (L'Esquirol, Vallfogona and Granollers), according to their variability in meteorology. In addition, as input to the CEPA, the consumptions of these 3 locations have been aggregated and the industrial customers have also been modelled (named Aggregated below). The average results for each of these cases are as follows:

Table I: EST Grid Numeric Results

Location	MAPE	RMSE
Aggregated	0.3749	14.935
L'Esquirol	0.7695	1.1052
Vallfogona	1.2811	0.9924
Granollers	0.8363	0.5801

Pilot: German- SWH grid

In this scenario data from 8 substations of the Germany pilot were used for training forecasting models and testing their performance.

Table J: SWH Grid Numeric Results

Node	MAPE	RMSE
HAS03	0.15	6.012
HAS05	0.079	7.645
HAS18	0.159	6.269
HAS19	0.21	5.241
HAS20	0.34	11.682
HAS26	0.19	3.261
HAS52	0.253	8.279
HAS74	0.263	1.648

Pilot: German- SWW grid

In this scenario data from 6 substations of the Germany pilot were used for training forecasting models and testing their performance.

Table K: SWW Grid Numeric Results

Node	MAPE	RMSE
Box Heizwerk	0.138	56.365
Burgstrasse	1.162	18.552

Larchenweg	0.676	21.173
Furthammer	3989.94	28.658
Bayreuther Strasse	0.257	7.479
Box Bayreuther	0.872	14.813

Target Value	<7%

Interpretation regarding pilot

UCY

The EF service of the CY pilot is active, and improvements are applied to further reduce the error. The MAPE value achieved the predefined target by staying below the 7% threshold for the forecasting EF service.

UdG

Spain - EST

The results obtained show that the error is significantly lower when consumptions are aggregated. This is a result to be expected when models created for residential areas have very low consumptions, since a single sample falling to zero introduces a bias in the MAPE metric for these models and results very high values. Usually, average consumption for households is below 3.5kWh per day and many of them are lower. As a simple example of such cases that raise the average error rate we look at the graph below. In this figure we can see how this node is behaving far too randomly, around zero, to actually be able to predict its consumption. Besides, this node oscillates a lot around zero due to its capacity to generate power, this alone would make the MAPE value really high.

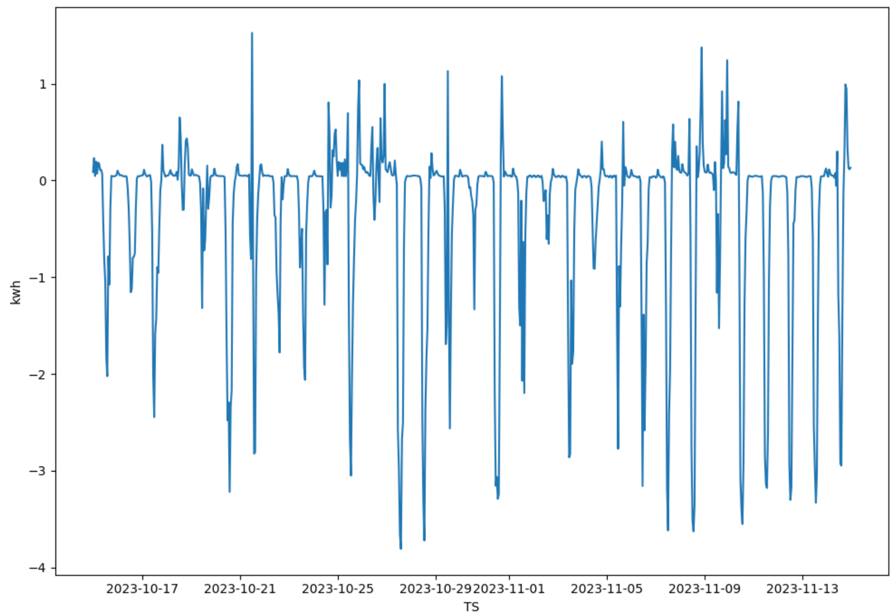


Figure D: Spanish Grid - Energy node with random profile

In general, however, the aggregate models used for the CEPA module perform quite well and are similar to the real values.

Germany - SWH

The data set has been used in different scenarios in order to analyse performance of the models when trained under different two operation conditions:

- "Windowing" or next-hour forecasting: the last sample from the previous hour is available (continuous sampling).
- Day ahead forecasting: The data for forecasting is available for two days before the forecasted day. This is the default configuration and refers to the use of data as if it were provided daily by smart meters.

Figure E shows the impact of the next hour forecast with respect to the day-ahead forecasting strategies that are typically applied when using smart meter data that only reports once a day.

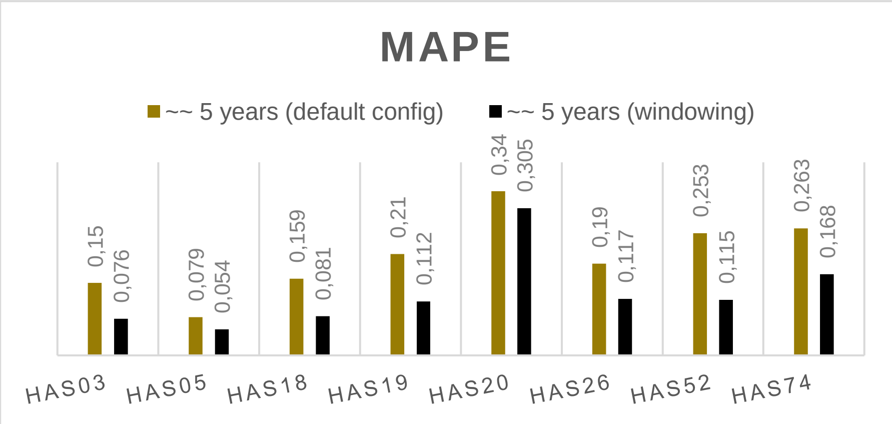


Figure E: SWH Grid Configuration Comparison MAPE

We can see that the improvements are significant as we can reduce the error by quite a large margin in some cases. We would be able to increase our forecasting accuracy when looking at the MAPE by almost 50% in the best case while in the worst case it would be an improvement of around 10% MAPE. This proves that the availability of close to real time data would really help to increase our forecasting accuracy.

We have also analysed the impact of historic data by using training data sets of different lengths. The next figure shows the MAPE values when the whole data set in the two scenarios previously described and how it is degraded when less data is used for the windowing scenario.

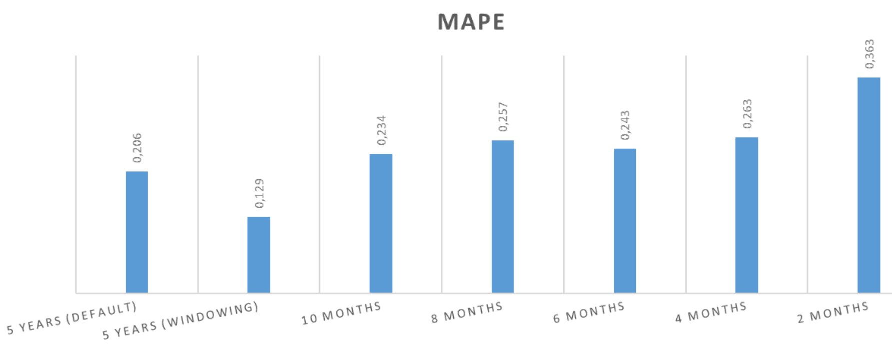


Figure F: SWH Grid Training Periods MAPE

We can see that the model with the best results is the one that uses the most data, 5 years, and also uses a configuration that is close to real time, windowing. It seems like using different periods of months of data does not really matter. However, training with less months (2-3) seems performance recovers a little. This fact could be attributed to changes in consumption patterns of the households depending on the time of the year.

We can conclude that the more data we have, the better the models will perform. On top of that, if we could have close to real time data, the models would perform even better.

Germany - SWW

As in the German SWH pilot, this section presents the analysis performed to assess the impact of the hour-ahead forecast with respect to the daily forecast. Typically, the daily forecasting strategy is applied when using data from smart meters that only report once a day.

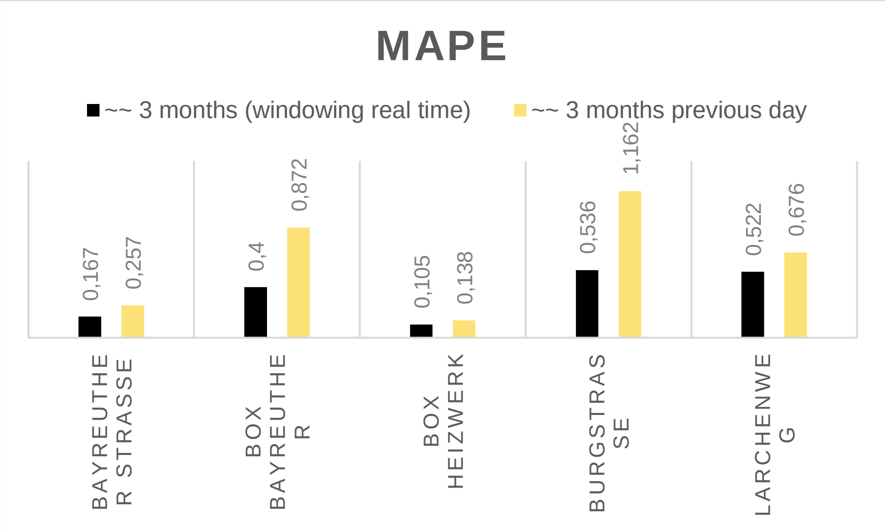


Figure G: SWW Grid Configuration Comparison MAPE

It should be noted that in the MAPE graph the result of the *Furthammer* substation has been omitted. This is because due to its high value it made the rest of the values difficult to compare. This high value is due to the fact that it is a point where there is imported energy and exported (or "negative") energy. However, a comparison of the graphs of the actual and predicted values shows that the prediction is good.

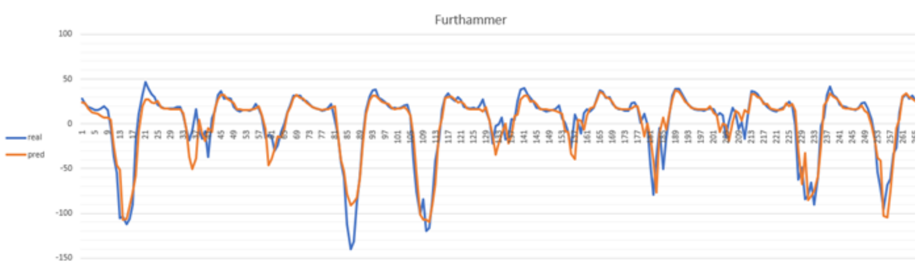


Figure H: SWW Furthammer substation. Prediction vs Real consumption

As in the previous case, it can be concluded that if real-time data were available, the models would work even better.

KPI	DOA_09: Peak demand reduction
Short Description	Peak demand reduction (ratio of average and maximal daily power)

Responsible Party	INEA
Results/ Measurement	**<u>Germany- SWW:</u>** 9-PIE-008: up to 18% 9-PIE-009: down to 36% 9-PIE-010: down to 35% 9-PIE-011: down to 41% 9-PIE-012: up to 91% and down to 20% 9-PIE-017 up to 14% "Up to" denotes a change in power increasing production or decreasing consumption, and "down to" the opposite. **<u>Spain - EST</u>** <u>Period: 01/09/2023 – 15/12/2023</u> Without adaptations we obtained using 15-minute P_max values the following K_peak values: Industry1: 4.3+/-1.3, Industry 2: 1.8+/-0.14, Industry 3: 5.8 +/-3.5, Industry 4: 1.9+/-1-3, Industry 5: 1.7+/-1.1. If adaptations were executed at peak times, the peaks would be potentially reduced by the offered flexibility capacity, i.e., by Industry 1: 2 kW Industry 2: 2kW Industry 3: 20 kW Industry 4; 46.7 kW Industry 5: 36 kW In this case K_peak values of 3.2, 1.7, 3.9, 1.3 and 0.95 would be achieved for Industries 1-5, respectively. If we compare these K_peak values with values without adaptations we obtain reduction of 25%, 5%, 33%, 32% 44% respectively.
Target Value	>15%
Interpretation regarding pilot	**SWH**: There are no interventions planned on the demo site, therefore only the potential is estimated: 1) Jam factory 45/25kW -> 40/25kW, 2) water pumps 160/100kW-> 120/100kW The baseline of the CHP's is P=0 The cause of large KPI values is fact that flexibility is not assigned to a real prosumer with consumption needs, but rather to the stand by loads ready for adaptation with its full capacity. **SWW**:

	Due to the lack of real interventions the KPI is calculated as a potential from capacity offers. **EST:** The use case in Spanish pilot was not to reduce the peaks of individual prosumers, but to reduce consumption when instructed by the DSO. This means that the adaptations did not necessary occur at peak consumption. Most loads under our control did not operate continuously, but when the production process demanded. We were able to shift production to time intervals with lower demand but could not influence the amplitude of peaks. Baseline K_peak is therefore equal to pilot period one.

KPI	DOA_10: Fault detection and localization (missed incidents)
Short Description	Fault detection and localization (missed incidents)
Responsible Party	UdG
Results/Measurement	Spanish Pilot Set up: Monitoring devices (CVM) are placed at the low voltage feeders (400V) in two secondary substations and provide data at sampling time of 15 seconds. The FDA module operates online with a sliding window of 5 minutes. Test: Two tests were performed. • Test 1.1: Fault detection. First with manually induced faults (operation of switchgears capable to connect and disconnect circuits) to emulate the high impedance faults by connecting/disconnecting large loads. • Test 1.2: Voltage monitoring in a feeder: Second test focuses on voltage monitoring and aims to report infrequent disturbances of voltage that propagate through the grid and that can be relevant to identify specific phenomena. Examples of interest are identifying short voltage variations over or down the recommended operational thresholds (affectation to quality of supply), identifying the tap changes in upstream transformers, or variations that could be caused by the volatility of PV generation in the area. Results Test 1.1: Performance to fault detection Results of this test in terms of proposed KPIs are the following. $Accuracy$= 0.9715 (97.2%) $Precision$= 0.9260 (92.6%) TPR= 1 (100%) FNR= 0 (0%) FPR= 0.0443 (4.43%) Test 1.2: Performance to detect voltage events in a feeder.

This test cannot be evaluated by the proposed KPIs, since they are not faults but just events of interest and the identification of them is purely informative for the DSO since it does not imply a misoperation of the grid.

Main events of interest can be classified as:

Long duration voltage level (Example 1)

Short duration voltage drop/rise followed by a sudden change (Example 2 and Example 3)

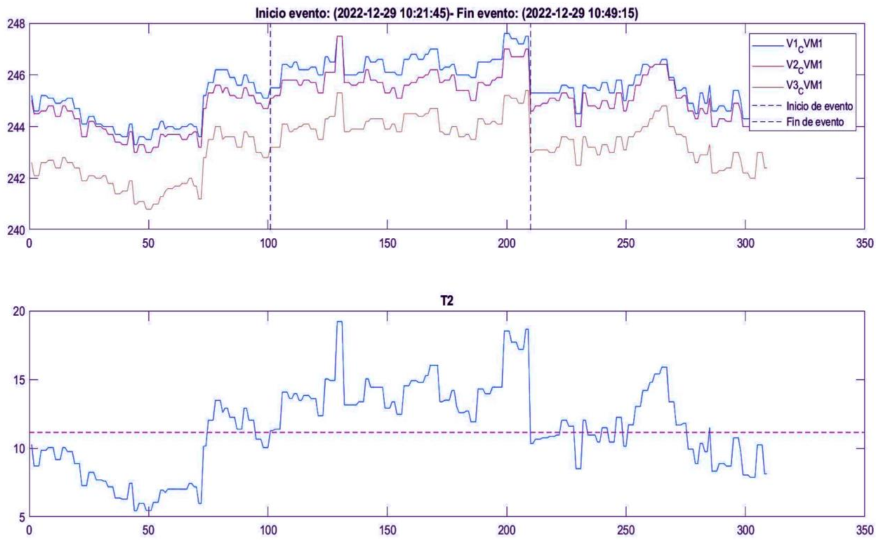


Figure I: Example 1: Long duration voltage level

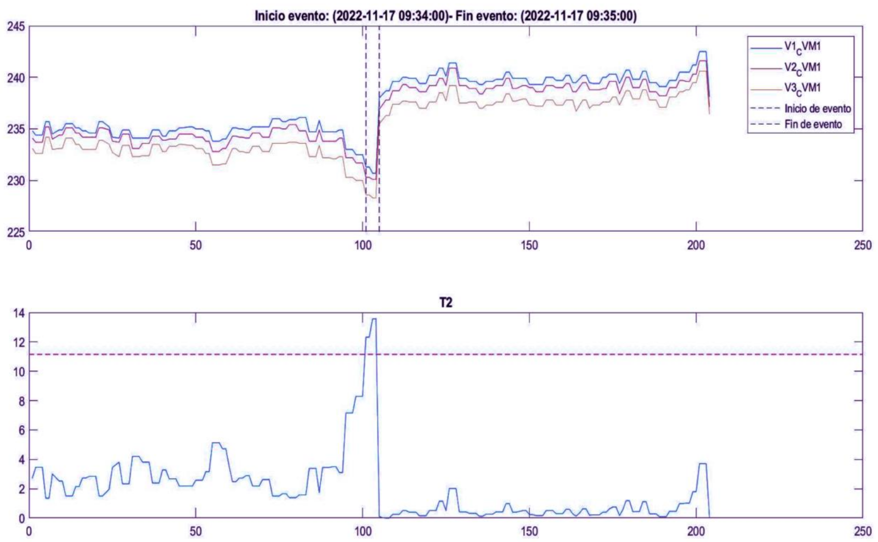


Figure J: Example 2: Voltage drop followed by a sudden change

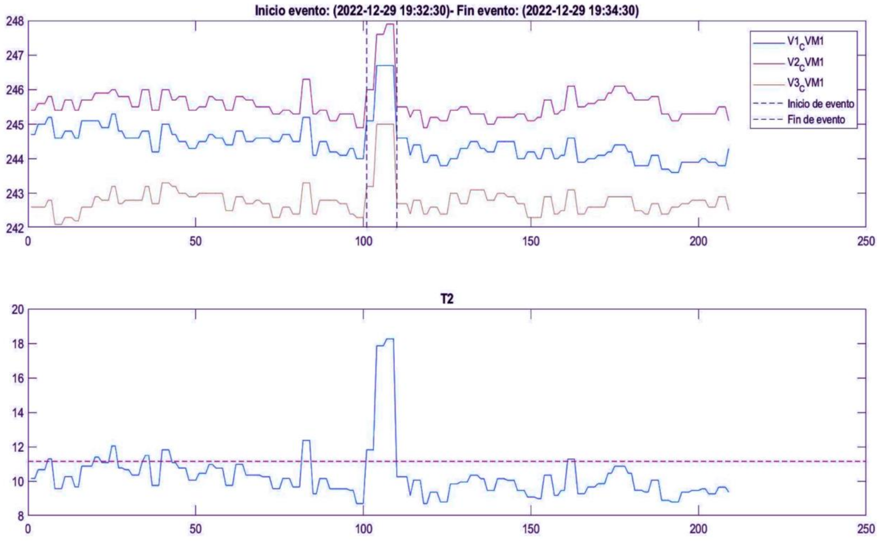


Figure K: Example 3: Voltage rise followed by a sudden change

German Pilot

Set up: Monitoring devices (PQMs) are placed at the busbar of secondary substations in the area of Schönbrunn. Data is only available offline. Five PQMs (corresponding to 4 substations) were used in the validation. The following table indicates these substations.

Table L: PQMS Substations

Breitenbrunner Strasse	PQM_1
Furthammer Schönbrunner Strasse	PQM_2
Schönbrunn Bayreuther Strasse Lang	PQM_3
Schönbrunn Box Heizwerk	PQM_5

The area presents a high-power quality in terms of voltage variations. It was observed that samples never go over the regulatory limits and statistical threshold were selected to detect infrequent events. Those events were analysed and a selection of the most representatives are reported below.

Tests: Two tests were performed.

- Test 2.1: Voltage monitoring in a substation: FDA module operates with data of a single PQM aiming to identify significant infrequent events. Four substations in the area of Schönbrunn were used in the analysis.
- Test 2.2: Wide area monitoring. Data from 4 PQMs installed in the secondary substations in the area of Schönbrunn and connected to the same MV grid were included in a single model. This strategy aims to detect upstream disturbances affecting the whole area.

