



FlexCHESS

Horizon Europe Programme
Research and Innovation Action

This project has received funding from the European Union
Horizon Europe Research and Innovation Programme,
under Grant Agreement No° 101096946.

Start date of project: 1st December 2022

Duration: 42 months

D 4.3 Report on pilot sites results

Flexibility services based on Connected and Interoperable Hybrid Energy Storage



Deliverable details	
Work Package Title	Demonstration & Validation
Task Number	4.2.2
Deliverable Number	4.3
Deliverable Title	Report on pilot sites results
Revision Number	
Responsible Organization	UEDAS
Author(s)	Samed Pekdemir, Xun Jiang, Ursula Krisper, Habib Nasser, Ilari Vigna, Antonio Soler, Tim Farnham, Seifeddine Ben Eghali
Due Date	Monday, May 18, 2026
Delivered Date	Monday, May 18, 2026
Reviewed by	
Dissemination level	PU
Please cite as	
Contact person EC	Jasna RESIC

Contributing partners	
1.	AIX MARSEILLE UNIVERSITY – France (Coordinator)
2.	ALGOWATT SPA – Italy
3.	RDIUP – France
4.	ARCELIK A.S. – Türkiye
5.	ELEKTRO LJUBLJANA, D.D. – Slovenia
6.	CIP CITIZENS IN POWER – Cyprus
7.	LA SOLAR ENERGIA SOCIEDAD COOPERATIVA – Spain
8.	My Energia ONER, S.L. – Spain
9.	IREN SPA – Italy
10.	IREN ENERGIA SPA – Italy
11.	UNIVERSITA DEGLI STUDI DI GENOVA – Italy
12.	ULUDAG ELEKTRIK DAGITIM ANONIM SIRKKETI – Türkiye

Associated partners

1.	TOSHIBA EUROPE LIMITED –UK
2.	CARDIFF UNIVERSITY –UK.

Disclaimer: FlexCHESS is a project co-funded by the European Commission under the Horizon Europe Programme - Call: HORIZON-CL5-2022-D3-01-10 under Grant Agreement No. 101096946. The information and views set out in this publication are those of the author(s) and do not necessarily reflect the official opinion of the European Communities. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use, which may be made, of the information contained therein.

© Copyright in this document remains vested with the FlexCHESS Partners

Glossary

Abbreviation	Description
A.A.A.	Authentication, Authorisation, and Accounting
ADMS	Advanced Distribution Management Systems
A.M.I.	Advanced Metering Infrastructure
A.G.G.	Aggregator
B.R.P.	Balancing Responsible Party
B.S.P.	Balancing Service Provider
CAPEX	Capital Expenditure
CHES	Connected Hybrid Energy Storage System
C.H.P.	Combined Heat and Power
C.P.S.	Cyber-Physical System
DBMS	Database Management Systems
DC	Dynamic Containment
D.E.R.	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
D.L.T.	Distributed Ledger Technology
D.N.O.	Distribution Network Operator
DR.	Demand Response
DRES	Distributed Renewable Energy Source
D.S.M.	Dispatching Service Market
D.S.O.	Distribution System Operator
DF	Distributed Flexibility
DT.	Digital Twin
EC.	Energy Community
E.C.M.	Energy Community Manager
E.S.B.	Enterprise Service Bus
ESCo	Energy Service Company
E.S.O.	Energy System Operator
E.S.S.	Energy Storage System
EV.	Electric Vehicle
F.S.P.	Flexibility Service Provider
FlexCHES	Flexibility services based on Connected and interoperable HES
HES	Hybrid Energy Storage System
KPI	Key Performance Indicator
I.C.T.	Information and Communication Technology
MkaaS	Marketplace-as-a-Service
MDC	Metering Data Company
MOM	Message Oriented Middleware
NPRS	Non-Programmable Renewable Sources
OPEX	Operational Expenditure
P&S	Publish & Subscribe
P.L.A.	Production and Load Aggregator

Abbreviation	Description
PLSA	Production, Load and Storage Aggregators
PV.	Photovoltaics
PRO	Producer
PRS	Prosumer
RDBMS	Relational DataBase Management System
RES	Renewable Energy Source
SPG	Steam Power Generation
SUP	Supplier
SCADA	Supervisory control and data acquisition
TNO	Transmission Network Operator
TOU	Time Of Use
TSO	Transmission System Operator
UI.	User Interface
UX	User Experience
VESS	Virtual Energy Storage System
V.P.P.	Virtual Power Plant
V2G	Vehicle To Grid