Results:

Performance of Test 2.1 voltage monitoring at substation

This test cannot be evaluated by the proposed KPIs, since they are not faults but just events of interest and the identification of them is purely informative for the DSO since it does not imply a misoperation of the grid.

The most interesting events are:

Extreme voltage drop/rise: statistically extreme and infrequent values of voltage (inside of operational values): Example 4 and Example 5

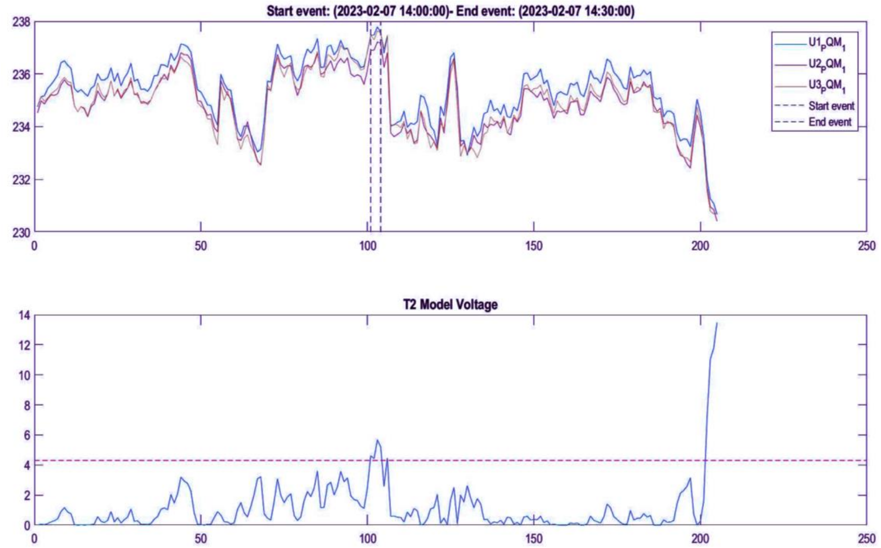


Figure L: Example 4: Extreme voltage rise

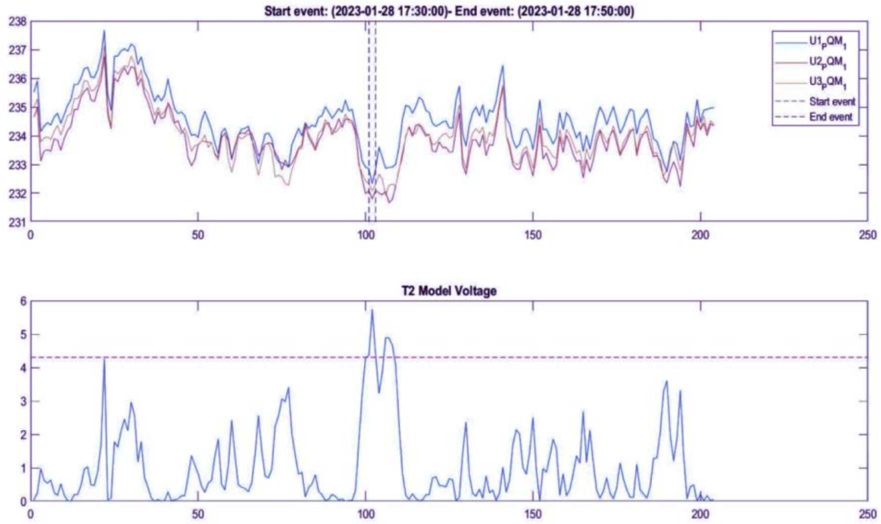


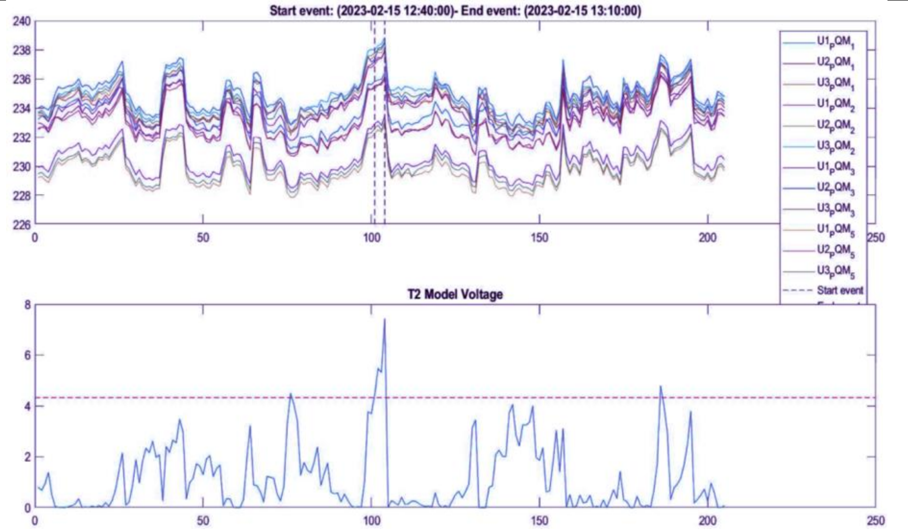
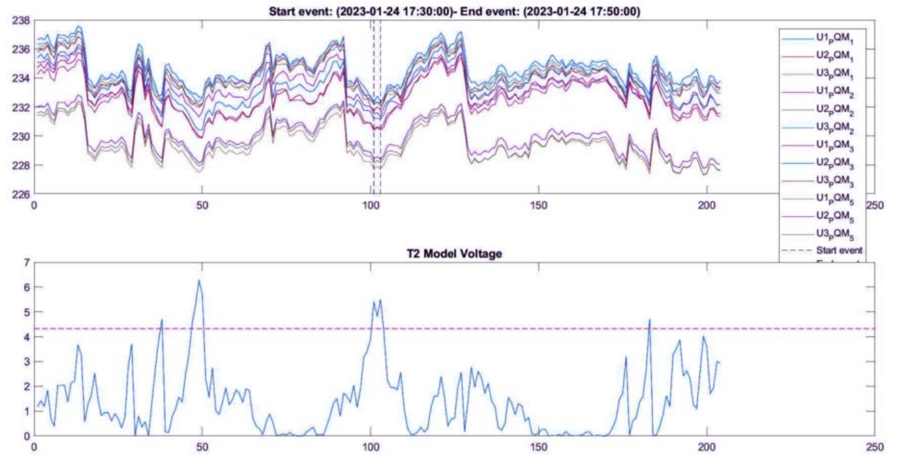
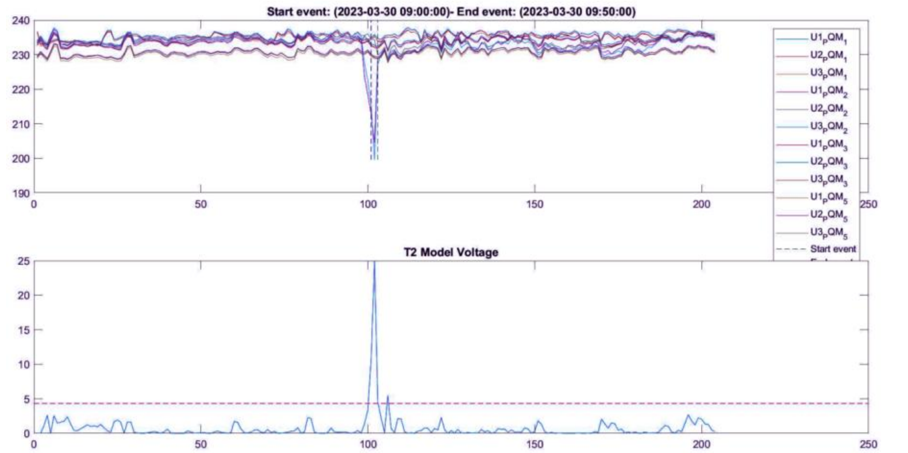
Figure M: Example 5: Extreme voltage drop

Performance of Test 2.2: Wide area monitoring

This test cannot be evaluated by the proposed KPIs, since they are not faults but just events of interest and the identification of them is purely informative for the DSO since it does not imply a misoperation of the grid.

The module has been demonstrated useful to detect three types of voltage variations affecting a wide area monitored by 4 substations.

Main events are the same as in the previous test, but they affect all the substations in a correlated way (example 6 and example 7) or some of them breaking the correlation (example 8).

	 Figure N: Example 6: Extreme voltage rise affecting the 5 substation  **Figure O: Example 7: Extreme voltage rise affecting the 5 substation**  **Figure P: Example 8: Extreme voltage drop affecting V1 and V3 in PQM2**
Target Value	<5%

Interpretation regarding pilot /HLUC success	The FDA module has been demonstrated to be versatile to be adapted to different monitoring conditions that range from Fault detection to voltage monitoring. Wide area monitoring allows monitoring multiple devices in the same grid with a single model instead of creating a single model for each substation. German pilot uses a time granularity of 10 minutes, which means that events to detect have to be larger than in the Spanish pilot. Online implementation requires a continuous flow of data that not always has been guaranteed in the pilots.
KPI	DOA_11: Peak demand reduction (MV/LV transformer)
Short Description	Peak demand reduction, as measured at the MV/LV transformer
Responsible Party	INEA
Results/ Measurement	**SWH**: 80% SWW: up to 48% and down to 61% "Up to" denotes a change in power increasing production or decreasing consumption, and "down to" the opposite. **EST**: Without adaptations the average 15-minute P_max value of the demo prosumer portfolio was 600 kW, while the average consumption was 290 kW which gives 2.1 for the K_peak. If adaptations were executed at peak times, the peaks would be potentially reduced by the sum of offered flexibility capacity of all prosumers, i.e. 106.7 kW, giving K_peak equal to 1.8 which is a 18% decrease in K_peak.
Target Value	>25%
Interpretation regarding pilot	**SWH**: The same interpretation as at DOA_09. At **EST** the larger KPI value will be achieved in summer, when the prosumers' solar production will decrease the absolute value of the peak. The project addressed for the demonstration only a portion of flexible assets. The target value could be achieved if the project would integrate all detected adaptation potential at the prosumers.

KPI	DOA_12: Increasing the RES hosting capacity at the distribution grid
Short Description	Increasing the RES hosting capacity at the distribution grid for protection of citizens from electrical outrages and other problems
Responsible Party	EST
Results/ Measurement	In case of the Spanish pilot the increase of hosting capacity is calculated locally for every LV network of the grid with flexible assets: industrial clients, IDPR and V2G. In each case the limiting maximum power has been selected between the admissible current of the smallest cable section or the capacity of the transformer. In Spain, the total rated power of the distribution grid

	should be lower than the 50% of the transformer rated power, lower than 50% of the thermal limit of the affected feeders, so we will consider in all cases a 50% safety factor. <u>V2G</u>: The V2G semi-fast charger of 22kW is connected to Estabanell's office transformer station through a limiting circuit of a 17mm² Cu cable with a 20A admissible current at 400V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{400 \cdot 20 \cdot \sqrt{3}}{1000} = 13.86\ kW$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum V2G = 1 \cdot 13.86 + 22 = 35.86kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = 158.77\%$$ As the charger is connected directly to an antenna, there is no safety factor, and the capacity is referred to the whole capacity of the line. Therefore, the available capacity of the grid is greatly increased in this particular case. <u>IDPR (10kW)</u>: In the case of the grid where the IDPR is connected the limiting power is a 95mm² Al cable with a 208A admissible current at 230V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{230 \cdot 208 \cdot \sqrt{3}}{1000} = 82.86\ kW$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum IDPR = 0.5 \cdot 82.86 + 10 = 51.43kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = -37.93\%$$ In this network there is no increase in capacity as the LV network is already over dimensioned. <u>Industrial clients</u>: IC1) For the first industrial client, with a 46.9kW flexible load available for the pilot, the limiting maximum power in the LV grid is a 240mm² Al cable with an 344A admissible current at 400V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{400 \cdot 344 \cdot \sqrt{3}}{1000} = 238.33\ kW$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum Pc = 0.5 \cdot 238.33 + 49.9 = 166.07kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = -30.32\%$$ In this network there is no increase in capacity as the LV network is already over dimensioned. IC2) With a 244kW flexible load available for the pilot, the limiting maximum power in the LV grid is a 240mm² Cu cable with an 1320A admissible current at 400V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{400 \cdot 1320 \cdot \sqrt{3}}{1000} = 914.52\ kW$$

	$$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum Pc = 0.5 \cdot 914.52 + 244 = 701.26kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = -23.32\%$$ In this network there is no increase in capacity as the LV network is already over dimensioned. IC4) With a 10.4kW flexible load available for the pilot, the limiting maximum power in the LV grid is a 16mm² Al cable with a 70A admissible current at 400V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{400 \cdot 70 \cdot \sqrt{3}}{1000} = 48.50\ kW$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum Pc = 0.5 \cdot 48.50 + 10.4 = 34.65kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = -28.56\%$$ In this network there is no increase in capacity as the LV network is already over dimensioned. IC5) With a 74kW flexible load available for the pilot, the limiting maximum power in the LV grid is a 240mm² Al cable with a 344A admissible current at 400V voltage level. $$P_{max} = V_{max} \cdot I_{max} = \frac{400 \cdot 344 \cdot \sqrt{3}}{1000} = 238.33\ kW$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot P_{max} + \sum Pc = 0.5 \cdot 238.33 + 74 = 193.17kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = -18.95\%$$ In this network there is no increase in capacity as the LV network is already slightly over dimensioned. IC3) For the last industrial client, with a 212.3kW flexible load available for the pilot, as it is connected directly in MV, the limiting maximum power in the LV grid is the 250kVA transformer at a 21500V voltage level. $$S_{max} = 250\ kVA$$ $$\Delta Hc = x \cdot P_{max} + P_{FEVER} = x \cdot S_{max} + \sum Pc = 1 \cdot 250 + 212.3 = 462.30kW$$ $$DOA_{12} = \frac{\Delta Hc - \% \cdot P_{max}}{\% \cdot P_{max}} 100\% = 84.92\%$$ As the client is connected directly to the transformer, we don't apply the safety factor, and the capacity is referred to the transformer capacity. It is the only case for industrial clients where the capacity is increased.
Interpretation regarding pilot	Traditionally the grid is greatly over dimensioned, and you would require very large flexible loads to see an increase of capacity. This means that the impact of PV and EV are still small in our LV network, as we will see a bigger impact as it grows. However, there are still two cases where the capacity does increase. One is at Estabanell's office, where the V2G chargers are connected to an antenna. This is a particular case due to its pilot-phase nature.

	Finally, in the case of the last industrial client, where the capacity is very well dimensioned for the client's demand directly connected in MV, we do see an expected increase in capacity, above the minimum targeted value of 25%.

KPI	DOA_13: Maximization of the use of infrastructures
Short Description	Maximization of the use of actual infrastructures through active energy management and balancing at LV level as reflected in CAPEX and OPEX
Responsible Party	EST

Results/ Measurement

On a first instance we will calculate the costs implied on the FEVER solutions. The calculation of this KPI will only take into consideration the initial investment:

Table M: Costs implied on the Fever solutions

Concept	Units		Unit Cost	Total
PED	1	units	72382.14 €	72382.14 €
Installation	27.5	hours	32.17 €	884.68 €
Integration & test	35	hours	41.72 €	1460.20 €
LV Switch Gear	3	units	1260.64 €	3781.92 €
Installation	16	hours	32.17 €	514.72 €
Integration	7	hours	37.08 €	259.56 €
Planned work	5	hours	35.81 €	179.05 €
CVM	9	units	174.66 €	1571.94 €
RUT-240	9	units	200.01 €	1800.09 €
Current Sensors	27	units	63.93 €	1.726.11 €
Installation	72	hours	32.17 €	2.316.24 €
Integrations	35	hours	41.72 €	1.460.20 €
V2G chargers	2	units	3000.00 €	6000.00 €
Installation	7	hours	32.17 €	225.19 €
Integration & test	10	hours	41.72 €	417.20 €
FEMS	5	units	3000.00 €	15000.00 €
Installation	16	hours	32.17 €	514.72 €
Integration & test	30	hours	41.72 €	1251.60 €
TOTAL				113,782.71 €

Adding up to a total of approximately 113.800€. Some considerations can be discussed for this calculation, on one side, many of these expenses are initial investments that will have a low operation and maintenance cost in the long run and lower investment costs in a more commercial phase of the product development. For example, the cost of the first PED was 72.382,14 € as stated, but it is foreseen that the commercial price will be around 35.000€.

Also, we could exclude the cost of the PED entirely as the Spanish pilot was unable to test its application due to the missing battery that could not be integrated. However, we will take into consideration this conservative value for the comparison with the normal operation nevertheless.

As mentioned, the approach on the calculation is based on the initial investment, as there is still not a clear estimation on the maintenance costs of the FEVER technologies, even though it is foreseen to be more economical than the normal operation maintenance knowing that the regulated average cost for maintenance for LV lines is around 600€/km and around 700€ for the transformers.

Also, the costs of the compensation for the flexibility activations for clients is also not included in this cost but should also be considered into the monthly operation costs with an average cost of around 100€/client per month. The summary of the compensation expenses for the Spanish pilot is summarised in the following table:

Table N: Summary of the compensation expenses for the Spanish pilot

	IC1	IC2	IC3	IC4	IC5	Total
Aug.	71 €	61 €	37 €	19 €	44 €	232 €
Sept.	50 €	257 €	223 €	11 €	55 €	595 €
Oct.	48 €	257 €	227 €	11 €	44 €	586 €
Nov.	53 €	262 €	254 €	11 €	45 €	624 €
Dec.	50 €	258 €	223 €	11 €	45 €	587 €
Total	272 €	1094 €	964 €	61 €	233 €	2,624 €

On the other hand, we must evaluate the normal operation costs. For each of the LV networks the flexible assets are connected to we have determined where is the limiting capacity, either on the admissible current of the smallest section cable from the line or the capacity of the transformer.

For the calculation of the KPI we have compared the regulated investment cost that would imply upgrading the limiting capacity of these networks either by changing to a bigger section cable of increasing the capacity of the transformer. For these we have consulted the Spanish regulation[3].

Table O: Normal operation costs

	Concept	unit		Cost		Total
IC1	Line	0.052	km	59,136	€/km	3,086 €
	Installation	20	hours	45	€/h	900 €
IC2	Line	0.005	km	59,136	€/km	270 €
	Installation	20	hours	45	€/h	900 €
IC4	Line	0.001	km	48,384	€/km	37 €
	Installation	20	hours	45	€/h	900 €

[3] https://www.boe.es/eli/es/o/2015/12/11/iet2660/dof/spa/pdf

<table>
<tr><td rowspan="10"></td><td rowspan="2">IC5</td><td>Line</td><td>0.052</td><td>km</td><td>59,136</td><td>€/km</td><td>3,102 €</td></tr>
<tr><td>Installation</td><td>20</td><td>hours</td><td>45</td><td>€/h</td><td>900 €</td></tr>
<tr><td rowspan="2">IC3</td><td>transformer</td><td>1</td><td>unit</td><td>30,598</td><td>€</td><td>30,598 €</td></tr>
<tr><td>Installation</td><td>30</td><td>hours</td><td>50</td><td>€/h</td><td>1,500 €</td></tr>
<tr><td rowspan="2">IDPR</td><td>Line</td><td>0.003</td><td>km</td><td>16,714</td><td>€/km</td><td>52 €</td></tr>
<tr><td>Installation</td><td>20</td><td>hours</td><td>45</td><td>€/h</td><td>900 €</td></tr>
<tr><td rowspan="2">V2G</td><td>Line</td><td>0.010</td><td>km</td><td>13,675</td><td>€/km</td><td>133 €</td></tr>
<tr><td>Installation</td><td>20</td><td>hours</td><td>45</td><td>€/h</td><td>900 €</td></tr>
<tr><td>Total</td><td colspan="6">44,177 €</td></tr>
<tr><td colspan="7">Initially the traditional remuneration system has a lower investment. However, this comparison of total cost would not be entirely fair as the FEVER technologies help regulate the whole LV network while the upgrade of a line only has a local effect to that one client. To have the same effect on the LV network we would have to multiply the final “business as usual” (BAU) cost by an average of 3 times, adding up to around 130,000€. For example, in the V2G case, currently in the pilot it is connected to Estabanell’s offices through an antenna. Increasing the section of that cable would only affect Estabanell, so, one client. However, in a commercial phase of the product development, a V2G charger could provide flexibility services to a whole neighborhood and affect multiple clients.

Also, on the upgrade of the transformer only the basic has been considered, investments costs would increase if we opted for a transformer with load regulation, being approximately 47,000€.

Not only in money, also in installation and integration time we can see that FEVER technologies have an easier and immediate installation compared to normal upgrades, to offer a bigger range of operation.</td></tr>
<tr><td>Interpretation regarding pilot</td><td colspan="7">The FEVER technologies can apply to larger areas of the grid, while the traditional upgrades have only a localized effect. Overall, the conclusion is that FEVER technologies are convenient and economically competitive with current solutions.</td></tr>
</table>

KPI	DOA_14: Increase Power Quality
Short Description	Power quality: local supply voltage profiles: amount of time outside 5% of nominal
Responsible Party	UPC
Results/ Measurement	To calculate this KPI the threshold has been changed to 4% since no deviations outside 5% of nominal were found. For a 4% deviation, and a 3-week average: $$DOA\_14 = t_{dev} = 0 + 21 = 21\ h$$ Maximum Deviation (under-voltage) – 0.9518 p.u (per-unit).
Target Value	1%

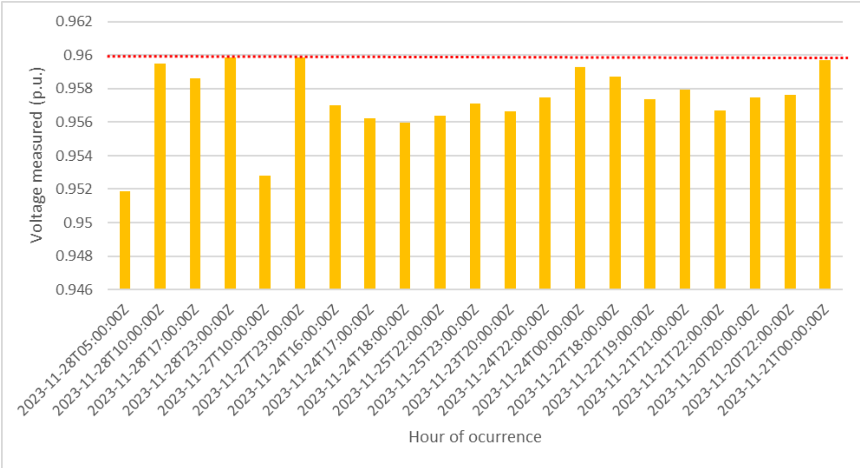
<table>
<tr>
<td>Interpretation regarding pilot</td>
<td>
Calculation is made automatically with a weekly time-window, based on the VCA results for real deviations found using SM data. For this report, a 3-week window was chosen to demonstrate the deviations found. The KPI indicates how many hours a week, deviations were found.
The graph provide a summary of all deviations found from 20/11 to 11/12, time in which the KPI was calculated.
Most of the deviations happened in the last week of November, no deviations found in December (until 11/12)


Figure Q: DOA_14 summary of deviations
It must be noted that all of these deviations happen in a single node number 2307, located in the rural area of the Vallfogona town in Spain. Although the number of deviations found is low, especially considering the initial 5% threshold, this is not due to flexibility activation but a demonstration of the DSO Toolbox monitoring capacities to show pilot’s behaviour.
</td>
</tr>
</table>

<table>
<tr>
<td>KPI</td>
<td>DOA_18: CO2 emission reduction</td>
</tr>
<tr>
<td>Short Description</td>
<td>Percentage reduction in CO2 emissions (concerning the values at the beginning of the project)</td>
</tr>
<tr>
<td>Responsible Party</td>
<td>UCY, EST, Es-geht!, SWH</td>
</tr>
<tr>
<td>Results/
Measurement</td>
<td>
UCY
CO2 Reduction for CY pilot (since the beginning of the project) = 6.3%
EST
In the Spanish mix CO_2 equivalent: 0,27 kg CO2eq/kWh [7]
Based on the Adaptation Report that includes all monthly flexibility adaptations from the industrial clients we observe a total of 653,28kWh* from all activations throughout the pilot. This means, the total amount of energy that has been reduced through flexibility.
Overall, the CO_2 reduction has been: $653.28 \cdot 0.27 = 176.39\ kgCO2eq$
Compared to the total foreseen capacity of approximately 11MWh this stands as a 5.85% reduction.
</td>
</tr>
</table>

SWW

In SWW the eq. CO2 reduction is calculated on an aggregate level

2019 (Before) = 797,730.24 tCO2eq

2023: (After) = 680,741.45 tCO2eq

$$CO_2 Reduction\ German\ Pilot\ SWW\ \frac{(797{,}730.24 - 680{,}741.45)}{797{,}730.24} = 0.146652064 \approx 14.7\%$$

SWH

Table P: Total quantity CO2 2019 SWH

2019				
Energy source	**Quantity**	**Unit**	**CO2-Äq. Kg/EH**	**Total quantity CO2 (kg)**
Electricity mix	38,802,865	kWh	0.266	10,321,562
CHP natural gas	2,018,257	kWh	0.420	847,668
Biomass	12,121,937	kWh	0.230	2,788,046
Wind	63,184,136	kWh	0.011	695,025
PV	11,542,405	kWh	0.066	761,799
Sum	127,669,600			**15,414,100**

Table Q: Total quantity CO2 2022 SWH

2020				
Energy source	**Quantity**	**Unit**	**CO2-Äq. Kg/EH**	**Total quantity CO2 (kg)**
Electricity mix	37,324,676	kWh	0.109	4,068,390
CHP natural gas	3,489,195	kWh	0.420	1,465,462
Biomass	12,539,035	kWh	0.230	2,883,978
Wind	58,812,833	kWh	0.011	646,941
PV	24,171,780	kWh	0.066	1,595,337
Sum	136,337,518			**10,660,108**

$$CO_2 Reduction\ German\ Pilot\ SWH = \frac{(15{,}414{,}100\ \mathrm{kg} - 10{,}660{,}108\mathrm{kg})}{15{,}414{,}100\ \mathrm{kg}} = 0{,}3084$$

=30,84%

Target Value	>10%

Interpretation regarding pilot

UCY

Reductions in the CO2 emissions were demonstrated since the beginning of the project, however, the CO2 reduction for the CY pilot will be estimated as soon as the flexibility trading is performed for the CY pilot.

	EST The CO_2 footprint of the energy mix at all the asset sites on the Spanish pilot has not changed over time as Estabanell Impulsa guarantees 100% renewable energy through PPAs and there were new assets installed since the beginning of the pilot. Therefore, the CO_2 emissions related to the shift of consumption through flexibility activations were considered instead. Even if the shift of the consumption doesn't directly imply a reduction it does guarantee the availability of that capacity in the grid that could be covered by the injection of distributed renewable generation on the grid. The 5.85% reduction does not reach the 10% target as there were fewer activations than expected. This has been mostly due to the difficulties engaging clients in changing their processes to offer flexibility. An economic remuneration was offered to increase this engagement. **SWW** Since the project's outset, SWW has prioritized investments in renewable energy capacity and optimization processes to tackle rising CO2 equivalent emissions from energy consumption. Through these efforts, SWW has achieved a notable 14.7% reduction in CO2 equivalent emissions. By expanding renewable energy sources and enhancing efficiency measures, SWW has diversified its energy mix, minimized reliance on fossil fuels, and optimized energy usage patterns. This reduction not only aids global climate efforts but also showcases SWW's commitment to sustainable practices and innovation in energy management. **SWH** At Stadtwerk Haßfurt, CO2 emissions have been reduced by 30.84% since the beginning of the project. Throughout the project, there has been a notable reduction in the electricity mix, particularly concerning the generated CO2 emissions, attributed to the energy community (LEC) and the Flexibridge. By adopting a grid-oriented approach by the FEMS (Jam Factory, CHP, Water Pumps) during sunny hours, the overall energy demand was optimized or reduced. The increased utilization of sunny hours also led to a change in the CO2 equivalent of the electricity mix, decreasing from 0.266 kg/EH in 2019 to 0.109 kg/EH in 2022. In this context, the Fever solutions are largely responsible for the significant reduction in CO2 emissions within the electricity mix.

KPI	DOA_19: Secure information and communication technologies
Short Description	Expresses the number of vulnerabilities detected in relevant scenarios to the solution
Responsible Party	ICOM
Results/ Measurement	The Common Vulnerabilities and Exposures (CVE) list will be used as a basis to detect possible vulnerabilities in the solution. Basic scenarios will be identified on the user of the system and the possible vulnerabilities will be scored based on a common vulnerability scoring system calculator. Based on these scores, the total number of vulnerabilities will be populated.

	Table R: Vulnerabilities
	(see table below)

#	Technology	Critical	High	Medium	Low	Total #CVEs	#CVEs during the project period
1	Django	9	29	62	2	102	32
2	nginx	2	19	19	0	40	5
3	ingress-nginx	0	5	3	0	8	8
4	Kubernetes	5	15	31	5	56	28
5	Spring Framework	0	3	7	1	11	0
6	Spring Security	4	8	7	0	19	10
7	Keycloak	5	26	46	4	81	54
8	Docker	2	26	21	4	53	23
9	RabbitMQ	1	5	9	0	15	7
10	PostgreSQL	7	63	78	7	155	26
-	**Total**	**35**	**199**	**283**	**23**	**540**	**193**

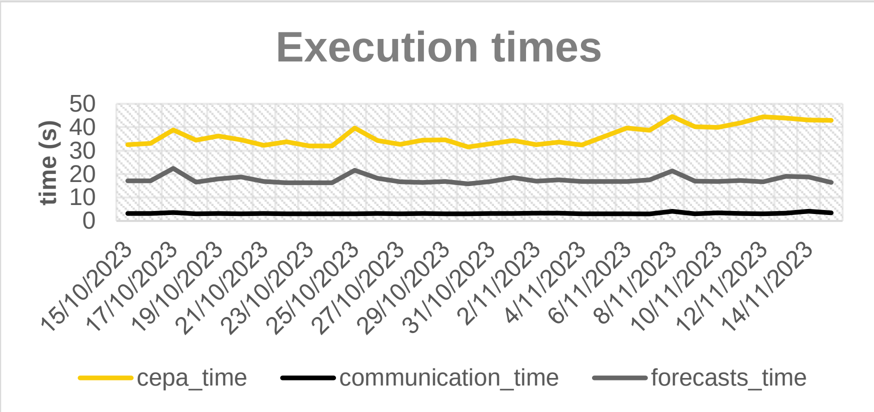
Target Value	According to CVE
Interpretation regarding pilot	Continuous monitoring and alarm is configured to ensure high availability of all the software solutions.

KPI	DOA_20: Integration performance
Short Description	This KPI is associated with several performance sub-indexes of the integration middleware: Throughput, Latency Time of completion Connectivity, Reuse
Responsible Party	ICOM
Results/Measurement	**Throughput**: Number of I/O transactions to the data repository of DSO Toolbox - flowing through the Integration Middleware (see D3.5). 6793 transactions/per hour. Max 1500 transactions /per second **Latency**: The time between when Integration Platform (see D3.5) receives a request and when it returns the response. It will be measured on a request-type basis. • GET mdms-service 40 days query 16.88s server response time

	• GET scada-service 5 days query 8.37s server response time • GET weather-service 40 days query 45ms response time • POST grid-event-service CEPA 202.18ms response time • POST grid-event-service VCA 198.15ms response time **Time of completion**: Percentage of processes where completion falls within +/- 5% of the estimated time completion. A baseline for each process will be calculated. • GET weather-service: The mean value is 42.25 and the percentage of values within ±5% of the mean is: 12.50% • GET mdms-service: The mean value is: 16.96 and the percentage of values within ±5% of the mean is: 100.00% **Connectivity**: Expresses the percentage of time where the different applications were connected to the middleware. This excludes downtime due to predicted maintenance. • forecast-Load: 95.082% • forecast-PV: 34.426% • grid-event-CEPA: 98.361% grid-event-VCA: 85.246% **Reuse**: Expresses the reusability of the processed developed in the middleware. Will be assessed via the number of authorised clients per process. • Group 1: Pushing data to platform: 6 services use this process • Group 2: Pulling data from platform: 7 services use this process • Group 3: Platform polling data: 3 services use this process
Target Value	This KPI is associated with several performance sub-indexes of the integration middleware: Number of transactions flowing through the bus (Throughput): 1500 per sec Percentage of processes where completion falls within +/- 5% of the estimated time completion: <5% Connectivity: 100% applications connected Reuse: 100% re-usage of reused processes Latency: Speed and processing throughput of transactions: 1ms (without proxy server) Throughput
Interpretation regarding pilot	Target values partially achieved: • Connectivity in Cyprus pilot faced challenges due to a cyberattack on UCY network infrastructure (not FEVER related) • Reusability was fully achieved • Throughput was enough to effectively support all pilot HLUCs • Throughput variation was higher than expected in some cases but with no impact on the demonstration of the HLUCs

4.3.2 Technical solution level KPI

KPI	KPI_PUC01_1: Responsiveness of close to real-time prevention

Short Description	Expresses the time required for identifying the potential violation and proposing the mitigation actions in the close-to real time scenario.
Responsible Party	UdG
Results/ Measurement	 **Figure R: Execution Times of CEPA** We can see that the time required to identify potential violations and proposing the mitigation actions is between 30 to 50 seconds, with little to almost no variability to the time it takes to communicate the possible events that are going to take place. While it is true that the time to execute the whole process always seems to stay below a minute, we can also report that before a certain date, the time it took to execute the entire process was considerably longer. The main reason that the execution time of the process has been lowered noticeably from mid-October forward is because of a lower communication time. Thanks to an improved communication time and a relatively low forecasting time, the CEPA is executed in less than a minute.
Interpretation regarding pilot / HLUC success	We can see that the time to execute the whole process always seems to stay below a minute. It is also noteworthy that the CEPA time seems to increase over time, however it coincides with the activation of additional code to record results as local files, mainly voltages and currents in the grid. Despite this, the whole process is still around one minute.

KPI	KPI_PUC01_2: Performance of critical event forecasting
Short Description	True positive, false positive (false alarms), true negative and false negative (missed detections) ratios of forecasted critical events.
Responsible Party	UdG
Results/Measurement	Accuracy is a global indicator that can be calculated as a ration between right detections over the total number of observations. True Positive Rate (TPR), also known as recall, is a metric that measures how often our trained model identifies correctly the critical events that did actually happen.

<table>
<tr><td></td><td>False Positive Rate (FPR), also known as false alarms, is a metric that measures the proportion of critical events that were inaccurately predicted positively by our trained model.

Table S: Performance of critical event forecasting
<table>
<tr><th>Pilot</th><th>Accuracy</th><th>TPR</th><th>FPR</th></tr>
<tr><td>Spanish pilot - EST</td><td>99.95%</td><td>93.01%</td><td>0.05%</td></tr>
<tr><td>German pilot - SWW</td><td>99.44%</td><td>83.44%</td><td>0.13%</td></tr>
<tr><td>German pilot - SWH</td><td>99.66%</td><td>87.24%</td><td>0.26%</td></tr>
</table></td></tr>
<tr><td>Interpretation regarding pilot /HLUC success</td><td>Results show a high accuracy, the reason is the high imbalance of outcomes in our class. That is to say, we have too many true negatives in comparison to the rest of possible occurrences and that is helping tilt this metric to 1.

Critical event forecasting has been tuned to reduce FNR that is the situations with existing critical events not detected, as a direct consequence is an increase of false alarms (FPR). However, the FPR values obtained are not very high as there are few false positives in proportion to the true negatives.

On the other hand, FNR and TPR are complementary, so given the FNR values seen in DOA06 the TPR values are as expected.</td></tr>
</table>

<table>
<tr><td>KPI</td><td>KPI_PUC02_1: Responsiveness of grid reconfiguration planning</td></tr>
<tr><td>Short Description</td><td>Expresses the time required for identifying and applying the series of commands of grid switchgear</td></tr>
<tr><td>Responsible Party</td><td>UdG, ICOM</td></tr>
<tr><td>Results/

Measurement</td><td>UdG:

Once a specific plan is available, its execution is not immediate, since it can be affected by many factors (e.g. validation by an operator, the refresh or cycle of the SCADA, communication delays, etc.).

In the case of the Self-Healing Application (SHA), the status of the pilot is checked every 60 sec. Computation and sending time is nearly irrelevant. A calculation based on the average of several measured times concludes that this time is approximately 1.25s.

On the other hand, the estimated time to change physically the state of a switch is between 2-3s.

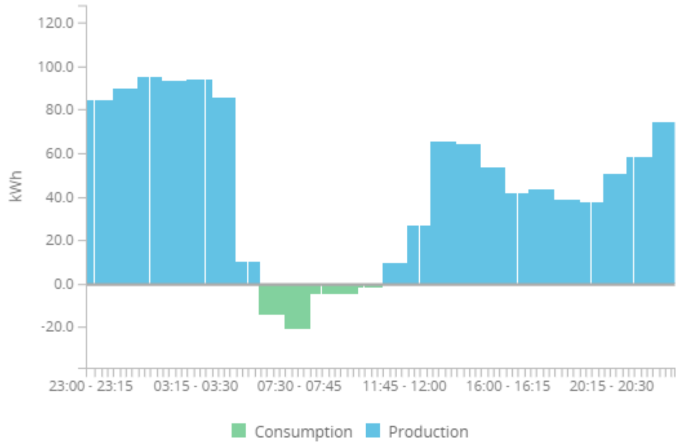
ICOM:

The process’s duration can range from 1 to 9 minutes, depending on the responsiveness of the toolbox on the end-user side validation and the number of retries need to complete the switchgear movements.</td></tr>
</table>

Interpretation regarding pilot / HLUC success	**UdG**: Measurements in the pilot are theoretically collected every 15s. However, the status capture of the switches is at least every minute (they can suffer delays of several seconds, i.e. observed until 18s). It can be concluded from the above that from the time a fault occurs until it is solved by interacting with the switches, in the worst case it can take about 1 minute, while in the best case it can take less than 10 seconds. **ICOM:** The range of the duration of the process is considered adequate for the scope of the HLUC04, aiming the continuation of the supply of a grid area for a period of time (constrained by the battery size) following a disruption, until it is resolved.

KPI	KPI_PUC02_2: Efficiency of grid reconfiguration planning
Short Description	Expresses the amount of valid dispatches of the plan, with respect to the total requested
Responsible Party	UdG
Results/ Measurement	**NA**
Interpretation regarding pilot /HLUC success	This KPI could not be calculated since reconfiguration is not possible for security reasons and has been tested only under controlled conditions, showing a 100% success rate in the tests performed.

KPI	KPI_PUC03_1: Amount of requested energy flexibility
Short Description	Expresses the total amount of energy deviation (ΔkWh) requested by a flexibility service consumer (e.g., DSO, BRP).
Responsible Party	INEA
Results/Measurement	**EST**

	 **Figure S: Amount of energy deviation Estabanell** DSO requests were obtained for day ahead with 15-minute time slot, and it consisted of production increase and consumption increase. In the period from 01.09.2023 to 15.12.2023 the total amount of requested consumption capacity was 188.2 MWh, while the total amount of requested production capacity was 52.1 MWh. Requests to reduce consumption were usually in the morning between 6 AM and 11 AM (UTC).
Interpretation regarding pilot /HLUC success	Since EST pilot site has oversized feeders, and thee threshold critical event prevention has been virtually reduced, the achieve volumes cannot provide much information for the current flexibility needs of the grid. In Estabanell requests to reduce consumption constitute 25% of their total what is still a significant amount much larger than available capacity in demo. Therefore, with the loads, which were included in the pilot, we were able to cover approximately 6% of the needs.

KPI	KPI_PUC03_2: Amount of delivered energy flexibility
Short Description	Expresses the total amount of energy deviation (ΔkWh) delivered in a response to a flexibility request
Responsible Party	INEA
Results/Measurement	**SWH**: 2485kWh per day **SWW:** 44.5 kWh per day **EST:** Period: 01/09/2023 – 15/12/2023 With the pilot we could cover only requested production capacity. In the test period the total amount of requested production capacity was 52.1 MWh. Daily requests had an average of 505 kWh with Full Width at Half Maximum (FWHM) equal to 980 kWh. The total assigned flexibility was 3.2 MWh with daily average of 17.2 kWh and FWHM equal to 13.3 kWh.