Content

Glossary	4
Content	6
Table of Content	6
Executive Summary.....	10
Introduction	13
1. The Role of WP4 in FlexCHES	13
2. Overview of Pilot Sites and Their Objectives.....	14
3. Methodology	15
Pilot Sites' Results.....	17
Pilot 1: UK Pilot – VESS for Industrial Buildings	17
Pilot 2: Slovenian Pilot - EV Community Based VESS	27
Pilot 3: Spanish Pilot - Renewable Energy Community	40
Pilot 4: Italian Pilot (CHES Node for Multi-buildings).....	56
Pilot 5: Turkish Pilot - Islands citizen energy community	88
Comparative Analysis Across Pilot Sites	103
Conclusion & Next Steps.....	108
References.....	111
Contact.....	113

Table of Content

1. Index of Figures.

Figure 1: Demonstration Area for the UK Pilot Site.....	17
Figure 2: Structure of the industrial steam system in a pulp & paper mill	18
Figure 3: The Delivery Power Curves of VESS and SPG.....	19
Figure 4: The implementation strategy of the VESS in UK pilot site	20
Figure 5: (a) Grid frequency variation in Scenario A. (b) Delivery ratios of DCH service. (c) Delivery power curves within the VESS.	21
Figure 6: (a) Grid frequency variation in Scenario B. (b) Delivery ratios of DCH service.....	22
Figure 7: (a) Delivery power curves within the VESS. Related power curves of the ESS. (c) SOC changing process of the ESS.....	23

Figure 8: Dynamic service results in Scenario A. The delivery power curves of the (a) VESS, (b) SPG, and (c) ESS; (d) SOC change curve of the ESS.....	24
Figure 9: Dynamic service results in Scenario B. The delivery power curves of the (a) VESS, (b) SPG and (c) ESS; (d) SOC change curve of the ESS.....	25
Figure 10: The architecture of the DSO's flexibility system	29
Figure 11: RDIUP site visits for Evylor.....	29
Figure 12: Principle of an aggregated flexibility.....	30
Figure 13: User interface for charging stations within a specific geographical area .	32
Figure 14: Reservation flow within the mobile application	33
Figure 15: Reservation essential session data.....	34
Figure 16: Dashboard.....	35
Figure 17: 15-minute interval load profiles for specific substations.	35
Figure 18: Request Flexibility prompt	36
Figure 19: Aggregator-flexibility provider message	37
Figure 20: Spanish pilot overview	42
Figure 21: PV plant at municipality rooftop - Spanish pilot	42
Figure 22: PV inverters - Spanish pilot	43
Figure 23: Battery - Spanish pilot.....	43
Figure 24: Flexible load: HVAC units - Spanish pilot	43
Figure 25: Flexible load: DHW tank - Spanish pilot.....	44
Figure 26: Shelly Pro EM-50	44
Figure 27: Shelly Pro installation in a user's electric board.....	44
Figure 28: Gateway and Smart Plug from ARCELIK - Spanish pilot.....	45
Figure 29: HomeWhiz configuration - Spanish pilot	45
Figure 30: Installation of low-cost skycamera.....	46
Figure 31: Skycamera web interface	47
Figure 32: FSP Activation Analysis - Spain accounts for 42,621 of the 56,109 total activations (76%)	49
Figure 33: FSP Dashboard showing revenue & penalties tracking and service distribution for Spanish markets.....	49
Figure 34: UC3 - Renewable Energy Community Self-Consumption Analysis with community KPIs.....	50
Figure 35: <i>FlexCHES FME showing Spanish markets (ES) with Real-Time Services and Energy Markets</i>	51
Figure 36: Schematic representation of the Italian pilot.....	56
Figure 37: Rooftop PV array of the Italian pilot	57
Figure 38: Example of EV charging station of the Italian pilot	58
Figure 39: Small-scale battery of the Italian pilot	58
Figure 40: Data Quality Assessment across all source systems - Italian pilot achieving 96.3% quality score.....	60
Figure 41: FlexCHES Dashboard showing real-time monitoring of Italian pilot CHES Node with aggregated power profiles	61
Figure 42: Data Mapping interface showing device-to-asset mapping for Italian pilot data sources	61
Figure 43: Italy Pilot Deployment Integration	62