	Daily requests have significant variation, 980 kWh compared to the daily average of 505 kWh. On average 6% of requested capacity was assigned.
Interpretation regarding pilot /HLUC success	EST: Most of the offered flexibility was assigned. SWH: As explained in DOA_09 there were no real DSO requests therefore the upper limit estimation is given, SWW: As explained in DOA_09 there were no real DSO requests, therefore the simulated ones are used in a result. The result consists of production and consumption assignments total. The value is monthly average, where 2-3 interventions occurred per week.

KPI	KPI_PUC03_3: Total flexibility request cost
Short Description	Expresses the total flexibility service consumer (e.g., DSO, BRP) cost incurred for requesting flexibility services
Responsible Party	INEA
Results/ Measurement	**SWH** Up to 200 EUR per day **SWW** 111 EUR per month **EST** Period: 01/09/2023 – 15/12/2023 Fixed costs for flexibility assignments were used, equal to 0.132 EUR/kWh. Total assigned energy between 01.09.2023 to 15.12.2023 was 3.2 MWh, which gives 422 EUR. Total offered capacity in this period was 5.7 MWh which would cost 766 EUR if all was utilized.
Interpretation regarding pilot / HLUC success	There is no flexibility request planned in SWH, therefore only the upper limit is estimated. The result in SWW is the monthly average with adaptation performed 2-3 times per week. The adaptation price 0,08 EUR/kWh was used as provisional for testing. The real price was not specified due to the legislation constraints. It should be noted that consumers are not paid for the assigned energy but for the adapted energy which was significantly different since adaptations were done manually in some cases. In case of EST pilot customers were paid also for capacity reservation (0.07 EUR/kW/h). All prosumers offered reduced consumption for one hour every second day which gives 12 hours per month (0.84 EUR/kW/month). The power capacity was determined from nominal device values, which was 112 kW. This means that the cost of all prosumers is 95 EUR/month. Total costs for 5 prosumers were 215 EUR/month. The 215 EUR/month were built from the cost of reservation capacity in height of 95 EUR/month and the adaption costs in height of 120 EUR/month. The cost of capacity reservation (95 EUR/month) was 45% of total costs, while the cost of adaptations (120 EUR/month) would be 55% if all assigned energy was realized.

KPI	KPI_PUC04_1: Amount of offered energy flexibility
Short Description	Expresses the total amount of energy flexibility (in kWh) offered by the flexibility service provider.
Responsible Party	INEA
Results/ Measurement	**SWH** • Jam factory: 14kWh (day), 98kWh (week), 450 kWh(month) • Water pumps: 70kWh (day), 490kWh (week), 2200 kWh(month) • CHP H2: 1600kWh (day), 11200kWh (week), 50000 kWh(month) • CHP NG: 3200kWh (day), 22400kWh (week), 100000 kWh(month) **EST** Total offered production capacity in the test period of 01/09/2023 – 15/12/2023 was 5.7 MWh. Every prosumer offered flexibility every second day for 1 hour. The offered capacity per activation were as follows, • Industry 1: 2 kWh, • Industry 2: 2 kWh, • Industry 3: 20 kWh, • Industry 4: 46.7 kWh and • Industry 5: 36 kWh. **SWW**: • 3-PIE-003: 350kWh/day for production and -45kWh/day for consumption • 3-PIE-009: -25kWh/day for consumption • 3-PIE-011: -4kWh/day for consumption • 3-PIE-017: 6kWh/day for production and -10kWh/day for consumption UCY: Total offer flexibility was 330kWh per day
Interpretation regarding pilot / HLUC success	**EST**: The flexibility is provided from the domestic asset, air conditioning and several mechanical production devices, which basically does not provide large energy capacity. **SWH**: The flexibility is provided from cogeneration units with large capacity and water pumps, while coolant storage, despite its size, it does not provide significant flexibility due to low power. **SWW**: The adaptable assets were cogeneration unit, production device, photovoltaic, and heat pump. Largest flexibility capacity is provided by cogeneration unit.

KPI	KPI_PUC04_2: Amount of delivered energy flexibility

Short Description	Expresses the total amount of energy flexibility (ΔkWh) delivered by the flexibility service provider.
Responsible Party	INEA
Results/ Measurement	**EST** Total assigned energy in the test period of 01/09/2023 – 15/12/2023 was 3.262 MWh. Daily delivered assignments per prosumer were as follows: • Industry 1: 1.2 kWh, • Industry 2: 1.5 kWh, • Industry 3: 13 kWh, • Industry 4: 21.5 kWh and • Industry 5: 17.5 kWh **SWW** Total assigned energy in the test period of 01/07/2023 – 31/12/2023 was 5,02 GWh for production and -1,03GWh for consumption. Daily delivered assignments per prosumer were as follows: • 3-PIE-004: 3.25kWh/day, 25kWh/month (2-3 activations per week) • 3-PIE-004: -2.5kWh/day, -3kWh/month (2-3 activations per week) • 3-PIE-017: 3.5kWh/day and -0.5kWh/day, 29kWh/month and -1,8kWh/month (2-3 activations per week)
Interpretation regarding pilot / HLUC success	The assignments mostly followed the offered capacity, however it is smaller the maximal capacity, because the assignments occurred outside the intervals, where the maximal capacity was available.

KPI	KPI_PUC04_3: Total reward
Short Description	Expresses total reward obtained for issuing flexibility services.
Responsible Party	INEA
Results/ Measurement	**EST** Period: 01/09/2023 – 15/12/2023 Fixed costs for flexibility assignments were used, equal to 0.132 EUR/kWh. In addition, prosumers were paid also for capacity reservation (0.07 EUR/kW/h). Prosumers were paid for production adaptations while consumption adaptations were disregarded. Adaptations, capacity reservation and rewards are presented in the following table.

Table T: EST – Total Reward (PUC04_3)

	Adaptation (kWh)	Capacity Reservation (kW)	Rewards (EUR)
Industry 1	12.2	26.4	80

	Industry 2 | 0 | 1.7 | 5 **Industry 3** | 367.6 | 35.4 | 153 **Industry 4** | 62.4 | 7.8 | 31 **Industry 5** | 234.8 | 40.7 | 151 **SWW** • 3-PIE-004: 2.0 EUR/month • 3-PIE-004: 0.1 EUR/month • 3-PIE-017: 2.3 EUR/month
Interpretation regarding pilot / HLUC success	**EST** The rewards are significantly lower than expected, since not all assigned energy was realized. **SWW** Prices used in HLUC12 do not reflect the real situation because the retailor due to legislation constraints does not provide corresponding price list. The prices are set for the demo needs and activations were not compensated

KPI	KPI_PUC05_1: Prosumer reliability
Short Description	Describes how well certain flexibility providers deliver the traded flexibility
Responsible Party	INEA
Results/ Measurement	**EST** KPI was calculated for every prosumer for every 15-minute time slot for the period from 01/09/2023 to 15/12/2023. The aggregated values for the test period are as follows, • Industry 1: 60% • Industry 2: 0 • Industry 3: 100% • Industry 4: 30% • Industry 5: 50% **SWW** For HLUC12, some prosumer reliability is considered 0 as they were not responding to activation requests. • PIE-004: 100% • PIE-009: 5% • PIE-011: 0% • PIE-017: 100%
Interpretation regarding pilot / HLUC success	**EST** The KPI value 0 means the prosumer has not delivered, what has promised (or it has delivered in wrong direction). The value 100% means that realization might has exceeded the request (but the KPI is limited due to the

<table>
<tr><td></td><td>revenues). It should be noted that realization varied significantly from adaptation to adaptation for all prosumers which poses a problem grid balancing. Human factor is the main cause of this variability since all industries required a manual operation of the flexibility activation action. In the case of the industry with 0 reliability, the cause was a disruption of the communication with the human operator.

<u>SWW</u>

Underperformance is usually caused by stochastic components in measurements (i.e. PV production) however in this demo site human factor (disability of automatic control), and technical factors (communication device outage) reasoned the low KPI. On the other hand the over-performance (limited by 100%) occurred due to the systematic lower capacity estimation to provide some adaptation reserve.</td></tr>
</table>

<table>
<tr><td>KPI</td><td>KPI_PUC06_1: Congestion management effectiveness</td></tr>
<tr><td>Short Description</td><td>Average efficiency of congestion management actions.</td></tr>
<tr><td>Responsible Party</td><td>UdG</td></tr>
<tr><td>Results/
Measurement</td><td>A congestion is defined as an excess of current (I), over a threshold, I_{th}, in a specific asset (e.g. transformer, line segment).

The calculated indicators try to show the average effectiveness on congestion management based on reduction of current in the asset and reduction in the duration of the congestion time. The test was performed in the Spanish pilot.

Table U shows the days on which congestion has been detected and flexibility has been applied by any company, within the trial period.

Table U: Flexibility applied on congestion days. Columns equal the flexibility provider.
<table>
<tr><th></th><th>3-PIE-001</th><th>3-PIE-004</th><th>3-PIE-007</th></tr>
<tr><td>2023-10-04T08:00:00.000000000</td><td>nan</td><td>nan</td><td>20.67370</td></tr>
<tr><td>2023-10-04T09:00:00.000000000</td><td>nan</td><td>4.30860</td><td>nan</td></tr>
<tr><td>2023-10-06T08:00:00.000000000</td><td>nan</td><td>15.27540</td><td>5.60460</td></tr>
<tr><td>2023-10-24T08:00:00.000000000</td><td>nan</td><td>nan</td><td>7.21790</td></tr>
<tr><td>2023-10-24T10:00:00.000000000</td><td>nan</td><td>4.63270</td><td>nan</td></tr>
<tr><td>2023-10-26T08:00:00.000000000</td><td>nan</td><td>nan</td><td>15.83420</td></tr>
<tr><td>2023-11-08T08:00:00.000000000</td><td>nan</td><td>nan</td><td>nan</td></tr>
<tr><td>2023-11-09T09:00:00.000000000</td><td>nan</td><td>7.70530</td><td>nan</td></tr>
<tr><td>2023-11-09T10:00:00.000000000</td><td>nan</td><td>35.32530</td><td>nan</td></tr>
<tr><td>2023-11-10T09:00:00.000000000</td><td>2.31530</td><td>nan</td><td>nan</td></tr>
</table>
The results were calculated considering the days shown in Table U. The following two figures show these results.</td></tr>
</table>

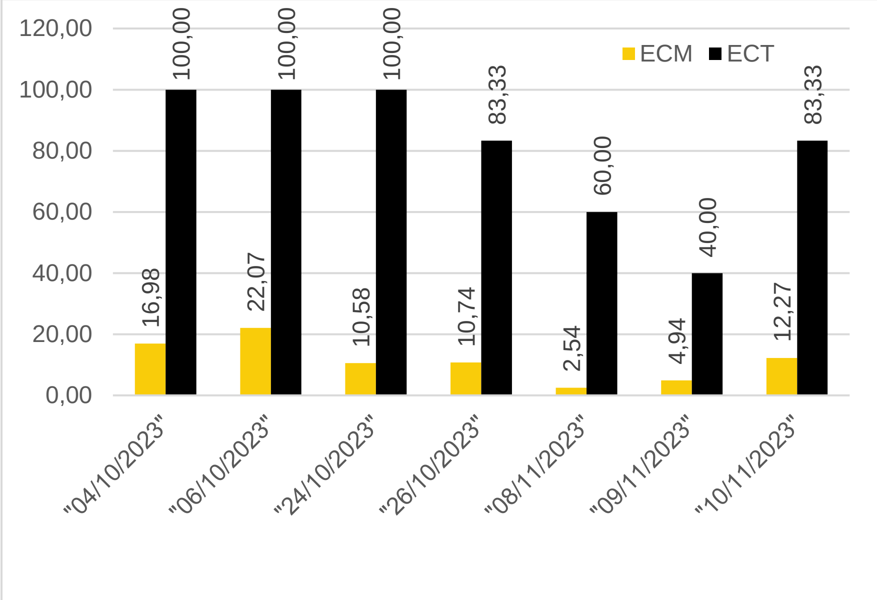
<table>
<tr>
<td></td>
<td>


Figure T: Effectiveness of Congestion management in Magnitude (ECM) and Effectiveness of Congestion management in Time (ECT). Values in %

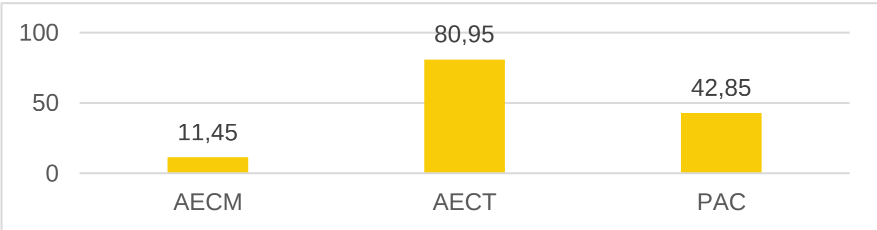


Figure U: Average of effectiveness of congestion management in magnitude (AECM), Average of effectiveness of congestion management in time (AECT) and Percentage of avoided congestions (PAC). Values in %
</td>
</tr>
<tr>
<td>Interpretation regarding pilot / HLUC success</td>
<td>The results support the application of flexibility in the pilot, as the number of congestions, either in terms of magnitude or duration, is considerably reduced.

It is noteworthy that out of 52 days of analysis, only 7 days were used for the calculations. This is due to the fact that only those days are used on which congestion occurs, and in turn, those on which flexibility has been applied by an industrial customer.</td>
</tr>
</table>

KPI	KPI_PUC06_2: Voltage compensation effectiveness
Short Description	Average efficiency of voltage compensation actions
Responsible Party	UPC
Results/Measurement	NA

Interpretation regarding pilot /HLUC success	Calculation is made automatically with a weekly time-window, based on the VCA results for forecasted and real deviations found using SM data. However, many challenges appeared when trying to activate reactive power flexibility. Not many assets were capable of provide reactive power and most important, these assets are installed at the substation and not close to where the voltage deviations frequently occur, which is the end of the feeder. For these reasons, even though reactive power flexibility has been requested and offered, no matching and therefore no real activation was possible. Therefore, the KPI calculations, which are based on measurements before and after activation, could not be computed.

<table>
<tr><td>KPI</td><td>KPI_PUC06_3: Loss compensation effectiveness</td></tr>
<tr><td>Short Description</td><td>Average efficiency of technical loss reduction actions.</td></tr>
<tr><td>Responsible Party</td><td>UdG</td></tr>
<tr><td>Results/ Measurement</td><td>This KPI aims to measure how technical losses can be reduced by reducing energy exchange with the main grid at substation level. Then, two sub-indicators, can be calculated:

Loss reduction due to reduction of imported energy (Energy > 0): When the consumption is higher than generation the secondary distribution network is importing energy.

Loss reduction due to reduction of exported energy (Energy < 0): When the generation exceeds the amount of demand and the exceeding energy is exported upstream of the substation.

The test was executed in the Spanish pilot and data from October and November were used for the calculation of the results.

Table V: IE and EE
<table>
<tr><th>Period</th><th>IE</th><th>EE</th></tr>
<tr><td>01/10/2023 – 27/11/2023</td><td>-5.03%</td><td>36.02%</td></tr>
</table>
</td></tr>
<tr><td>Interpretation regarding pilot /HLUC success</td><td>The results show how a loss reduction due to imported and exported energy is achieved. However, the reduction seems to be more significant due to exported energy. It should be noted in this last case that the result could only be calculated on the basis of a few hours over the entire period evaluated, as no more hours with energy exports were detected within this period.</td></tr>
</table>

KPI	KPI_PUC06_4: Self-healing effectiveness
Short Description	Average efficiency of self-healing reduction actions.
Responsible Party	UP, UdG

Results/ Measurement	NA
Interpretation regarding pilot / HLUC success	**UP** In the new scenario of SH with island management, the sequence of Smart Grids will be predefined. However, this does not hold significance. **UdG** This KPI has not been calculated as there were no actual faults in the grid. Neither during the course of the project nor during the field tests were any customers affected.

KPI	KPI_PUC06_5: Faulty feeder detection accuracy
Short Description	Expresses the forecast accuracy of the faulty feeder.
Responsible Party	UP
Results/Measurement	96%
Interpretation regarding pilot / HLUC success	The objective of the fault detection tool is to detect the faults occurring in the distribution grid. Hence, it is necessary to quantify the performance of the tool by calculating its accuracy regarding the detection of faulty feeders

KPI	KPI_PUC06_6: Faulty branch identification accuracy
Short Description	Expresses the forecast accuracy of the faulty branch.
Responsible Party	UP
Results/Measurement	Branch identification ranges from 95% for very small fault resistance values to 72% for high resistance value.
Interpretation regarding pilot / HLUC success	The branch identification shows that the range is about 23% from a high resistance value to a small fault resistance value.

KPI	KPI_PUC06_7: Distance error of fault detection
Short Description	Expresses the distance error between the actual location of the fault and the predicted one.
Responsible Party	UP
Results/Measurement	The error in distance ranges from 3% to 24% of the total normalized length of the branches, in case of small and high resistance values, respectively.

Interpretation regarding pilot / HLUC success	The error in distance ranges shows that the range is about 21% from the total normalized length.

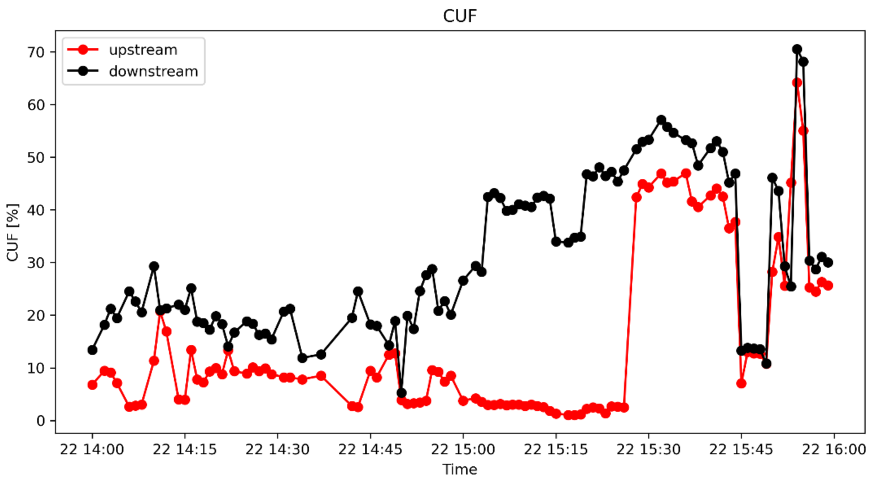
KPI	KPI_PUC07_1: Responsiveness of close-to real time prevention
Short Description	Expresses the time required for identifying the potential violation and proposing the mitigation actions.
Responsible Party	UPC
Results/Measurement	NA
Interpretation regarding pilot / HLUC success	During the project, some limitation arise regarding the availability of real-time data in the pilots. For this reason, most of the services were set to operate with historical data or on a day-ahead flexibility market (using data from the day before). These are based on forecast and predictions in a day-ahead scenario, hence solutions forecast future deviations and request flexibility for the following day. Having a day-ahead operation, the KPI losses its scope the time required to identify a potential violation and propose a mitigation action will always depend on the 24h of day-ahead with predicted deviations, and when the market matches the flexibility requests for activation. None of these time windows reflect the speed or responsiveness of the services, which was the initial intent of this KPI calculation, and therefore it was not computed.

KPI	KPI_PUC08_1: Islands detected
Short Description	Expresses the percentage of successful island detections.
Responsible Party	UPC
Results/Measurement	NA
Interpretation regarding pilot / HLUC success	During the project the HLUC03 was repurposed into HLUC05 since during the laboratory testing phase it was detected that most commercial inverter nowadays have anti-islanding protection that instantly triggers in case of no voltage reference is provided. Hence, no results are provided for the KPI.

KPI	KPI_PUC09_1: Responsiveness of close-to real time mitigation
Short Description	Expresses the time required for de-energizing the uncontrolled island after the mitigation request.
Responsible Party	UPC
Results/Measurement	NA

Interpretation regarding pilot / HLUC success	For similar reasons with KPI_PUC08_1 the KPI was not calculated.

KPI	KPI_PUC09_2: Islands mitigated
Short Description	Expresses the percentage of successfully mitigated uncontrolled islanding situation problems
Responsible Party	UPC
Results/Measurement	NA
Interpretation regarding pilot / HLUC success	For similar reasons with KPI_PUC08_1 the KPI was not calculated.

KPI	KPI_PUC10_1: Power Quality Indicator
Short Description	Expresses the percentage of improvement of power quality indicators thanks to PED mitigation strategies.
Responsible Party	UPC
Results/Measurement	Here a snapshot of the KPIs recorded during the test day in l'Esquirol is given. First the behaviour of the Current Unbalance Factor (CUF) is provided. The downstream signal (black) shows the intensity of current unbalances recorded by CVM8 in the "non-mitigated" zone, as if the power quality mitigation PED was absent. The red signal instead shows the CUF index after the PED mitigation. At 15:30 PM the PED has been disconnected, and the CUF level on the upstream side (red line) aligned back to the black signal, showing the end of the compensating action of the PED.  **Figure V: Current Unbalance Factor**

This is the behaviour of the calculated KPI (PUC10_1) which corresponds to the CUF % change between the upstream “mitigated” zone and the downstream “non-mitigated” zone.

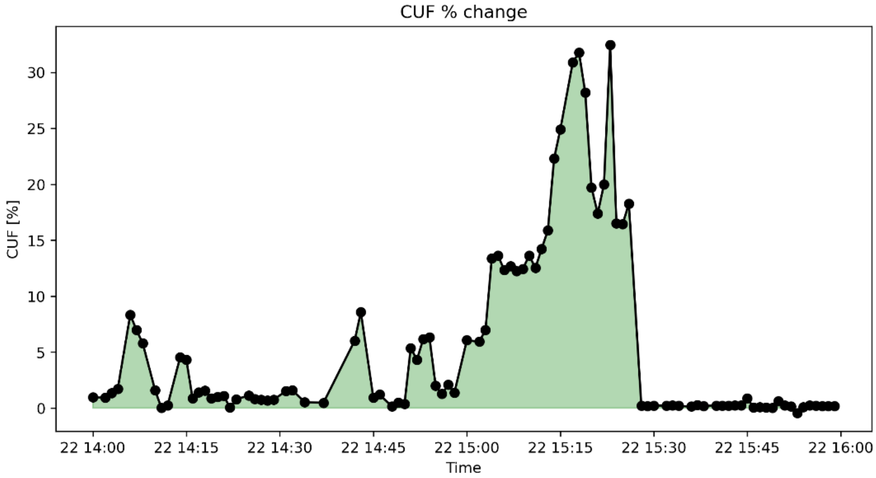


Figure W: Current Unbalance Factor % change

During PED compensations, the PUC10_1 reached a peak of almost +30% improvement of quality indicators for the pilot.

Considering the amount of time, the PED has been ON and compensating quality issues, the following were recorded:

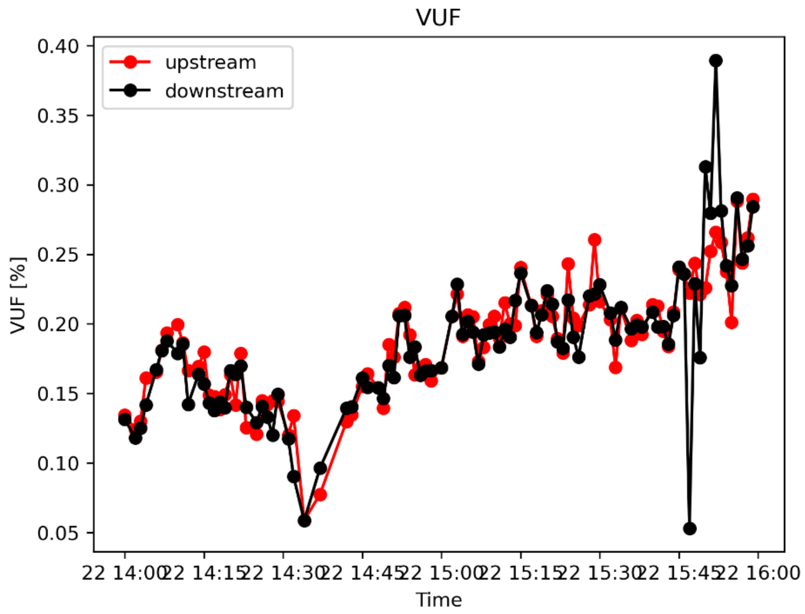
$$\overline{CUF}_{downstream} = 4.51\ \%$$

$$\overline{CUF}_{upstream} = 30.84\ \%$$

$$PUC10_1 = \overline{CUF}_{change} = 85.37\ \%$$

On average, the current unbalance factor is improved by more than 80% when the PED compensation service is active.

On the other hand, while the VUF% change has been recorded, it has been acknowledged that voltage unbalances do not play a major role in power quality issue for the current pilot in analysis. Voltage deviations are typically small and quite balanced as the VUF chart below suggests.

	 **Figure X: Voltage Unbalance Factor**
Interpretation regarding pilot / HLUC success	The previous numbers and KPI calculations were taken and performed during an test made on the 22nd November 2023. During this day, the flexibility activation of the PED located in the L'Esquirol site were evaluated. The PED harmonic and unbalances compensation have been set off during few minutes in order to showcase the impact of its compensation. The tests time window spans approximately between 14:00 PM and 16:00 PM. During these tests the different operating conditions of the PED were tested and electrical quantities were measured thanks to the installed CVMs. Particularly, the CVM placed upstream the PED with the aim of measuring the output of PED operations (called "mitigated state") and the one placed downstream the PED, with the aim of measuring the grid in non-mitigated conditions. In summary, the PED were successfully compensating harmonics and phase unbalances and therefore increasing power quality.

KPI	KPI_PUC11_1: Improvement of power quality
Short Description	Expresses the reduction of losses due to reduction of harmonics and reduction of imbalances in presence of lack of power quality.
Responsible Party	UPC
Results/Measurement	Please refer to DOA_07.
Interpretation regarding pilot / HLUC success	Please refer to DOA_07.

KPI	KPI_PUC12_1: Responsiveness of self-healing

Short Description	Expresses the time required for identifying the fault and proposing the mitigation actions.
Responsible Party	UdG
Results/ Measurement	The different times proposed as indicators cannot be calculated precisely, but an estimate can be made taking into account the following factors: • In the case of the Self Healing Application (SHA), the status of the pilot is checked every 60 sec. Computation and sending time is nearly irrelevant. A calculation based on the average of several measured times concludes that this time is approximately 1.25s. • The estimated time to change physically the state of a switch is between 2-3s. • Measurements in the pilot are theoretically collected every 15s, while the status capture of the switches is at least every minute.
Interpretation regarding pilot / HLUC success	It can be concluded from the above the following estimated times: • Time required to identify the fault (TTI): 1-61 seconds • Time required to propose a mitigation plan (TTM): 1.25 seconds • Time required to extinguish the fault (TTE): 10-71 seconds According to Spanish regulation the quality of service is accounted by the indexes called TIEPI and NIEP (time and Number of interruptions equivalent to the installed power). Those indexes consider all the interruptions (programmed and non-programmed) with a duration longer than 3 minutes (180 sec). So the implementation of SHA (time to extinguish the fault between 10-71 sec) avoids including those faults in the computation of NIEPI and TIEPI, resulting on an effective improvement of these indices.

KPI	KPI_PUC13_1: Loss reduction
Short Description	Percentage of loss reduction w.r.t BAU.
Responsible Party	UdG
Results/Measurement	Please refer to KPI_PUC06_3
Interpretation regarding pilot / HLUC success	Please refer to KPI_PUC06_3

KPI	KPI_PUC22_1: Target SoC reached
Short Description	Expresses the percentage of target State of Charge (SoC) reached.
Responsible Party	UPC
Results/Measurement	PUC22_1 = 100%

Interpretation regarding pilot /HLUC success	The target SoC was calculated with simulations, and it is one of the objectives of the GEMS. When a EV is disconnected after trading flexibility it will always be fully charged, hence 100% SoC. The test was also performed on-site against an EV emulator. Still, since this device has infinite capacity, a synthetic capacity limit had to be added to the charger software to allow it to achieve a SoC of 100%.

KPI	KPI_PUC22_2: Economic benefit of using FEVER EV charging
Short Description	Expresses the economic benefit of using FEVER EV charging.
Responsible Party	INEA
Results/Measurement	Flexibility gain: 4kWh*(0.0432 – 0.03) EUR/kWh = 0.0528 EUR Charging cost: 3.8kWh * (0.03) EUR/kWh = 0.114 EUR KPI_PUC11_1 = 0.46 %
Interpretation regarding pilot / HLUC success	Although the V2G chargers were installed and their power capacity (7.2 kW) validated using an EV emulator, there are no real dedicated EV's and therefore no real flexibility has been traded yet. For this reason, the KPI calculation is based on reported flexibility and is rather potential (if realization would exactly follow the offer), than actual value. The offer prices are set to incentives used in industrial sector as they are consuming on demand.

KPI	KPI_PUC27_1: Daily Number of interventions
Short Description	The number of interventions within 24 h to compensate for deviations from planning.
Responsible Party	SWW
Results/Measurement	NA
Interpretation regarding pilot / HLUC success	Due to the high amount of generation occurring in the grid of SWW, balancing issues caused by lack of power fed-in into the grid has not been executed. Locally produced energy is being used locally and will always be prioritised, so in case of too much power being generated and fed-in, the excess electricity will be fed-in into the power grid of the upstream DSO. As a result, there aren't any interventions available as there is no demand.

KPI	KPI_PUC27_2: Amount of needed energy flexibility

Short Description	Amount of needed energy flexibility
Responsible Party	SWW
Results/Measurement	NA
Interpretation regarding pilot / HLUC success	Not calculated for the same reason as KPI_PUC27_1.

KPI	KPI_PUC27_3: External procurement
Short Description	Internal prioritization of own generation, storage and flexibility depending on price signals; External procurement below the specified value
Responsible Party	SWW
Results/Measurement	The assumption is that it will be used 4380 h/a The load shifting potential can be regarded as: $1.1\ MW \times 4380 \frac{h}{á} = 4{,}818 \frac{MWh}{á} = 4{,}818{,}000 \frac{kWh}{á}$ $\frac{1{,}984{,}500\ €}{5{,}924{,}126\ kWh} = 0.33\ €/kWh$ $\frac{492{,}000€}{5{,}924{,}126\ kWh} = 0.11\ €/kWh$ The calculation in Schönbrunn (HLUC13 sector coupling) includes calculations of utilisation of a 1.1 MW heating rod. An electrical flexibility potential of 4,818,000 kilowatt-hours (kWh) is currently accessible. In year 2022, the generated revenue from electricity amounted to €1,984,500, while revenue from heating reached €492,200.
Interpretation regarding pilot / HLUC success	There is a very high excessive generation as the installed capacity is very high. There aren't any interventions available as there is no demand due to this reason. However, regarding the costs to make the prioritization, the cost of electricity can be determined by dividing the electricity revenue by the total electricity consumption, resulting in an approximate value of €0.33 per kWh. The local execution of power consumption is contingent upon electricity prices prevailing in the power exchange markets. The criterion for utilizing internal power generation for sector coupling is dependent on the comparative cost-effectiveness of heat production from the pellets boiler, factoring in Operational Expenditure (OPEX), in relation to the calculated electricity price of €0.33 per kWh. Consequently, internal power consumption for sector coupling will persist as long as the cost of heat production remains below €0.33 per kWh. For the heating sector, a similar threshold can be established by dividing the revenue from heating by the corresponding heating consumption, yielding an approximate threshold price of €0.11 per kWh.

KPI	KPI_PUC29_1: Critical loads connectivity
Short Description	Critical loads which need to remain connected in islanding operation.
Responsible Party	UCY
Results/Measurement	5%
Interpretation regarding pilot / HLUC success	5% of the total critical loads of the CY pilot site should remain connected during the islanding mode of the pilot. No issues were demonstrated with the critical load during the demonstration period.

KPI	KPI_PUC29_2: Frequency regulation
Short Description	Frequency to be retained within limits in islanding operation.
Responsible Party	UCY
Results/Measurement	200ms
Interpretation regarding pilot / HLUC success	A portion of the CY pilot grid becomes electrically isolated (nanogrid) from the main grid but continues to operate. During islanding, the isolated section the nanogrid manage its own power generation and load balance without external support from the main grid. The time required to balance the frequency of the CY pilot are 200 ms and within the limits to keep the grid from running.

KPI	KPI_PUC29_3: Voltage regulation
Short Description	Voltage to be retained within limits in islanding operation.
Responsible Party	UCY
Results/Measurement	10
Interpretation regarding pilot / HLUC success	During islanding, the CY pilot requires 10 seconds to retain the voltage stability (within limits)

KPI	KPI_PUC29_4: Power supply continuity
Short Description	Expresses the continuous supply of power to customers' loads in islanding operation.
Responsible Party	UCY

Results/Measurement	SAIFI = 0.111, SAIDI = 0.49
Interpretation regarding pilot / HLUC success	The SAIFI, SAIDI and T_MED metrics will be recalculated when additional activations will occur. However, based on the first results the 3 metrics are considered as successful for the CY pilot site during the islanding operation.

KPI	KPI_PUC29_5: Flexible loads
Short Description	Expresses the number of flexible loads available in the pilot area.
Responsible Party	UCY
Results/Measurement	15
Interpretation regarding pilot / HLUC success	15% of the total loads of the CY pilot are flexible loads that can used to trade flexibility.

KPI	KPI_PUC29_6: Trading flexibility
Short Description	Number of flexible loads implemented for trading flexibility.
Responsible Party	UCY
Results/Measurement	18
Interpretation regarding pilot / HLUC success	18 of the flexible loads of UCY were implemented and prepared to trade flexibility for the CY pilot.

KPI	KPI_PUC29_7: Operation cost
Short Description	Change of operation cost due to the management and trade of flexibility.
Responsible Party	UCY
Results/Measurement	9652
Interpretation regarding pilot / HLUC success	Improved operational cost based on the suggestions for flexibility based on the project's solutions suggestions.

KPI	KPI_PUC31_1: External Procurement

<table>
<tr><td>Short Description</td><td>Internal prioritization of own generation, storage and flexibility depending on price signals</td></tr>
<tr><td>Responsible Party</td><td>SWH, SWW</td></tr>
<tr><td>Results/Measurement</td><td>
Calculations are presented below for the German pilot. The weight is composed of the respective share of the total operation hours.
<u>SWH</u>
Table W: Internal prioritization (SWH)
<table>
<tr><th>System Type</th><th>“Clean” generation price per kWh</th><th>Operation hours 2022</th><th>Weight</th></tr>
<tr><td>CHP</td><td>18.1</td><td>42.557</td><td>78%</td></tr>
<tr><td>Wind</td><td>3.2</td><td>6.616</td><td>12%</td></tr>
<tr><td>PV</td><td>8.5</td><td>5.736</td><td>10%</td></tr>
</table>
$\bar{x}_{\omega'} = 18{,}1 ct. \times 78\% + 3{,}2 ct. \times 12\% + 8{,}5\ ct. \times 10\% = 15{,}30\ ct./kWh$
<u>SWW</u>
Table X: Internal prioritization (SWW)
<table>
<tr><th>System Type</th><th>“Clean” generation price per kWh</th><th>Operation hours
2022</th><th>Weight</th></tr>
<tr><td>PV</td><td>6.5 ct</td><td>1300</td><td>11%</td></tr>
<tr><td>Wind</td><td>2 ct</td><td>2300</td><td>20%</td></tr>
<tr><td>CHP bio</td><td>20 ct</td><td>8000</td><td>69%</td></tr>
</table>
$\bar{X}_{\omega'} = \bar{x}_{\omega'} = 6.5\ ct. \times 11\% + 2ct. \times 20\% + 20\ ct. \times 69\% = 14.92\ ct./kWh$
</td></tr>
<tr><td>Interpretation regarding pilot / HLUC success</td><td>
<u>SWH</u>
The Energy mix costs in SWH was at 15,30 ct./kWh.
As long as the energy mix stays lower than the price offered by external providers, power will be consumed locally first.
<u>SWW</u>
The Energy mix costs in SWW was at 14.92 ct./kWh.
As long as the energy mix stays lower than the price offered by external providers (i.e., die EC in SWH), power will be consumed locally first.
</td></tr>
</table>

KPI	KPI_PUC32_1: Transaction processing throughput

Short Description	Expresses the throughput of transaction processed by the platform. The platform should be scalable and able to process high throughput of these (at least 5 per second), incurred by different peers.
Responsible Party	FLEX
Results/Measurement	• 7.38 Authorization transactions/sec • FlexCoin transactions/sec • 1.08 FlexTrading transactions/sec (new bid creation)
Interpretation regarding pilot / HLUC success	Our throughput measurements show that our current P2P-FTP deployment/setup used in FEVER offers transaction throughput rates, which are acceptable for real-world applications. Here, user authorization transactions are fastest (7.38 transactions/sec); FlexCoin transactions are slightly slower (3.85 transactions/sec) due to involved HLF machinery (endorsing, etc.); FlexTrading transactions are slowest (1.08 transactions/sec) due to involved HLF machinery, and also due to (internationally) distributed transaction processing using external chain code services (deployed in separate EU countries);

KPI	KPI_PUC32_2: Number of peers
Short Description	Number of peers that are actively participating in the peer to peer trading, by requesting and offering flexibilities.
Responsible Party	FLEX
Results/Measurement	<u>Demo 1 - Centralized flexibility trading using FTP and FlexCoin DAPP:</u> 11 simulated prosumer users 2 DSO users <u>Demo 2 - Decentralized electricity trading using FMS and FlexTrading DAPP:</u> 12 users 1 EC Operator
Interpretation regarding pilot / HLUC success	For Demo 1, we currently have 11 simulated prosumer users (peers) actively participating in centralized flexibility trading using FTP and FlexCoin DAPP. They actively generate flexibility offers (FlexOffers) which are then matched against those from other peers and 2 participating DSOs. During this demo, authorization and FlexCoin transactions are continuously being generated and stored on an HLF. For Demo 2, we have a community of 12 active smart-plug users (peers) from SWW & SWH. Each peer buys electricity in FlexCoins within a single energy community based on actual power readings from 12 (of 21 available) smart-plugs via FMS. In this demo, a single energy community operator acts as an aggregator and sells electricity at a pre-defined fixed FlexCoin price to all of these peers. During this demo, authorization, FlexCoin, and FlexTrading transactions are continuously being generated and stored on an HLF.

KPI	KPI_SUC01_1: Performance of forecasting
Short Description	Accuracy of the forecasting: Mean absolute percentage error (MAPE)
Responsible Party	UCY, UdG
Results/Measurement	Please refer to DOA_08
Interpretation regarding pilot / HLUC success	Please refer to DOA_08

KPI	KPI_SUC02_1: Data received
Short Description	Percentage of data received vs expected per period.
Responsible Party	ICOM
Results/Measurement	• MDMS: 92.78% • SCADA: 46.53% • WEATHER: 100%
Interpretation regarding pilot / HLUC success	The completeness of the dataset is adequate for supporting the operation of HLUC01-07. The reduced amount of completeness for SCADA data, relates to specific periods where the communication disruption (i.e. CVM, PED, m2m), which was eventually resolved. Since historical data from SCADA are not accessible, the missing data could not be retrieved upon communication restoration. In regard to the MDMS data, there were only a few days where the data completeness didn't allow the operation of CEPA/LRA (HLUC01/06)

KPI	KPI_SUC02_2: Availability of data received
Short Description	Percentage of data received in the expected refreshing period.
Responsible Party	ICOM
Results/Measurement	• MDMS: 92.78% • SCADA: 46.53%
Interpretation regarding pilot / HLUC success	The availability of the dataset is adequate for supporting the operation of HLUC01-07, as analysed in the SUC02_1. In case of incompleteness of SCADA data due to periods of communication disruption (e.g., CVM, PED, m2m) that were resolved by interpolation and/or gathering data afterwards.

KPI	KPI_SUC02_3: Consistency of data received
Short Description	Percentage of consistent data
Responsible Party	ICOM
Results/Measurement	MDMS: 92.78 % SCADA: 46.52 %
Interpretation regarding pilot / HLUC success	The availability of the dataset is adequate for supporting the operation of HLUC01-07. The number of outliers was very limited, hence this metric is almost equivalent to KPI SUC02_1.