Figure 44: Control of Assets using Time and Power Flexibility (a) generic status profiles (b) mapping within BESS schedules through CHES adapters.....	64
Figure 45: Digital Twin Environment Showing EVCS CHES Twin Graph Models and 3D view	66
Figure 46: Italian Pilot - Aggregate Power Consumption Heatmap showing distinct weekday/weekend patterns.....	67
Figure 47: Italian pilot - Daily Load Profiles by Meter and UC1 Peak Shaving Demonstration	68
Figure 48: Italian pilot, UC1.1 Peak Shaving daily demonstration on real IREN data (Wednesday 2025-07-09).....	69
Figure 49: Italian pilot, UC4.1 DAM_IT cost optimisation on real IREN data (Wednesday 2025-07-09).....	70
Figure 50: Offered Current Control Tests for two EV vehicles.....	72
Figure 51: Renault Zoe (a) Power and currents (b) Power factor.....	73
Figure 52: Opel Corsa (a) Power and currents (b) Power factor	73
Figure 53: Summary of EVCS Power Demand for hours in the day and day in the week (a) lowest (b) highest	74
Figure 54: Power Prediction Error versus Hour of the Day (a) absolute error (b) normalised absolute error (non-zero demand)	76
Figure 55: Overall ML Prediction of Total Charging Power and Associated Error	76
Figure 56: Predicted EVSE flexibility power for weekdays	77
Figure 57: Daily PV generation and EVCS demand power	79
Figure 58: Cost of EVCS charging with and without PV/BESS actual cost = base + €0.1 per kWh	79
Figure 59: Combined HVAC, PV and EVCS Power (a) low solar capture (b) high solar capture	81
Figure 60: Overall Flexibility Benefit (a) Costs Reduction (b) Energy shift potential	82
Figure 61: Prediction of Energy Cost Benefit with Different BESS Capacity (for High and Low building solar coefficient <i>sun</i>)	83
Figure 62: 100 kWh Battery Energy Storage System (BESS)	89
Figure 63: Heat Pump Indoor Unit	90
Figure 64: Fancoil	91
Figure 65: OPTO2 WiFi Kit	91
Figure 66: EV Charging Station	92
Figure 67: EV Charger while charging	93
Figure 68: Gökçeada Energy Community - Daily profile, weekly pattern, monthly energy, and load balancing demonstration.....	97
Figure 69: UC3 - Energy Community Self-Consumption analysis with community KPIs.....	98

2. Index of tables

Table 1: Main parameters of the industrial steam system	18
Table 2: Charging stations involved in Slovenian pilot.....	27

Table 3: **Validation of claims and KPIs at the Spanish pilot** 53

Table 4 : Summary of actual BESS use in the Pilot (over 2 months) 78

Table 5 : Summary of benefits and future expansion..... 83

Table 6: **Validation of claims and KPIs at the Italian pilot** 84

Table 7: **Validation of claims and KPIs at the Turkish pilot** 100

Executive Summary

The FlexCHES project addresses one of the most pressing challenges of the ongoing energy transition: enabling electricity networks to operate reliably and efficiently under increasing penetration of renewable energy sources, distributed energy resources, electric mobility, and flexible demand. Traditional grid infrastructures are increasingly challenged by decentralized generation patterns, intermittency, and dynamic consumption behaviours. In this context, Connected Hybrid Energy Storage Systems (CHES) emerge as a key technological and operational solution capable of enhancing grid flexibility, resilience, and interoperability.

This deliverable, “D4.3 – Report on Pilot Sites Results”, presents the implementation activities, methodologies, findings, and lessons learned from the pilot demonstrations conducted under Work Package 4 (WP4) – Demonstration & Validation. The report consolidates results from five pilot sites deployed across the United Kingdom, Slovenia, Spain, Italy, and Türkiye, each representing different technical, regulatory, and operational environments. Through these demonstrations, the FlexCHES project validates the capability of CHES-based solutions to provide flexibility services, support renewable energy integration, optimize distributed assets, and facilitate the participation of consumers and prosumers in future energy markets.

The UK pilot focused on the development of a Virtual Energy Storage System (VSS) for industrial buildings by combining an industrial pulp and paper mill with a Battery Energy Storage System (BESS). The pilot demonstrated the coordinated operation of industrial steam power generation and energy storage to deliver frequency regulation and flexibility services. Simulation results confirmed that the Energy Storage System successfully compensated for the limited ramping capability of industrial assets, enabling the VSS to meet Dynamic Containment service requirements and provide reliable flexibility support. Economic assessments also indicated additional revenue opportunities through ancillary service participation.

The Slovenian pilot demonstrated an EV-community-based flexibility framework led by the Distribution System Operator (DSO) Elektro Ljubljana. The pilot integrated electric vehicle charging stations, local renewable energy sources, and flexibility activation mechanisms through interoperability standards and aggregation platforms. A dedicated mobile application developed by RDIUP enabled reservation-based charging management and user participation in flexibility services. The pilot validated the feasibility of aggregated EV flexibility provision, real-time flexibility activation, and user engagement mechanisms, while also identifying challenges related to EV data accessibility, interoperability, and integration of legacy charging infrastructure.