<table>
<tr><td>KPI</td><td>KPI_SUC04_1: Performance of planning</td></tr>
<tr><td>Short Description</td><td>Measured in terms of improvement of the optimisation criteria.</td></tr>
<tr><td>Responsible Party</td><td>UdG</td></tr>
<tr><td>Results/Measurement</td><td>
This KPI measures the improvement achieved with respect the situation resulting of not applying any optimization, obtaining the IOC index (Improvement of the Optimisation Criteria).
The index has been calculated considering those days when no congestion event was detected, that is, when the optimization algorithm operated. The total number of these days for the evaluated period is 33.
Table Y: Performance of planning
<table>
<tr><th>Period</th><th>IOC</th><th>Days</th><th>Working days</th></tr>
<tr><td>01/10/2023 – 31/10/2023</td><td>112.58%</td><td>10</td><td>0</td></tr>
<tr><td>01/11/2023 – 29/11/2023</td><td>104.36%</td><td>23</td><td>14</td></tr>
</table>
</td></tr>
<tr><td>Interpretation regarding pilot / HLUC success</td><td>An improvement from the optimisation algorithm can be seen through the IOC index. Surprisingly, however, the indices for each month are quite different. A more detailed observation showed, that for October all days analysed were public holidays, while for November most days are working days. This justifies this difference as the total consumption on working days is much higher (Figure Y) and difficult to adjust.</td></tr>
</table>

	 **Figure Y: Example of one week consumption and forecasted data.**

KPI	KPI_SUC05_1: Asset state response time
Short Description	Asset monitoring response time is defined and respected (within agreed limits)
Responsible Party	INEA
Results/Measurement	<u>**EST**</u> The response time is bellow measurable period 1minute. <u>**SWH**</u> • Jam factory: not applicable (not participating in adaptations) • Water pumps: 120 sec • CHP H2: 60 sec • CHP NG: 60 sec <u>**SWW**</u> The assets responded within 2-3 minutes
Interpretation regarding pilot / HLUC success	<u>**EST**</u> Response time is adequate for the HLUCs of the project. In the use case in EST the adaptations were mainly manual where the prosumer were informed a day ahead and visually once again an hour ahead. Therefore, in the successful cases the assets were sometimes adapted even a bit earlier then required. However, there were several cases with no response due to human factor. <u>**SWH**</u> Jam factory is not applicable since the asset control is not integrated. The result is interpreted in DOA_04 <u>**SWW**</u> The result is interpreted in DOA_04

KPI	KPI_SUC05_2: Asset control reaction time

Short Description	Asset control reaction time is defined and kept (within agreed limits)
Responsible Party	INEA
Results/Measurement	**EST** The response times were between 1-2 minutes **SWH**: • Jam factory: not applicable • Water pumps: 180 sec • CHP H2: 120 sec • CHP NG: 120 sec **SWW:** The assets responded within 3-4 minutes
Interpretation regarding pilot / HLUC success	The result is interpreted in DOA_04 And in SUC05_1

KPI	KPI_SUC06_1: Number of Flex offers per time unit
Short Description	Expresses a total number of Flex-Offers generated within a time unit
Responsible Party	INEA
Results/Measurement	**EST** Period: 01/09/2023 – 15/12/2023 Flex offers were generated every second day for a1-hour period. They were sent one day in advance to be confirmed by the prosumers. **SWH** • Jam factory:12 per day • Water pumps: 1 per day • CHP H2:6 per day • CHP NG:6 per day **SWW** HLUC12 prosumers are generating 4 offers per hour, 96 per day
Interpretation regarding pilot / HLUC success	**SWH** The devices are available 24/7. The flex offers are delivered according to asset operation constraints **SWW** The flex offers are generated all the time and their status is updated every 15 minutes **EST** Flex offer generation is adapted to the use case, which requires day-ahead assignment and prosumer's confirmation.

KPI	KPI_SUC06_2: Flex offer accuracy
Short Description	Accuracy of Flex offers: MSE between predicted baseline energy and actual consumed energy
Responsible Party	INEA
Results/Measurement	**SWH**: • Jam factory: 0,21 • Water pumps:0,17 • CHP H2: - • CHP NG: - SWW: • PIE-004: 0.22 • PIE-009: 0.31 • PIE-009: 0.59 • PIE-017: 0.02 **Pilot: EST** The prosumers' KPI s were as follows: • Industry 1: 0.41, • Industry 2: 0.03, • Industry 3: 0.32, • Industry 4: 0.14 and • Industry 5: 0.06.
Interpretation regarding pilot / HLUC success	**SWH**: The accuracies of Jam factory and water pumps are high due to the relatively low and consumption and stochastic operation. CHPs are stand-by assets therefore baseline is not applicable. **SWW**: Industrial prosumer should have large consumption with very predictable profile. Larger value is related to the photovoltaic production, which has larger stochastic component. **EST**: In addition to the baseline models, its accuracy depends on stochastic variations in consumption. More stable consumption result in lower KPI. Larger values are related to resistance buildings with large stochastic component. The rest are industrial, where one representative also has a large photovoltaic installed.

KPI	KPI_HLUC03: Power continuity
Short Description	Reduction of individual average interruption duration / frequency index
Responsible Party	EST

Results/Measurement	
Interpretation regarding pilot /HLUC success	This KPI was defined to study the impact of FEVER technologies on the LV network of the case study where a battery to operate in island mode with the PED was planned to be installed. However, it was not possible to install the battery and therefore it has not been possible to measure this KPI. Also, the external automatic operation of SG is not allowed by the DSO and only supervised on-site tests could be performed to validate the communications. The original idea was to calculate the reduction of fault time by using the islandic mode. However, the number of non-planned interruptions on the grid are minimum. In MV in 2022 there were 16 interruptions in the whole municipality of the use case, with only 2 interruptions significantly over 3min that is accepted by regulation. Accumulated, it is permitted up to 6h a year of interruptions and the municipality only accounted for 0.46h. In the worst-case scenario, a 10min interruption, there could be an improvement of 7min with the use of FEVER technologies. In conclusion, for the pilot testing there would were to produce faults artificially.

Table Z: Maximum Islanded operation duration in minutes

Possible Scenarios for Islanded Operation Duration (min)				
PED State of Charge	**MG Configuration (b)**		**MG Configuration (c)**	
	Half	**Peak Load**	**Half**	**Peak Load**
100%	**54.5**	**27.3**	**26.1**	**13.0**
80%	**43.6**	**21.8**	**20.9**	**10.4**
60%	**32.7**	**16.4**	**15.7**	**7.8**
40%	**21.8**	**10.9**	**10.4**	**5.2**

5 Impact Assessment

In this chapter, an assessment of the demonstration of the HLUCs at a pilot level is presented; and lessons learned highlighted. This is followed by a SWOT analysis, which reflects the strengths, weaknesses, opportunities and challenges of the solutions developed.

5.1 Pilot Assessment

To validate the project results, the individual HLUC of each pilot were treated separately in order to illustrate the thematic and regional differences. Validation therefore takes place at pilot level. The relevant HLUCs and respective goals are briefly described and pilot-specific outcomes, experiences are summarized, which were collected during the project´s lifetime and out of the numerous tests and associated KPIs.

5.1.1 Cyprus

5.1.1.1 HLUC 02 - Voltage compensation via reactive power procurement

HLUC 02 at the UCY pilot site tackled the challenge of voltage stability in the distribution grid by leveraging the reactive power capabilities of battery storage systems. The primary goal was to create a responsive and adaptive system capable of managing voltage fluctuations efficiently.

The UCY pilot faced the intricate task of calibrating battery storage systems to react promptly to voltage changes, ensuring grid reliability. This integration resulted in a marked improvement in voltage stability, which was crucial for maintaining a continuous and reliable power supply.

The experience gained from this HLUC emphasized the significance of real-time grid monitoring and the implementation of advanced battery technologies for voltage regulation. It also highlighted the broader implications for grid resilience, particularly in the face of increasing renewable energy integration.

5.1.1.2 HLUC 05 - Flexibility exploitation for islanded microgrid operation

In HLUC 05, the UCY pilot site focused on optimizing energy management within its facilities through the advanced coordination of the microgrid scheduler (mgEMS) with the Building Energy Management System (BEMS) and an integrated storage system. The objective was to achieve a more efficient and sustainable energy usage pattern by fine-tuning the control over energy consumption, production, and storage.

The challenge lies in the intricate process of integrating disparate systems (mgEMS, BEMS, and storage) to function cohesively. This required not only technical integration but also a deep understanding of the energy consumption patterns and needs specific to the UCY facilities. The successful implementation led to a more streamlined and efficient energy management process, demonstrating the effectiveness of integrated control systems in reducing energy waste and optimizing resource allocation. This HLUC showcased the potential of smart energy management in institutional and commercial settings, offering valuable insights into the benefits of integrating renewable energy sources and storage solutions for sustainable facility management.

5.1.1.3 HLUC 08 - Economically optimised flexibility leveraging for a connected microgrid

HLUC 08 at the UCY pilot site was aimed at enhancing the grid's operational efficiency through effective communication between the Building Energy Management System (BEMS) and flexibility trading mechanisms. The focus was on leveraging the potential of BEMS to contribute to grid stability by managing energy demands more dynamically.

The challenge involved creating a robust and reliable communication network that could handle the complex data flow between the BEMS and the grid operators, facilitating real-time decision-making and energy allocation. This integration was crucial in optimizing building energy usage while contributing to the overall stability and efficiency of the grid. The outcomes from this HLUC highlighted the importance of adaptive communication systems in modern energy management and the role of innovative trading mechanisms in enhancing the flexibility and resilience of the energy grid. This pilot provided key insights into the potential of building-level energy management systems to play a significant role in broader grid management strategies, especially in the context of increasing renewable energy integration and evolving energy markets.

5.1.2 Germany

5.1.2.1 HLUC 01 - Advanced network congestion management

This use case has the objective of preventing congestion issues in the distribution grid by exploiting network flexibility, i.e. reconfiguration of the network topology in the problematic grid area, and DER flexibility, provided by dispatchable DERs located at distribution level.

In the network area of Stadtwerk Haßfurt GmbH, more than 25 MW of photovoltaic and 35 MW of wind power contribute to a substantial amount of renewable energy. Despite adequate investments in infrastructure to enhance the distribution network and the deployment of large electrical storage units, it cannot be avoided completely that congestion may occur. However, unlimited investments cannot be made as the financial resources of small distribution network operators are limited. Here, congestion management provides a solution. Also, the other German Pilot site SWW has increasingly invested in the Wunsiedel network area in the course of the past years. The installed capacity of local generation and storage systems has been expanded, thereunder 16 MW wind power, 16 MW PV and 16 MW CHP as well as an electrolyser. In addition, SWW takes high efforts on motivating citizens and other local stakeholders with own energy-production- and -storage facilities to be integrated to the local grid in order to increase the available flexibility in the area of Wunsiedel.

In the course of the project, several congestion management tests were conducted and critical infrastructural strands were identified. An important lesson learned from this use case is the fact, that a balanced network model is crucial for testing. To avoid distortions in the test results, it is advisable to pay special attention to designing the network model before initiating the tests. Subsequent changes to the network model are time-consuming and compromise the accuracy of the test results. Therefore, it is recommended to ensure thorough preparation and carefully configure the network model from the outset to avoid later adjustments.

In the context of distributed storage integration, SWH leverages a total of 4,605,743 kWh through the Jam Factory, Water Pumps, and the CHP system, while SWW leverages 70,268,000 kWh through the Electrolyser and Heating Rod. SWH demonstrated a Power-2-Cold flexibility of 185 kW. For the flexibility of virtual energy storage, SWH could offer approximately 15 kWh for 1 hour through the Jam Factory, with an overall average of 60 kW. The rest remains in standby mode, aligning with its consumption. In contrast, SWW prosumers offered their entire consumption or production for flexibility, resulting in a 100% KPI value.

No interventions were planned for peak demand reduction on the demo site. Therefore, only potential estimates were made: 1) Jam Factory from 45/25 kW to 40/25 kW, and 2) Water Pumps from 160/100 kW to 120/100 kW. The same for the measurements on the MV/LV transformer. The following potential was estimated here: 200/125kW -> 160/125kW. In the German pilot, a CO2 reduction of 14.7% at SWW and 30.84% at SWH was calculated compared to the project's start, accounting also the moves of both Stadtwerke to expand RES in their network, enhance energy efficiency and diversify their energy mix.

Prosumer reliability is rated at 100% for SWW, while no adjustment requests were planned for SWH, leading to no assignments. Results from testing the effectiveness of congestion management support the application of flexibility in the pilot project, significantly reducing the number of congestions. Out of 52 analysis days, only 7 were used for calculations, considering days with congestions and applied flexibility.

Regarding short-term spatio-temporal forecasting, the quality of data was critical in the performance of the models. Precautions were taken for secure information and communication technologies, including continuous monitoring and alerting to ensure the high availability of all software solutions. The completeness and availability of the dataset was sufficient to support the operation of HLUC01. Lower completeness of data refers to specific periods where communication disruptions were identified.

5.1.2.1 HLUC 02 - Voltage compensation via reactive power procurement

This use case has the objective of preventing voltage excursions in the distribution grid by exploiting battery storage reactive power flexibility located at distribution level.

A rapid response to voltage issues is crucial to ensure network stability and minimize potential impacts. Network stability guarantees network security and a continuous power supply in Haßfurt. The algorithm has also successfully tested emergencies. Here too, the network model, along with the requirements discussed in the previous UC, plays an important role. The calculation for improving power quality was performed automatically within a weekly time window, based on the VCA results for real deviations identified through smart meter data.

The tests for the responsiveness of close-to-real-time prevention could not be successfully conducted, as real-time data was not available in the pilot projects. Therefore, most services operate with historical data.

5.1.2.2 HLUC 04 - Self-healing operation after critical event

This use case intends to give a response for temporary events, including those provoked by extreme weather conditions such as strong wind episodes or storms, causing temporary and localized affectation to the grid (outage).

The implementation of PQ measurement systems enables precise monitoring and evaluation of network quality, crucial for the self-healing process. PQ meters should ideally measure the strands considered in the network model to identify potential overloads in advance. Mobile PQMs, in particular, have the advantage of testing various line sections in different network model sections.

SWW has installed several Power Quality Measurement (PQM) units in Schönbrunn, to monitor and detect crucial events within the grid. Those devices monitor different aspects and values of occurrences, and though this method proved to be successful, communication issues and events by third parties and by a force major could still occur causing a “blinding” and impairing the ability to react.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 04. An accuracy of 96%for detecting faulty feeder was achieved, whereas branch identification accuracy ranges from 95% for very small fault resistance values to 72% for high resistance value.

The localization of impacts on the network, especially during extreme weather events, can complicate the identification of affected areas. The implementation of Geographic Information Systems (GIS) and local monitoring systems could counteract this by facilitating the localization of impacts. A reliable communication infrastructure is crucial for obtaining real-time data from various parts of the network and responding promptly. The establishment of a reliable and high-performance communication infrastructure for the exchange of real-time data and coordination of response measures is essential for this purpose.

5.1.2.3 HLUC 06 - Leveraging DER flexibility towards enhancing network operational efficiency

Under a high RES penetration scenario in distribution network, there is a need to increase the local consumption of RES production at primary or secondary substation level. The exploitation of dispatchable distributed production/consumption/storage assets for better matching the consumption and generation profiles locally as well as for shedding network peak demands will enable better exploitation of the existing grid capacity.

The use of flexible distributed systems allows for dynamic adaptation to local conditions, leading to better utilization of the distribution network. Flexibility, alongside reliable algorithms for detecting network hazards, plays a crucial role. The individual and network-dependent operation of consumption or generation facilities allows for a unique solution to network congestion. The identification of potentially flexible systems is based on the network model. Furthermore, the early involvement of operators of flexible systems is crucial. Industrial partners can be acquired as participants by involving them in the early stages of the project. Transparent information transmission and individual remuneration rates within flexibility provision can bind partners to the company in the long term and contribute to network stability.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 06.

Results from testing the Loss reduction indicate a reduction through imported and exported energy. However, the reduction appears more significant through exported energy. It's essential to note that the result is based on 5 hours over the entire evaluated period, as no additional hours with energy exports were detected.

The tests for Target SoC and the Economic benefit of using FEVER EV charging did not apply to the pilot project since there were no EVs.

The integration of storage solutions and the implementation of load-shifting strategies are crucial to better align RES production with consumption and reduce network peaks. To facilitate this, incentives for investments in energy storage and load-shifting projects could be established to enhance flexibility in the grid.

5.1.2.4 HLUC 12 - Creating dynamic tariffs based on flexibility use in the actual regulatory framework

This use case implements an advanced dynamic pricing mechanism for the procurement of flexibility in the congestion and overload states of the grid and remuneration for costs of extraction of flexibilities in the scope of equivalent or actual sequential operational close down of DER at the distribution level.

Traditional network fees and tariffs are not sufficient to adequately assess flexibility in network overload conditions. Advanced dynamic pricing mechanisms are crucial to evaluate flexibility with high spatial and temporal resolution. The integration of CO2 pricing mechanisms can contribute to incorporating environmental aspects into flexibility assessment. The diversity of incentives, including non-monetary mechanisms, can promote participation and diversity in flexibility trading. It will be important to adapt dynamic tariffs to the rapidly changing energy world. In addition, incentives should be chosen in a way that a customer or participant in the flexibility market cannot bypass an intelligent and network-stability-oriented operation of their private systems.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 12.

In the test for the amount of delivered energy flexibility, HLUC12-prosumers were only simulated in SWW so that no physical energy was supplied. However, the response to a real adjustment request was real. For SWH, no adaptation requests were planned, therefore no assignment was provided.

The development and implementation of an advanced dynamic pricing mechanism requires complex mathematical models and transparent compensation structures to adequately assess the various flexibilities. To reduce complexity and foster greater acceptance, more transparent communication and training for all stakeholders could help enhance understanding of the pricing and compensation structures.

5.1.2.5 HLUC 13 - Improving the outcome in flexibility by introducing sector coupling

To fully integrate distributed RES into a local LV/MV grid the overall energy production and consumption are to be considered. With the main focus on electricity, the coupling with other sectors of a utility company shall be established for flexibility trading. With the use of CHP systems and other sector coupling technologies (e.g. Power-to-Gas plant) energy/flexibility can be shifted into the sectors of gas and heat. The hydrogen-converted energy can be converted back into electricity or heat via CHP plants. The overall flexibility extraction process is enhanced with the coupling of the former mentioned sectors aiming to improve the outcomes of the flexibility trading.

The coupling of different sectors, especially power and heat, improves the overall process of flexibility extraction. Sector coupling contributes to increasing efficiency and trade possibilities in the flexibility market. In particular, the connection of electricity, gas, and hydrogen in the intelligent operation of P2G plants through surplus renewable electricity and the back-electrification via natural gas or hydrogen CHPs plays a crucial role.

For this HLUC, SWW has installed a heating rod in the CHP in Schönbrunn, connected to an 80,000L water tank. The test of supplying power and heat to the nearby area through sector coupling has shown its feasibility and effectiveness, specifically by electrifying the heating sector. The Schönbrunn CHP, equipped with diverse assets, serves as both a combined power generation unit and a tool for sector coupling applications. The test addressed two crucial aspects: surplus energy production and deficit scenarios. In both cases, energy needed to be redirected to address deviations in power production and consumption. Local electricity generation is physically consumed within the area. During a surplus, such as on a sunny day, excess electricity is diverted to warm the heat storage unit, subsequently feeding into the local heating system for a warm water supply. If the power generated is insufficient for the surrounding areas, the CHP reallocates power to electricity production, depleting the heating storage tank. Since external power generation is photovoltaic-based, insufficient power may occur during dark doldrums, particularly during peak hours. In such cases, the pellet boiler becomes the primary heating asset, while any available energy production suitable for electricity is redirected toward that purpose. Moreover, in cases of excessive heat demand, power can be sourced from assets in the SWW grid, including a large battery.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 13.

For the amount of offered energy flexibility, at SWW HLUC13 prosumers were simulated, and prosumers were constantly offering 1.2, 1.1, 1 and 1.43 MW of heating power and 0.38 of electrical power. At SWH, no flexibility request is planned, therefore only the capacity is estimated. In the test for the amount of delivered energy flexibility, HLUC13 was completely simulated. However, the average delivered power in the simulation was 400 kW.

SWW was able to charge a production price of 0.33 euros/kWh for electricity and 0.11 euros/kWh for the heating sector. As long as the external electricity price or the cost of heat is higher than the calculated numbers, energy produced in-house is used. If the price is lower, the energy is purchased externally.

The coupling of different sectors to enhance efficiency in utilizing flexibility resources requires sophisticated control and regulation systems to achieve the desired outcomes in the realm of flexibility trading. Future advancements in control and regulation systems contribute to better addressing these challenges and enabling optimal utilization of flexibility resources.

5.1.2.6 HLUC 14 - Form a first example of a regional flexibility exchange model

This use case introduces a regional marketplace and marketplace operator for trading energy flexibilities as opposed to trading energy products. The competitors are BRPs both on the supply and demand sides.

The use of the *Flexibridge* enables the connection and trade between different local energy communities, especially in regions without alternative markets (see also chapter 2.2). The creation of specific marketplaces for flexibility enables targeted management of congestions and contributes to increased efficiency. The example between Wunsiedel and Haßfurt illustrates well that trading flexibilities or needed/excess energy markets are meaningful. Thus, imbalances due to different generation or consumption facilities can be meaningfully complemented. This creates a balanced account of the two distribution networks on an economic level. It is important to choose partners within a *Flexibridge* so that complementary behaviour can be ensured. Peers with nearly identical conditions cannot generate complementary benefits, as the actual circumstances at the respective times will be too similar.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 14.

The Energy mix costs in SWH were at 15,30 ct./kWh and in SWW 14,92 ct./kWh. As long as the energy mix stays lower than the price offered by external providers, locally produced energy will be consumed primarily.

The implementation of an innovative trading method may face resistance. Convincing participants of the positive aspects and promoting market acceptance could pose a challenge. Targeted communication campaigns, conveying the benefits of the new trading approach, along with the creation of incentives for participation, can counteract this resistance.

5.1.2.7 HLUC 15 - P2P flexibility trading

This use case had to demonstrate the automated trading of flexible energies (electricity, heat) in the context of energy communities.

The integration of various participants, from small prosumer households to small businesses and local utility companies, brings challenges and opportunities. An opportunity arises from the synergy of small prosumers, businesses, and local utility companies, enhancing overall flexibility. Conversely, a challenge stems from the diverse participant base, resulting in distinct data protection and security requirements. Connecting energy communities and other energy markets through specific roles offers opportunities for expanded exchange. Automated trading systems enable efficient and quick handling of flexibility transactions within energy communities.

Through the analysis of Key Performance Indicators, numerous results were collected and assessed. The following provides interpretations of these results for HLUC 15.

The throughput measurements show that the current P2P-FTP deployment/setup used in FEVER offers transaction throughput rates, which were acceptable for real-world applications. Here, user authorization transactions were fastest (7.38 transactions/sec); FlexCoin transactions were slightly slower (3.85 transactions/sec) due to involved HLF machinery (endorsing, etc.); FlexTrading transactions were slowest (1.08 transactions/sec) due to involved HLF machinery, and also due to (internationally) distributed transaction processing using external chain code services. In the tests for the number of peers, there were 11 simulated prosumer users (peers) actively participating in centralized flexibility trading using FTP and FlexCoin DAPP. They actively generated flexibility offers (FlexOffers) which were then matched against those from other peers and also 2 participating DSOs. Also, there was a community of 12 active smart-plug users, (peers) from SWW & SWH. Each peer bought electricity in FlexCoins within a single energy community based on actual power readings from 12 (of 21 available) smart plugs via FMS.

The integration of various renewable energy sources and smart technologies into existing network infrastructures poses technological challenges. Investments in technologies and standards to ensure seamless integration of different systems can minimize such issues. Additionally, partnerships with technology providers and experts help tackle technological complexity successfully.

The acceptance and recognition of Energy Communities in the local community can be a challenging task. Convincing the community of the benefits and goals of the Energy Community is crucial for its long-term success. Therefore, enhanced informational campaigns can be initiated to communicate the advantages of Energy Communities.

5.1.3 Spain

5.1.3.1 HLUC 01 - Advanced network congestion management

This use case has the objective of preventing congestion issues in the distribution grid by exploiting network flexibility, i.e. reconfiguration of the network topology in the problematic grid area, and DER flexibility, provided by dispatchable DERs located at distribution level.

The Spanish pilot is distributed in three different locations: L'Esquirol, Granollers and Vallfogona. Also, the combined impact of the project's solution has been tested on the combination of the three sites and five industrial clients (ICs), composing the LV network of the three sites mentioned, the ICs and also the transmission network connected them. This aggregated grid, or virtual grid, is the basis of many flexibility services as it enables the usage of power flow analysis to assess the project's results.

Therefore, one of the first tasks was to create forecasting models for each of the locations but also for the aggregated energy consumptions that constitute the virtual grid, whose accuracy (KPI DOA_08) - in terms of RMSE - was less than 5%. However, the RMSE is the quadratic mean of the differences between the observed values and predicted ones and expressing it as a % does not make sense. So, in general, a lower value is better than a higher one, but this measure is independent on the scale of the values used. For this reason, it would be convenient to normalise the RMSE value in order to facilitate the comparison between different models.

The analysis has been done by zones, or pilots. The results of the average NRMSE values for each pilot are as follows:

Table AA: NRMSE for EST energy forecasting models

	Virtual grid	L'Esquirol	Vallfogona	Granollers
NRMSE	12.95%	18.57%	22.75%	15.02%

These values are high for the areas of L'Esquirol, Vallfogona and Granollers. These areas are mainly composed of residential consumption, which explains the RMSE values as these consumptions tend to be random and, in many cases, very close to zero. On the other hand, the value obtained for the virtual grid is much better, and this is due to the aggregation of residential consumption and the forecast of industrial customers, even though some of them also showed irregular consumption. However, and very fundamentally, the aggregated forecast followed the behaviour of the real consumption and this was important as a basis for forecasting events. Another aspect to be consider is the quality and availability of smart meter data that act as input to the forecasting algorithm. The performance of the model can significantly decrease in case where the completeness of the dataset is low. Other related indices are evaluated in the KPI_SUC01_1, which can be seen in more detail in section 4.3.2.

Subsequently, the study of critical event forecasting performance is shown in KPI DOA_06. This analysis has been performed as the ratio of events predicted with respect to those really happening. The objective of DOA_06 is achieve an FNR (False Negative Ratio) or missed incidents regarding critical events less than 5%. The mean value obtained in the evaluated period is 6.98%, slightly above the established value. This deviation is mainly due to the error introduced by the energy forecasting models and to working with an artificial limitation of the capacity of the lines, as already mentioned in the DOA_06. In addition, other measures that give value to the performance of the critical event detection module are shown in KPI_PUC01_2, which is detailed in section 4.2.2.

In general terms, when working with aggregate consumption, forecasting errors are minimized, just as when dealing with large consumptions such as those we see in industrial customers. In this last case, however, it is important to be aware of local or extraordinary holiday periods, which have a significant influence on model error. On the basis of a good energy forecast, the congestion forecast is reliable at all times.

5.1.3.2 HLUC 02 - Voltage compensation via reactive power procurement

This use case has the objective of preventing voltage excursions in the distribution grid by exploiting battery storage reactive power flexibility located at distribution level.

The primordial function of voltage compensation in the distribution systems is to provide a stable supply voltage level within an acceptable range for all loading conditions. The usage of reactive power compensation to control voltage magnitudes have been used extensively worldwide. Since the voltage drop is proportional to the magnitude of demand current and the entire impedance between the source and the customer, larger customers and the ones located far from the transformer will experience a larger voltage drop. This makes the Spanish pilot sites a good fit to evaluate these issues, as it has two sites located in rural areas that have long feeders in the LV network.

Here, voltage deviations are forecasted in a day-ahead scenario and flexibility is requested and traded via the FTP. In order to do so a sensitivity analysis is made in order to assess the impact of reactive power injections in distribution grid. Similar to the German pilot, the network model has a fundamental role to the execution of this KPI. In contrast, in the Spanish pilot the SMs infrastructure provides communication in which data can be acquired for the measurements of past days. This monitoring capabilities enables forecasting services and others such as the VCA the capability of having an automated daily operation. Challenges emerged due to the few assets present capable of providing reactive power. Also, most of the assets are located near substations whereas the deviations often occur at the end of the feeders. This scenario made it difficult to activate flexibility and also to assess the impact of reactive power to solve the voltage deviations found.

This KPI analysis is made in a time-window basis of 3 weeks. Under normal operation in the pilots the voltages do not deviate over 5%, and mostly stay in the range of 2%-3%. For that reason the limits of the KPI were made stricter (to 4%) in order for deviations to be found. Results show that very often the voltage deviations are recurrent and happen in specific buses especially in sparse areas of LV distribution grids and in the presence of RES. These could be permanently fixed if a flexible asset capable of providing reactive power is located nearby the faulty node.

5.1.3.3 HLUC 04 - Self-healing operation after critical event

This use case intends to give response for temporary events, including those provoked by extreme weather conditions as strong wind episodes or storms, causing temporary and localized affectation to the grid (outage). Self-healing process after fault occurs in the network entails the identification of the grid boundaries affected by the fault and the extraction of a mitigation plan, in terms of both grid and DER flexibility, to minimize the isolated area and maximize the electrified grid end-users.

The objective of KPI DOA_10 is achieving an FNR (False Negative Ratio) or missed incidents regarding faults in the grid less than 5%.

However, faults in the grid are not frequent and typically are caused by external agents. In monitored areas no faults occurred during the project duration. So, validation of the method has consisted of managing records with artificially produced faults (operation of switchgears capable to connect and disconnect circuits). Using this strategy, the obtained FNR has been 0%.

On the other hand, the SHA application has proven useful for detecting other types of events that are occurring in the grid and that, despite not being faults, they are events of informative interest for the DSO. Some of them can be seen in KPIs DOA_10.

Finally, based on the tests for the responsiveness of self-healing, the following estimated times can be derived:

• Time to Identify Fault (TTI): 1-61 seconds

• Time to Propose a Damage Control Plan (TTM): 1.25 seconds

• Time to Execute Fault Elimination (TTE): 10-71 seconds

These times have proven to be adequate for a fairly early detection of faults that may occur and they are within the stipulated time according to Spanish regulations (see KPI_PUC12_1).

5.1.3.4 HLUC 05 - Flexibility exploitation for islanded microgrid operation

The HLUC05 has the objective of ensure the power continuity of supply of an islanded microgrid and increase the reliability of the distribution network.

Initially, the HLUC03 was the one proposed to be deployed in the Spanish pilot and would enable the real-time detection and mitigation of uncontrolled islanding based on grid monitoring data. However, after intense laboratory testing it was concluded that the commercial power inverters nowadays already have anti-islanding protection that are able to detect any islanding scenario and trigger instantly. These findings are reported in D3.9, and as a conclusion the HLUC03 was repurposed to HLUC05 in which the PED located in L'Esquirol would be able to operate in island to improve the indexes of energy supply. This use case was integrated with HLUC04, in which first the SHA acts on the isolation of faults and then the IPMA starts islanding operation depending on the battery SoC and number of clients disconnected. Unfortunately, due to hardware issues with the batteries we could not achieve full island operation in the pilot. However, the service is operative and proved to be communicating and able to perform remote switching, as well as the laboratory results which already shown that the PED is able to operating in island given the battery issues would be solved.

5.1.3.5 HLUC 06 - Leveraging DER flexibility towards enhancing network operational efficiency

Under a high Renewable Energy Source (RES) penetration scenario in distribution network, there is a need for increasing the local consumption of RES production at primary or secondary substation level. The exploitation of dispatchable distributed production/consumption/storage assets for better matching the consumption and generation profiles locally as well as for shedding network peak demands will enable better exploitation of the existing grid capacity.

In a local consumption scenario, it is important to reduce losses due to local use of energy (shift towards the “zero km” paradigm) and the optimal operation of storage converters (harmonic compensation, reactive power compensation, balancing).

Part referring to loss reduction due to reduction of local imported and exported energy is linked to KPI_PUC06_3 and KPI_PUC13_1. Then, the loss reduction has been 5% and 36% for imported and exported energy respectively. It should be noted that the losses due to the reduction of imported energy are far from the target. This could certainly be improved if companies could extend the hours in which they provide flexibility.

Besides the operation of storage converters in l’Esquirol and Vallfogona, this HLUC was also tested in Granollers through the deployment and use of the FEVER V2Gs. Since no EVs were available, the target SoC was calculated with simulations. As one of the objectives of the GEMS (V2G controller), when an EV is disconnected after trading flexibility it will always be fully charged, hence 100% SoC. The test was also performed on-site against an EV emulator. Still, since this device has infinite capacity, a synthetic capacity limit had to be added to the charger software to allow it to achieve a SoC of 100%. The V2Gs also allowed the calculation of the potential economic benefit that could bring EV owners to use the FEVER V2Gs as charging stations thanks to load-shifting. Finally, V2Gs also allowed the reduction of peak active power at a small scale.

5.1.3.6 HLUC 07 - Improving power quality and reducing losses through local storage utilization

The goal of this use case is to use DER assets and power electronics to improve power quality and reduce losses. This is made through compensation of phase unbalances and harmonics at the terminals of the secondary transformer.

The actual modernization of electric power systems with more electronic devices, non-linear loads, and different types of generation and storage systems requires constant monitoring of the power quality of the supplied energy. The term power quality in power systems covers a wide range of problems related to the quality of the electricity supplied. Under scope of HLUC07, the aim is to provide harmonic and phase unbalances compensation using the PED.

Although the PED is capable of achieve both types of compensation, the PQS has to provide day-ahead forecasts besides the mitigation activation. Two challenges can be highlighted in the implementation of this use case: first, the mapping of phases has quickly become one of the main issues that DSOs are facing nowadays. Usually there is no information regarding the phase allocations of loads, which makes its forecast unfeasibly. This issue was alleviated through extensive and interactive update of the virtual grid used for training the ML models, but would be hard to replicate elsewhere. A new methodology and service for mapping phase allocation would be necessary. The second challenge faced was the granularity and accuracy of the harmonics data, as these values tend to be very small (especially for harmonics of higher order) the data measured falls into the accuracy range of the power analyzers and it becomes hard to distinguish between real data and noise.

Besides the challenges in the forecast, the results show that the PED is able to compensate those issues and significantly improve the power quality, reducing losses at the transformer. The results showed that on average, the mitigation action of PED is able to reduce by a 40% the intensity of total currents and therefore of the active power losses related to these currents. The l’Esquirol town in the Spanish pilot does not present high levels of harmonics formation, this turns into a minor effect of harmonics on power quality, which is instead mainly affected by unbalances.

5.2 SWOT Analysis

The SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) is a proven method for the strategic evaluation of companies, projects, or organizations. It enables a comprehensive examination of internal strengths and weaknesses as well as external opportunities and threats. The following steps and methods of the SWOT analysis are explained in detail:

1. Identification of relevant data sources:

For a valid SWOT analysis, it is crucial to identify relevant data sources. Internal data sources may include financial reports, performance metrics, employee surveys, and company documents. External data sources may encompass market trends, competitive analyses, legal regulations, and industry reports [8].

2. Data collection and analysis:

After identifying relevant data sources, data is collected and analysed. Internal strengths and weaknesses are determined based on company resources, capabilities, and competitive advantages. External opportunities and threats are identified through an analysis of the market environment and competitive situation. [9]

3. Categorization and prioritization of results:

The collected data is categorized based on its relevance to the company or project. The most important results are prioritized to focus on essential aspects. Weighting methods, point systems, or qualitative assessments may be used for prioritization. [10]

4. Derivation of action recommendations:

The identified strengths, weaknesses, opportunities, and threats are analysed to derive action recommendations. These recommendations aim to enhance strengths, improve weaknesses, capitalize on opportunities, and mitigate threats. Decisions are based on the analysed data and the strategic objectives of the company. [11]

5. Integration into the strategic planning process:

The results of the SWOT analysis are integrated into the strategic planning process of the company or project. The action recommendations are incorporated into the long-term corporate strategy to support the achievement of company objectives. The SWOT analysis is used as a tool for informed decision-making. [12]

Applying the aforementioned steps to the FEVER solutions the following factors turned out to be taken into consideration.

Table BB: SWOT Analysis

<table>
<tr><th colspan="2">Internal factors</th></tr>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Expertise and technology: Specialists in flexibility in the energy sector with in-depth expertise and innovative technologies to respond to the growing demand for flexible energy solutions.
Diverse asset management: FEVER offers solutions that enable the management of a variety of assets: industrial loads, EV charging and discharging, stationary batteries, building heating and cooling, residential load customised solutions covering a wide range of the value chain of flexibility.
Diversification of services: Offering a wide range of services in the area of active grid management, enabling DSOs to have increased observability and control over the grid.</td><td>Market volatility: The energy sector can be subject to strong fluctuations, which can lead to uncertainties in terms of income.
Energy market crises: Sudden market changes or crises can affect the stability of business models.
Regulatory obstacles: The electricity industry is subject to strict regulations and political decisions that can influence business activities.
Strong competition: Competition in the (energy) industry is intense, which increases the pressure on prices.
Technological risk: New technologies and solutions in the area of flexibility can be associated with uncertainties and risks, especially since different barriers can limit the demonstration of solution in real-life setups.</td></tr>
<tr><th colspan="2">External factors</th></tr>
<tr><th>Opportunities</th><th>Threats</th></tr>
<tr><td>Expansion of the range of services: Flexibility from various energy assets is increasingly adopted in energy markets, whilst novel local energy market enabled by flexibility are formulated to offer the more efficient operation of the energy system.
Energy efficiency: The demand for solutions to increase energy efficiency and reduce energy waste offers opportunities for a company.
Investment Deferral: The increasing need for grid investment form the wide penetration of DER, necessitates solution alternatives, reducing high investment costs
Financial benefits potential: Flexibility makes it possible to actively participate in energy markets offering services to the grid operators whereas it also enables portfolio self-balancing. This can lead to financial benefits.</td><td>Technological changes: Advances in technology could make existing business models obsolete.
Competition: Competition in the industry could lead to price pressure and make customer loyalty more difficult
Price volatility: Fluctuating energy prices can affect profitability.
User knowledge: As flexibility in the energy sector is a complicated topic, it is difficult for some users to fully understand exactly how it works and how it can be used.</td></tr>
</table>

6 Financial and societal gains, local flexibility provider can expect from the establishment of local markets

This chapter aims to provide a brief analysis of the financial and societal gains to be expected for the local flexibility providers, from the establishment of local markets, quantified by the results of FEVER's demonstrations. When assessing the numbers provided in this chapter, one needs to consider that since the demonstration of FEVER's solutions - in regards to flexibility trading - were realised in sandbox environments or simulations. Furthermore, different definitions and concepts are being mapped to the term "local markets". On one hand, the term could refer to the exchange of energy (e.g. peer-to-peer, peer-to-pool) in a confined geographical area for various purposes e.g. portfolio balancing, network management services. On the other, the term is also used to describe solutions enabling the provision of flexibility to the DSO, which is leveraged for various services (e.g. congestion management, voltage control, loss reduction). FEVER project embraces both concepts and provides solution for handing both p2p trading as well as markets where DSO is the main procurer of flexibility.

6.1 Societal gains

Concerning societal gains, in particular the project partners who contributed to use cases involving clients and private households collected valuable insights: Local communities are closely associated with social impacts. By cooperating, the community members get to know each other and share opinions and knowledge which leads to loyalty and mutual understanding. The increasing awareness of the public regarding the environmental impact of any infrastructural measure of this dimension reminds us to always consider the environmental and societal needs of future generations.

The active involvement of customers in the energy generation and grid operation by migrating them to be collaborative prosumers will empower them to take a responsive role in the local energy microcosmos. This applied either to customers and citizens joining Energy Communities or Cooperatives to bundle their smaller financial resources to empower them to take an active collaborative role in the local energy grid and market. In return, the awareness and capability for reaching societal development goals will be much higher than before, both on individual and collective levels. And very practical, a higher share of profit from operating the local energy system will stay local, and in parallel, the CO2 footprints of all stakeholders on all levels of the local energy system will reduce significantly.

Against the background of increasing energy prices, it can be stated, that this has already caused a considerably higher public awareness of energy topics in general as well as a higher number of clients willing to actively participate in research and innovation projects; field tests and related workshops. New business model approaches based on extended self-generation and storage of energy encompassing aggregation and trading of local flexibility are now being requested by the customers and citizens.

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6.2 Financial gains

The quantification of financial gains is stemming from different FEVER solutions:

- Flexibility System, whose results are analysed in Chapter 4 (see KPIs for PUC04 an PUC22)
- The Real-Time Market Mechanism, whose results from simulations based on actual pilot data are presented in D4.4 [4]

In regards to the Flexibility System, the more realistic figures are the ones related to the remuneration to the industrial clients that participated in the Spanish pilot, which are detailed in Annex A**Error! eference source not found.**. The prices established for the economic compensation remained constant throughout the pilot for simplicity at 0,132€/kW per hour of available flexible capacity offered by the clients and 0,07€/kWh for the realised upward flexibility activations, so, the energy they stopped consuming when demanded.