The Spanish pilot implemented a Renewable Energy Community (REC) in Bullas, Murcia, integrating residential prosumers, photovoltaic systems, batteries, HVAC units, and flexible loads through an advanced IoT infrastructure. The pilot achieved the highest number of flexibility service activations within the FlexCHES project and demonstrated extensive participation in balancing and flexibility market simulations. The deployment of smart metering infrastructure and AI-driven optimization tools

enabled advanced load shifting, peak shaving, and collective self-consumption strategies. Results demonstrated significant potential for community-based flexibility services and highlighted the importance of citizen engagement, simplified user interfaces, and regulatory adaptability for the large-scale deployment of energy communities.

The Italian pilot, located in Turin and operated by IREN, focused on the aggregation and coordinated operation of multiple distributed energy resources, including photovoltaic systems, EV charging stations, battery storage systems, and flexible building loads. The pilot validated digital-twin-assisted energy management strategies and advanced flexibility optimization scenarios. Through extensive data integration, machine learning-based forecasting, and interoperability testing, the pilot demonstrated improvements in energy cost optimization, peak shaving, renewable energy utilization, and EV charging flexibility. The Italian pilot also provided valuable insights into data quality management, interoperability challenges, and the integration of heterogeneous distributed assets into a unified CHES framework.

The Turkish pilot, implemented by UEDAŞ on Gökçeada Island, focused on demonstrating CHES-based flexibility strategies within a semi-isolated island energy system. The pilot integrated a Battery Energy Storage System, a controllable air-to-water heat pump, and EV charging stations to improve renewable energy integration and local grid stability. The pilot demonstrated the applicability of demand response strategies and distributed flexibility assets within islanded or weak-grid environments, supporting load balancing and renewable smoothing functionalities. The results highlighted the importance of flexibility assets for improving operational resilience in geographically constrained systems.

Across all pilot sites, the FlexCHES project successfully demonstrated that hybrid and interconnected flexibility solutions can provide measurable technical, operational, and economic benefits for future electricity systems. Common findings include improved renewable energy integration, enhanced flexibility provision, increased observability of distributed assets, optimization of energy consumption patterns, and stronger engagement of end-users and prosumers in energy services. The demonstrations also confirmed the importance of digital platforms, interoperability frameworks, AI-driven optimization, and real-time data acquisition for enabling scalable flexibility ecosystems.

At the same time, the pilots revealed several cross-cutting challenges, including interoperability between heterogeneous systems, communication reliability, data quality management, regulatory barriers, integration of legacy infrastructure, and user engagement limitations. These findings underline that successful deployment of CHES solutions requires not only technological innovation, but also robust operational coordination, stakeholder involvement, standardized communication architectures, and supportive regulatory frameworks.

Overall, the pilot demonstrations confirm the strong potential of the FlexCHES approach to support Europe's transition toward decentralized, flexible, resilient, and consumer-centric energy systems. The results obtained through WP4 provide

valuable technical and operational evidence for future large-scale deployment of CHESS solutions and establish a foundation for further research, replication, and commercialization activities beyond the project duration.

Introduction

The FlexCHES project is an ambitious initiative aimed at addressing the evolving challenges of modern energy distribution networks. With the increasing penetration of renewable energy sources (RES), particularly solar and wind power, electricity grids are facing new complexities related to intermittency, load balancing, and system stability. Traditional grid infrastructure, designed for centralized generation and predictable demand patterns, needs to adapt to decentralized generation, fluctuating energy supply and dynamic consumer behavior. In this context, Connected Hybrid Energy Storage Systems (CHES) emerge as a key enabler for ensuring grid flexibility, reliability, and efficiency. By integrating multiple energy storage technologies, CHES enhances the ability of electricity grids to respond dynamically to changing energy demands, mitigate fluctuations in renewable energy generation, and support overall energy system resilience.

The European Union's energy transition strategy strongly emphasizes the integration of flexible energy storage systems to optimize the use of renewable resources while maintaining the reliability of power supply. This transition is accompanied by increasing electrification across various sectors, including transportation and industry, which further amplifies the demand for robust and adaptive energy infrastructure. The FlexCHES project aligns with this vision by fostering the development of next-generation hybrid energy storage solutions that can serve as key components of future decentralized and intelligent power grids.

1. The Role of WP4 in FlexCHES

Work Package 4 (WP4) of the FlexCHES project plays a pivotal role in demonstrating and validating the effectiveness of CHES within real-world energy systems. WP4 focuses on testing and evaluating the performance of hybrid energy storage solutions across multiple pilot sites in Europe. These demonstrations provide empirical data on grid flexibility improvements, economic feasibility, and the integration of CHES with existing energy infrastructure. Through a structured validation process, WP4 ensures that CHES solutions can deliver reliable flexibility services to the grid, while addressing key technical challenges and keeping the eye on the evolving European and national regulatory frameworks.

Additionally, WP4 integrates advanced digital tools such as Distributed Ledger Technology (DLT)-enabled smart contracts and AI-driven decision support systems to optimize storage performance, market participation, and grid stability. These innovations can facilitate interoperability between different storage assets, testing how CHES nodes can participate in demand response, virtual energy storage and decentralized flexibility markets.

WP4 is structured into several key activities, including lab validation, preparation of pilots, demonstration of use cases, socio-economic assessment, impact evaluation, and comparative analysis and activities are reported in several deliverables. Specifically, D4.3 aims to illustrate pilot demonstrations activities (carried out

specifically in Task T4.2.2) exploring the use of CHES solutions in the different pilot sites of the FlexCHES project.

2. Overview of Pilot Sites and Their Objectives

Pilot 1: UK Pilot (FLEXIS Demonstration Area – South Wales, UK)

- Formulation of the VESS by combining industrial flexibility from a pulp & paper mill in the UK demonstration area with ESS.
- Development of smart energy management tools for coordinated control within the VESS.
- Integration of smart energy management tools into digital twin platform
- Testing the industrial VESS solutions for frequency regulation and flexibility service provision.
- Assessing the economic and technical benefits of the VESS.

Pilot 2: Slovenian Pilot (Elektro Ljubljana – Slovenia)

- Deployment of smart EV charging infrastructure integrated with DSO flexibility services.
- Integration of renewable energy sources, local PV power plants.
- Development of a flexibility management system for EVs .
- Validation of innovative virtual storage concepts to support grid balancing and demand response markets.

Pilot 3: Spanish Pilot (La Solar & MIW – Murcia, Spain)

- Creation of a Renewable Energy Community (REC) with 15 residential prosumers and municipal facilities.
- Integration of rooftop PV, batteries, and HVAC systems to enhance energy self-sufficiency.
- Testing community-driven demand response strategies using AI-based forecasting and optimization.
- Facilitate the access to flexibility markets to enable energy trading and storage sharing.

Pilot 4: Italian Pilot (IREN – Turin, Italy)

- Test of Hybrid Energy Storage System (HESS) consisting in the aggregation of different Distributed Energy Resources (DER) in IREN's facility in Turin, such

as electric vehicle charging stations, battery storage systems, flexible loads and renewable generation resources within multiple buildings.

- Evaluation of digital twin-assisted energy management strategies for building-scale flexibility services and scenarios and smart EV charging considering renewable integration.

Pilot 5: Turkish Pilot (UEDAS – Gökçeada, Türkiye)

- Testing CHES-based grid stabilization strategies on a semi-isolated island energy system.
- Integration of available 100 kWh Battery Energy Storage System (BESS) for renewable energy smoothing.
- Installation of an air-to-water heat pump (17 kVA) as a controllable demand-side flexibility asset.
- Installation of two 22 kW AC EV charging stations to study their impact on local grid stability.
- Implementation of demand response techniques to optimize the interaction between storage, loads, and renewable generation.

3. Methodology

The FlexCHES project employs a combination of simulation-based analysis, real-world experimentation and advanced data analytics to assess the feasibility and impact of CHES implementations across pilot sites. The methodological framework includes:

- **Digital Twin Technology:** Virtual modeling of Connected Hybrid Energy Storage Systems (CHES) for predictive analysis and performance optimization which are either prototypes or instances; synchronised with their physical counterparts.
- **Near Real-Time Data Integration:** Collection of live data from pilot sites, including power generation, demand response, and system performance metrics.
- **Blockchain and Smart Contracts:** Implementation of distributed ledger technology (DLT) to ensure transparency, security, and automation in flexibility markets.
- **Advanced Machine Learning Algorithms:** Forecasting energy demand and optimizing the scheduling of CHES assets to enhance system efficiency.
- **Grid Flexibility and Ancillary Services Evaluation:** Testing CHES contributions to voltage and frequency regulation, peak shaving, and demand-side response.

This deliverable (“D4.3: Report on Pilot Sites Results”) consolidates findings from the pilot demonstrations conducted under WP4 (specifically T4.2.2). The report is structured as follows:

- Section 2: Pilot Sites’ Results – This section provides detailed documentation of each pilot site’s implementation, including a summary of the technological solutions used for the pilot testing, as well of the methodologies implemented by technical partners, of results and of lessons learned.
- Section 3: Comparative Analysis – This section highlights common trends and best practices among the different pilot sites.
- Section 4: Conclusion and Next Steps – This section discusses key takeaways and future directions for CHES deployment.