The following table shows a summary of the quantified earnings of the industrial clients of EST pilot from August to December of 2023:

Table CC: Quantified earnings of industrial flexibility providers - EST Pilot

		IC1	IC2	IC3	IC4	IC5	TOTAL
Available Capacity [kWh]		563	2928	2548	125	632	**6796**
Aug.	# Activations	0	13	1	0	7	**21**
	Flexible Energy [kWh]	0	159.78	18.63	0	11.03	**189**
Sept.	# Activations	3	7	6	0	6	**22**
	Flexible Energy [kWh]	13.54	53.31	45.66	0	8.53	**121**
Oct.	# Activations	0	6	4	0	4	**14**
	Flexible Energy [kWh]	0	54.48	69.95	0	0.23	**125**
Nov.	# Activations	3	7	8	0	2	**20**
	Flexible Energy [kWh]	31.95	85.37	238.5	0	4.51	**360**
Dec.	# Activations	3	7	4	0	0	**14**
	Flexible Energy [kWh]	16.85	62.25	46.13	0	0	**125**
Total	# Activations	9	40	23	0	19	**91**
	Flexible Energy [kWh]	62.34	415.19	418.87	0	24.3	**921**
Total Compensation [€]		271.85	1,093.78	963.91	61.43	233.07	**2624**

Another set of results related to economic benefits of flexibility providers can be associated to the EV users and the V2G chargers demonstrated in the Spanish pilot. As reported in the KPI_PUC22, an economic benefit of 46% for individual prosumers was obtained, meaning that V2G charger users could get a charging cost reduction of up to 46% for a charge of ~4kwh.This cost reduction is calculated dividing the gain achieved thanks to flexibility by the charging cost. The former is calculated as a product of the flexibility price offered by prosumer and the amount of realised time shift. The offer flexibility prices are set to incentivise consuming on demand and are defined as 0.03€/kWh for increasing consumption, and 0.0132€/kWh for lowering consumption.

On the other hand, a real-time market platform implementing FEVER Real-Time Market Mechanism has been developed in order to meet the transmission and distribution network requirements in a real-time level (15-minute) and exploit the flexibility that can be provided by the Distributed Energy Resources (DERs) [4]. Leveraging data from the actual pilots of FEVER in Spain and Germany, the RTMM simulations calculate the activation of a flexible assets and their remuneration for providing grid service and alleviating network problems. The financial gain for flexibility service providers it calculate on the basis of the BAU scenario: if RTMM was not operational the flexibility providers would not be able to be receive any remuneration for such services. The financial gain is assumed to be an average of the Local Marginal Price (LMP) from every node, as summarized in the next table:

Table DD: Financial gains for flexibility providers from RTMM

Pilot	Financial gains [€/MWh]
SWW	80.94
SWH	97.21
EST	111.97

7 Conclusions

The FEVER Pilots' validation report provides a summary of the performance of solutions and tools developed by the members of the consortium and explains the impact from their demonstration in the different pilot sites in Cyprus, Germany and Spain, in respect to the different High Level Use Cases of the project.

Overall, the solutions developed and demonstrated in FEVER pilot sites provide a solid basis for marketable prototypes offering advanced distribution grid observability, extraction-aggregation-management of distributed flexibility and advanced market mechanisms enabling flexibility trading at local/regional and wholesale market levels. In all three pilot sites (Cyprus, Germany and Spain), a wide range of functionalities were deployed, fine-tuned and demonstrated. A comprehensive pool of dedicated test- and measurement data has been compiled to prove the performance of the developed solutions under the particular conditions of the respective pilot site and visualize the results by a detailed calculation of the related key performance indicators.

The challenges and constraints faced in the different pilots (e.g. technical, regulatory) that may hinder the adoption and operation of novel services were highlighted, whereas tangible benefits for the various stakeholders of the domain were quantified. Some key outcomes are analysed below.

From technical point of view, the heterogeneous landscape of grid operating systems is a challenge, whereas the availability of smart-metering infrastructure, able to provide real-time data is limited. A need for deployment of sensing infrastructure or upgrade of existing smart meter infrastructure of previous generations is a key factor in offering solution for active grid management to the DSO operating in real-time horizon. In case of high sampling frequency metering devices, one needs also to foresee adequate computational capacity, investment in such infrastructure from the DSO should not be neglected.

Furthermore, as reflected by demonstration of the results of *HLUC08 Economically optimised flexibility leveraging for a connected Microgrid*, *HLUC-4 Self-healing operation after critical event considering DER & grid flexibility, HLUC01 Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc)* and in general in the operation of energy forecasting algorithms, the importance of adaptive communication systems is increasing and even essential precondition for active management of the grid and innovative flexibility trading mechanisms towards increased resilience of the system.

From a regulatory point of view, the legal framework plays an important role for implementation as well as for flexibility exchange beyond the sandbox or simulation level. The operation of local flexibility markets was not part of the legal framework in the counties that FEVER's solution was demonstrated hindering the demonstration of *HLUC01 Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc), HLUC06 Leveraging DER flexibility towards enhancing network operational efficiency*. The same applies for others applied by FEVER such as the Flexibridge concept tested via *HLUC14 Form a first example of a regional flexibility exchange model*, flexible network tariffs tested via H*LUC12 Creating dynamic tariffs based on flexibility use in the actual regulatory framework,* and reactive power compensation services validated via *HLUC02 Voltage compensation via reactive power procurement* .

In term of financial benefits, the project has also proven that storage capacities play a significant role for a powerful and efficient energy and flexibility management system. The use of flexibility of stationary batteries, P2C and EV batteries through V2G technology can provide significant benefits both to the grid (e.g. peak reduction, losses reduction, grid self-healing, grid-islanding, voltage compensation), as well as to the flexibility providers, as showcased relevant HLUCs. From the perspective of the DSO, an assessment was performed for an investment plan for active grid management through FEVER technologies for the Spanish pilot considering the costs for monitoring equipment, flexibility management solutions, grid automation, V2G charging stations and stationary batteries with overall positive conclusions in regards to convenience and economically competitiveness of such technologies (compared to BAU investment scenarios).

In addition, financial benefits were quantified from the perspective of the flexibility providers based on the results of the demonstration. For example, the industrial customers of the Spanish demonstrator have shared 2.6K €, for providing approximately 1,7MWh of activated flexibility and 68KW/6.7MWh of available capacity, over a period of 5 months. On the other hand, results from bi-directional charging scenarios demonstrated a cost reduction of 46% for a flexible charge of approximately 4KWh in FEVER's V2G chargers. It was also estimated that the introduction of the Real Time Market Mechanism of FEVER could provide benefits from approximately 80€/MWh to 112 €/MWh to flexibility providers as obtained from the simulations realized utilizing data from the different pilot demonstrators in Spain and Germany. Such results can play a significant role in the uptake of local markets; one needs though to carefully consider the assumptions made in the project, due to the regulatory framework constraints in the different pilots.

From a business modelling aspect, useful insights were also collected. Energy Communities can act as a cradle of novel business model, empowering consumer and prosumers to take more active and responsive role in local energy management as it is demonstrated by the results of the technology deployed to support *HLUC15 P2P flexibility trading* and *HLUC14 Form a first example of a regional flexibility exchange model.* The use of pseudo-currencies such as *FlexCoin* – introduced via FEVER - could enable new business, beyond energy and flexibility trading. On the other hand, sector coupling, as it has been demonstrated with the use of Power-to-Cold, Power-to-Heat and V2G charging technologies (e.g. in *HLUC 13 Improving the outcome in flexibility by introducing sector coupling)*, can foster cooperation among business roles from different energy carriers.

The project faced several unforeseen challenges such as the COVID pandemic, which hindered the cooperation and the deployment of field infrastructure and the disruption of supply chain, which delayed the finalisation and deployment of some solutions. Nevertheless, all the solutions of the project were demonstrated successfully in the different pilot sites, gathering and exposing useful information on the use of flexibility in active management of the grid, covering as much as possible of the wide span of the value chain.

8 List of tables

9 List of figures

10 Bibliography

[1] FEVER, “D1.1 Flexibility at the distribution grid: Reference usage scenarios for market and system operation services,” 2020. [Online].

[2] FEVER, “D1.2 Functional and operational requirements,” 2020.

[3] FEVER, “D7.2 Definition of the pilots, the validation methodology and metrics,” 2021.

[4] FEVER, “D4.4 Report on simulation tests with data from pilots,” 2024.

[5] “https://github.com/flexoffer/flexoffer-specifications/,” [Online].

[6] International Energy Agency, “Global EV Outlook,” IEA Publications, Typeset in France by IEA - June 2020, 2020.

[7] “https://canviclimatic.gencat.cat/es/actua/factors_demissio_associats_a_lenergia/index.html,” [Online].

[8] Thompson, A. A., Peteraf, M. A., Gamble, J. E., & Strickland III, A. J.,, “Crafting & Executing Strategy: The Quest for Competitive Advantage,” McGraw-Hill Education, 2022.

[9] Nasution, A. H., Naufal, M. I.,, “Strategy Business Based on Analytical Hierarchy Process and Tows Matrix,” Atlantis Press SARL, 2020.

[10] Rothaermel, F. T., “Strategic Management,” McGraw-Hill Education, 2021.

[11] Porter, M. E., “Competitive Strategy: Techniques for Analyzing Industries and Competitors,” Free Press, 2019.

[12] Hitt, M. A., Ireland, R. D., & Hoskisson, R. E., “Strategic Management: Concepts and Cases: Competitiveness and Globalization,” Cengage Learning, 2019.

[13] S. d. A. Climática, “Factor de emisión de la energía eléctrica,” GenCat, Cataluña, 2023.

List of Abbreviations

Abbreviation	Term
AERP	Average efficiency of a reconfiguration plan
BAU	Business As Usual
BEMS	Building Energy Management System
CAPEX	Capital Expenditure
CB-EMS	Complex Building-EMS
CEF	Critical Event Forecaster
CEPA	Critical Event Prevention Application
CVE	Common Vulnerabilities and Exposures
DER	Distributed Energy Resources
DOA	Description of Action
DR	Demand Response
DSO	Distribution System Operator
EC	Energy Community
ECM	Effectiveness of Congestion management in Magnitude
ECT	Effectiveness of Congestion management in Time
EE	Exported Energy
EMS	Energy Management System
ESS-EMS	Energy Storage-EMS
EST	Estabanell
EV	Electric Vehicle
EVM	Effectiveness of Voltage Compensation Action in Magnitude
EVT	Effectiveness of Voltage Action in Time
EyPESA	Estabanell y Pahisa SA
FEMS	Factory Energy Management Systems
FLEX	Flexshape APS
FM	Flexibility Mechanism

FMS	Flexibility Management System
FN	False Negative
FNR	False Negative Rate
FP	False Positive
FSCA	Flexibility Service Consuming Agent
FSPA	Flexibility Service Provider Agent
FTP	Flexibility Trading Platform
FWHM	Full Width at Half Maximum
G-EMS	Global-Energy Management System (Cloud-hosted)
GOP	Grid Operation Planner
GUI	Graphical user interface
HLUC	High-Level Use Case
ICOM	Intracom Single Member SA Telecom Solutions
INEA	INEA informatizacija Energetika avtomatizacija Doo
IOC	Improvement of the Optimisation Criteria
IPMA	Island Power Management Application
KPI	Key Performance Indicator
LEC	Local Energy Community
LOC	Lost Opportunity Cost
LRA	Loss Reduction Application
LV	Low Voltage
MAPE	Mean Absolute Percentage Error
MER	Estabanell y Pahisa Mercator S.A
MgEMS	Microgrid Energy Management System
OPEX	Operational Expenditure
P2C	Power-to-Cold
P2P-FTP	Peer-to-peer Flexibility Trading Platform

PED	Power Electronic Device
PFS	Power Flow Simulator
PQ	Power Quality
PQM	Power Quality Meter
PQS	Power Quality System
PUC	Primary Use Case
PV	Photo Voltaic
RES	Renewable Energy Sources
RMSE	Root Mean Square Error
RTMM	Real-Time Market Mechanism
RTS	Real-Time Simulator
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SHA	Self-Healing Application
SME	Small and Medium Enterprises
SOC	State of Charge
SOCP	Second-Order Cone Programming
SDS	Switchgear Dispatch Scheduler
SUC	Secondary Use Case
SWH	Stadtwerk Haßfurt GmbH
SWW	Stadtwerk Wunsiedel GmbH
TEP	Total Energy Produced
THD	Total Harmonic Distortion
TN	True Negative
TP	True Positive
TTE	Time required to extinguish the fault

TTI	Time required to identify the fault
TTM	Time required to propose a mitigation plan
UC	Use Cases
UCY	University of Cyprus
UdG	Universitat de Girona
UP	University of Patras
UPC	Universitat Politécnica de Catalunya
V2G	Vehicle to Grid
VCA	Voltage Compensation Application
VUF	Voltage Unbalance Factor

Annex A Remuneration for Prosumers in Spanish pilot

For the development of the Spanish pilot, the industrial clients offering flexibility have been compensated on a simulated local flexibility market. This annex explains the conditions and development of this remuneration.

As a reminder, the Spanish pilot counts with 5 industrial clients providing upward flexibility with their assets:

- **IC1)** Industrial client that offers up to 46.9kW of flexible capacity with industrial machines (saws, polishers, etc.) activated manually with traffic lights.
- **IC2)** Industrial client that offers up to 244kW of flexible capacity with industrial machines (saws, lasers, etc.) activated manually with traffic lights.
- **IC3)** Industrial client that offers up to 212.3kW of flexible capacity with industrial machines (saws, ovens, etc.) activated manually with traffic lights.
- **IC4)** Healthcare facility that offers up to 10.74kW of flexible capacity with automatic air conditioning and two very small heat pumps (0.79kW in total).
- **IC5)** Healthcare facility that offers up to 74kW of flexible capacity between automatic air conditioning and manual laundry with traffic lights.

Table EE: Flexibility Providers flexibility capacity and cost for EST Pilot

	Available Power		Available Hours		Days/ month	Flexibility [kWh]	Total Flexibility [kWh]	Cost [€/kWh]	Capacity Cost [€]
IC1	7.5	kW	1	h/day	12	90	563	0.07	39.40
	7.5	kW	1	h/day	12	90			
	7.5	kW	1	h/day	12	90			
	5	kW	1	h/day	12	60			
	12	kW	1	h/day	12	144			
	7.4	kW	1	h/day	12	88.8			
IC2	13	kW	1	h/day	12	156	2928	0.07	204.96
	20	kW	1	h/day	12	240			
	30	kW	1	h/day	12	360			
	25	kW	1	h/day	12	300			
	78	kW	1	h/day	12	936			
	78	kW	1	h/day	12	936			
IC3	92	kW	1	h/day	12	1104	2548	0.07	178.33
	25	kW	1	h/day	12	300			
	25	kW	1	h/day	12	300			
	22	kW	1	h/day	12	264			
	48.3	kW	1	h/day	12	580			
IC4	2.2	kW	1	h/day	12	26	125	0.07	8.74
	4.1	kW	1	h/day	12	49			
	4.1	kW	1	h/day	12	49			
	0.34	kW	0	h/day	12	0			
	0.45	kW	0	h/day	12	0			
IC5	25.5	kW	1	h/day	12	306	632	0.07	44.27
	27.2	kW	1	h/day	12	326			
TOTAL	567.09	kW	1	h/day	12	6796	6796	0.07	**475.69**

To improve the engagement of the clients it was decided to include a remuneration for the flexibility services as it is done in other countries in Europe. Based on the high voltage flexibility regulation existing in Spain, a fixed remuneration value was stablished:

- 0.132€/kW per hour of available flexible capacity offered by the clients.
- 0.07€/kWh for the realised upward flexibility activations, so, the energy they stopped consuming when demanded.

The DSO Toolbox matched the forecasted events with these fixed prices as if it were a flexibility market even if the offered price never varied. This approach was taken to simplify the explanation to the prosumers.

The flexible capacity offered was based on the flexible assets audited and assessed at the beginning of the pilot that were monitored with the FEMS. The algorithm not only takes into consideration the power (kW) offered from each machine, but also its available hours throughout the month to have an estimation of the offered capacity. Also, there can be only one flexibility request per prosumer at a time.

All flexibility offers had a 1-hour duration all throughout the pilot. Initially the flexibility petitions were sent daily, and we received feedback from the clients that it was overwhelming and could not be sustained from their side. It was stablished to send offers every 2 days, for some clients excluding weekends, so the average of 12 days/month was stablished.

On the activations side, the DSO Toolbox made the matching on the day-ahead market and sent a flexibility petition directly to the clients through email or SMS. The prosumers have until midnight of the day ahead to confirm their activation by clicking the link on the petition that includes the information on the activation:

Figure Z: Flexibility petition - EST Pilot

If the client does not accept the petition by clicking on the link nothing will happen. If they do, then the activation would take place the day after with different protocols depending on manual or automatic loads.

If the flexible loads have an automatic control (the Air Conditioning units for IC2 and IC5), then no more action is needed from the client after the confirmation, and when the activation time comes de FEMS will turn it down automatically. After the flexible hour ends the FEMS automatically turns the machines back on.

The protocols differ with manual machines, even though the preference would have been to automatize as many as possible, however, many machines where old and incompatible with automatic remote control. Therefore, a traffic light was installed next to all the flexible assets to be controlled manually to indicate with green or red lights when it was possible to use or not that specific machine. Different protocols were tested to signal the flexible operation and was decided mid-way into the pilot the simplest possible to make it easier for the workers (not necessarily the person that accepts the flexibility request) to understand. The final protocol was:

- Traffic light would be off by default.

- After the acceptance of the flexibility offer, one hour before the traffic light turns green, signalling the machine can be used, but the flexibility time is approaching.
- 5 minutes before the flexibility time the traffic light will blink with the green light.
- At the time of the flexibility requirement the traffic light turns red and stays red for the whole hour.
- 5 minutes before the end of the hour the traffic light starts blinking red.
- At the end of the adaptation time the traffic light turns green.
- The traffic light stays green for 15min and then is turned off as default.

After the activations, the FEMS monitoring the loads detects their decrease in consumption as flexibility adaptation. Many challenges were faced on this phase:

- Training of the workers for the understanding of the traffic light system after multiple variations of the protocol.
- Discrepancies between the communication of activation attempts from clients and the readings from the FEMS.
- Discrepancies between the communication of activation attempts from clients and the identification of activations. Some clients would claim to have stopped machines, but the algorithm would not identify them as sudden drop of consumption. As they had a day-ahead notification, they would plan their processes to not consume at that time instead of abruptly interrupting it's use, making it harder for the algorithms to differentiate normal operation from flexibility activations.
- There could be a potential decrease of a particular machine but an overall increase of consumption from non-monitored machines in the factory.
- No individual petitions could be made for individual machines as in cases machines would change location.
- Unwillingness to turn off al machines simultaneously as it would disrupt their processes.
- Unwillingness to stop machines at maximum consumption time to prioritize their production as the remuneration was not enough incentive to compensate for the loss of production.
- Residual consumption of machines that are not stopped completely.
- Unwillingness to re-distribute workers for 1hour that cannot work at a specific machine.
- Continuously engage the clients into participating in the pilot and explaining it's impact.
- Difficulties to integrate the remuneration in Estabanell's own billing program.

The flexibility activations detected where then shared with Estabanell in a monthly report in an Excel file that then was manually integrated into the billing program of the company to pay the clients as flexibility service providers. The total compensation of the prosumers for the pilot has been over 2600€, including taxes.

Table FF: Total compensation of the prosumers

	August	Sept.	Oct.	Nov.	Dec.	Total
ICI	71.20 €	49.84 €	47.67 €	52.78 €	50.36 €	271.85 €
IC2	60.98 €	256.52 €	256.70 €	261.64 €	257.94 €	1.093.78 €
IC3	36.86 €	223.08 €	226.95 €	253.87 €	223.15 €	963.91 €
IC4	19.11 €	10.58 €	10.58 €	10.58 €	10.58 €	61.43 €
IC5	44.12 €	54.93 €	44.30 €	44.86 €	44.86 €	233.07 €
Total	**232.27 €**	**594.95 €**	**586.20 €**	**623.73 €**	**586.89 €**	**2,624.04 €**