By presenting a comprehensive analysis of pilot demonstrations, this report contributes to the broader goals of the FlexCHES project, supporting the transition to more resilient, efficient, and flexible energy systems.

Pilot Sites' Results

Pilot 1: UK Pilot – VESS for Industrial Buildings

1) Location & Context

The UK pilot site is located in the demonstration area of a £24 million project FLEXIS (Flexible Integrated Energy Systems), which developed energy system research capability in Wales, UK.

As shown in Figure 1, the demo area is located in Neath Port Talbot alongside Swansea Bay in South Wales. The demo area will serve as a pilot site in the FlexCHES project—the data of this demo area will be used for supporting simulation study in FlexCHES project.



Figure 1: Demonstration Area for the UK Pilot Site

The UK pilot site is aimed at formulating a CHES node to perform the use cases of frequency regulation and virtual energy storage system (VESS) for industrial buildings. For the frequency regulation, dynamic containment service was delivered to the electricity operator in the UK. In the use case of VESS for industrial buildings, the VESS in the pilot provided flexibility service to the local DSO.

2) Technologies Deployed

In the UK pilot site, the pulp & paper mill and battery energy storage were combined to create a VESS and acted as a FlexCHES node. The parameters of the pulp & paper mill and the battery energy storage are provided as follows.

1. Pulp & paper mill

The pulp & paper mill is composed of three subsystems, which is shown in Figure 2: the steam system (blue), the electric power system (orange), and the pulp & paper

production system (green). High-pressure steam is generated by the boilers at the Tier 1. Subsequently, it is delivered to the Tier 2 to meet medium-pressure steam demand of the pulp machines and to Tier 3 to fulfill low-pressure steam requirement of the paper machines. Moreover, any surplus steam is discharged through the blow-off valve at the Tier 3. The allocation of steam to different tiers can be achieved through both turbines and by-pass valves. Especially, when the steam passes through the turbines, it drives the generators to generate electricity.

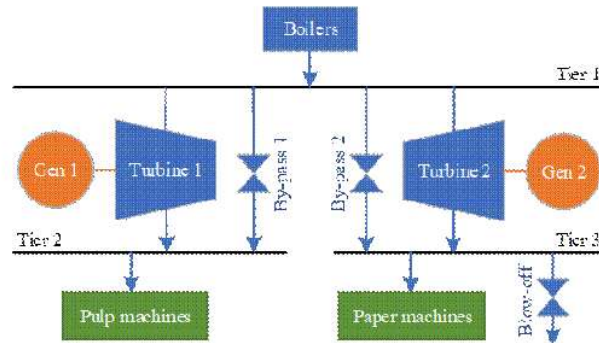


Figure 2: Structure of the industrial steam system in a pulp & paper mill

The parameters of the pulp & paper mill are provided as in the table below.

Table 1: Main parameters of the industrial steam system

Item	Parameter	Value
Boiler	Rated steam flow rate /(t/h)	120
Tier 1 steam	Steam enthalpy /(kJ/kg)	3354.7
Tier 2 steam	Steam enthalpy /(kJ/kg)	2904.8
Tier 3 steam	Steam enthalpy /(kJ/kg)	2856.6
Steam power generators	Power generation efficiency /%	72
	Rated steam flow rate /(t/h)	110
	Upward ramp rate of steam flow rate /(t/h/min)	3.3
	Downward ramp rate of steam flow rate /(t/h/min)	4.9
By-pass valves	Upward ramp rate of steam flow rate /(t/h/min)	4.0
	Downward ramp rate of steam flow rate /(t/h/min)	3.5
Blow-off valve	Rated steam flow rate /(t/h)	90

2. Battery energy storage

To provide effective dynamic containment service and the flexibility service in the pilot site, the sizing of the VESS is determined at 1.8179 MWh with its power capacity of 8.4685 MW. The sizing algorithm can refer to D3.5 [1].

As an industrial demand response resources, steam power generation (SPG) in the pulp & paper mill can offer a degree of flexibility without affecting the normal steam supply to production processes considering the interconnected nature of internal pipelines in industrial steam systems. Moreover, industrial steam systems are typically equipped with advanced control, measurement, and communication facilities, enabling accurate adjustment of SPG as required.

However, the ramp rate of SPG is influenced by the ramp rate of steam flow across its various pipelines, resulting in a relatively low ramp rate for SPG, which cannot meet the ramp rate requirements for the flexibility service such as the dynamic service in the UK.

The coordination of ESSs with SPG can be a solution to the bottleneck of slow ramp rates. When providing the ancillary services, the delivery power that needs to be provided by the overall VESS should be distributed between the ESS and the SPG. The basic principle is that the delivery power of the SPG should be used first to follow the delivery power of the VESS as much as possible, so as to fully utilize the significant energy potential of the SPG. Any difference between the delivery power of the SPG and the VESS, due to the slow ramp rate of the SPG, will be compensated by the ESS.

3) Methodology & Implementation

The UK pilot acts as a demonstration case study within the FlexCHES project. By combining the pulp and paper mill with a battery energy storage system to create a VESS, the pilot demonstrates use cases involving frequency regulation and flexibility provision for industrial buildings. Particularly for the frequency regulation scenario, the performance of the VESS in delivering Dynamic Containment (DC) services to support system frequency regulation in the UK is evaluated.

1. Methodology

The delivery power required from the overall VESS is distributed between the ESS and the SPG. The basic principle is that the delivery power of the SPG should be prioritized to match the delivery power of the VESS as closely as possible, in order to fully utilize the significant energy potential of the SPG. Any difference between the delivery power of the SPG and the VESS, due to the slow ramp rate of the SPG, will be compensated by the ESS. Figure 3 provides an example for the strategy for their coordinated power delivery. When the service commences, the delivery power of SPG gradually increases to approach the contracted quantity, with an upward ramp time of Δt_{up} . After the period of T_{dura} , the delivery power of the SPG gradually decreases to approach zero, with a downward ramp time of Δt_{down} . The shaded area represents the energy delivery volume by VESS within the duration of T_{dura} . During the ramping period of SPG, any difference between the delivery power of VESS and SPG is compensated by the delivery power of the ESS. Therefore, the required energy headroom (for charging) and footroom (for discharging) for the ESS are equal to the areas of S_1 and S_2 , respectively

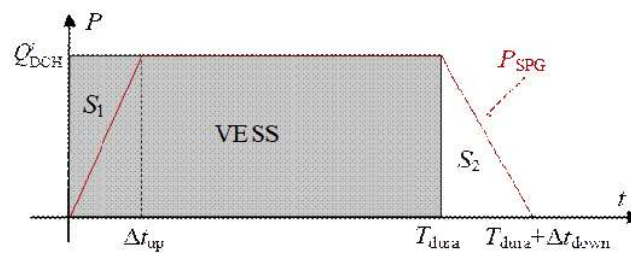


Figure 3: The Delivery Power Curves of VESS and SPG

The DC service requires a service provider to rapidly change its power generation or consumption patterns in response to frequency deviations in the power grid. As required by the National Energy System Operator, the maximum time allowed between a frequency deviation occurring and the full delivery is 1 second. The DC service includes two distinct types: DC High (DCH) service and DC Low service, designed respectively to address high-frequency and low-frequency events. Without loss of generality, the participation in the DCH service is investigated. For a DCH service provider, the actual amount of service required to be delivered (i.e., the power generation decrease or consumption increase, termed as “delivery power”, measured in MW), is decided by the deviation of the grid frequency from its nominal value (50Hz in the UK). When the grid frequency is between 50 Hz and 50.015 Hz (termed as “deadband”), no delivery power is required. When the grid frequency is above 50.015 Hz, the delivery power is linearly proportional to the deviation of the grid frequency from its nominal value. For instance, the delivery power achieves 5% of the contracted quantity when the grid frequency reaches 50.2 Hz. From this point, this percentage (termed as “delivery ratio”) increases in a piecewise linear way until it attains 100% of the contracted quantity when the grid frequency reaches 50.5 Hz.

The flexibility service consists of two stages. The first stage is the day-ahead process, while the second stage is the within-day process. In the day-ahead process, the input data include the maximum upward generation regulation of SPG, which can be obtained from a pulp & paper mill. For the flexibility service, the available capacity is declared to reflect their expected running or opportunity costs and the dispatch requests can be selected to be accept. In the within-day process, the inputs are the day-ahead declared capability, the notified dispatch instruction, and the industrial Time-of-Use price. The decision-making algorithm is employed to determine the control strategy for the VESS based on these inputs. The output consists of the delivery power of the SPG and the ESS within the VESS.

The detailed process for the two services can refer to the deliverable D3.5 [1].

2. Implementation

When conducting the above different use cases in the UK pilot sites, smart energy management tools within FlexPlatform will be activated as shown in Figure 4. Under “Frequency regulation” scenario, the tool of frequency response service will be activated. Under “VESS for industrial buildings” scenario, the tool of flexibility service will be activated.

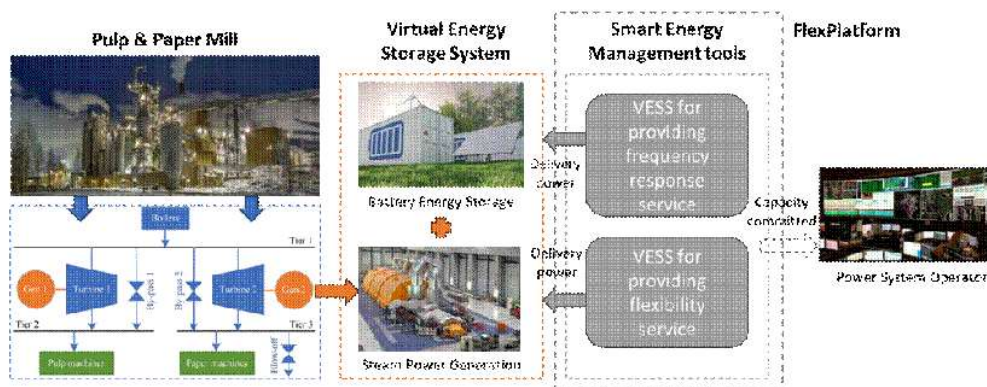


Figure 4: The implementation strategy of the VESS in UK pilot site

These smart energy management tools have been realised by Matlab models and integrated with digital twin platform, as part of the FlexPlatform, by using the Matlab Simulink compiler SDK. The tools have been used to derive the control signals for the delivery power of both the battery storage and the steam power generator within the VESS in the pilot. Since the owner of the battery energy storage system is the pulp & paper mill, the interfacing signals are transmitted between the pulp & paper mill, the FlexPlatform, and the power system operator.

4) Findings & Insights

The two use cases in the UK pilot site—frequency regulation and flexibility provision for industrial buildings—have been tested by different simulation scenarios.

1. Frequency regulation

The performance of the proposed VESS model within UK pilot has been evaluated across two grid frequency scenarios: Scenario A (regular scenario) and Scenario B (fault scenario).

1.1 Scenario A

Scenario A represents the most common scenario in which the frequency deviations remain within ± 0.2 Hz from the nominal value of 50 Hz, which is provided in Figure 5(a). In the DCH service, the service providers only need to respond when the frequency deviation exceeds 0.015 Hz. Figure 5 (b) shows the delivery ratios of the DCH service in Scenario A, which are all within 5% because the frequency deviations in this scenario are all less than 0.2 Hz.

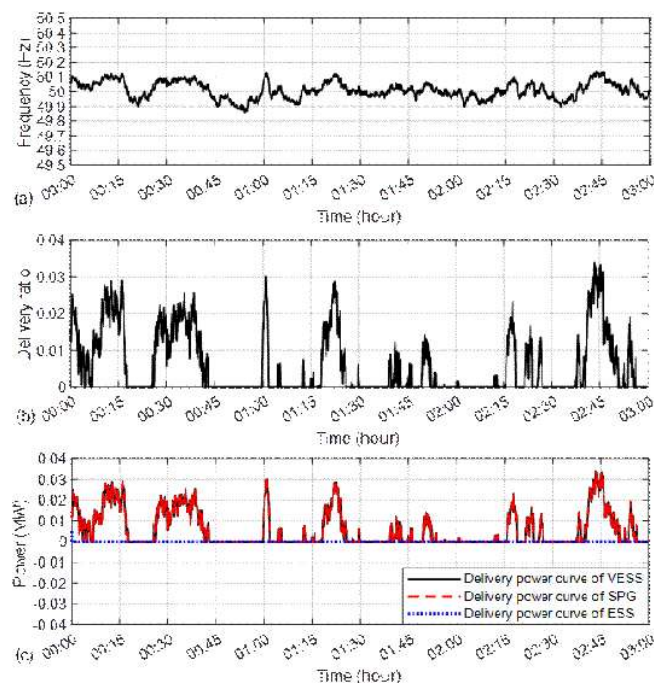


Figure 5: (a) Grid frequency variation in Scenario A. (b) Delivery ratios of DCH service. (c) Delivery power curves within the VESS.

Figure 5 (c) presents the delivery power of VESS in the UK pilot site and the related delivery power of SPG and ESS when participating in the DCH service in Scenario A. In this scenario, because the delivery power required by the DCH service is small, the ramp rate of SPG is sufficient to meet the delivery power requirements. Moreover, the delivery power of ESS is zero throughout the entire time horizon.

1.2 Scenario B

Scenario B represents a fault scenario, where the frequency experiences a sudden large deviation but is quickly adjusted to the nominal value, which is shown in Figure 6 (a). Figure 6 (b) illustrates the delivery ratios for the DCH service, which increase sharply when the frequency deviations exceed $+0.2$ Hz.

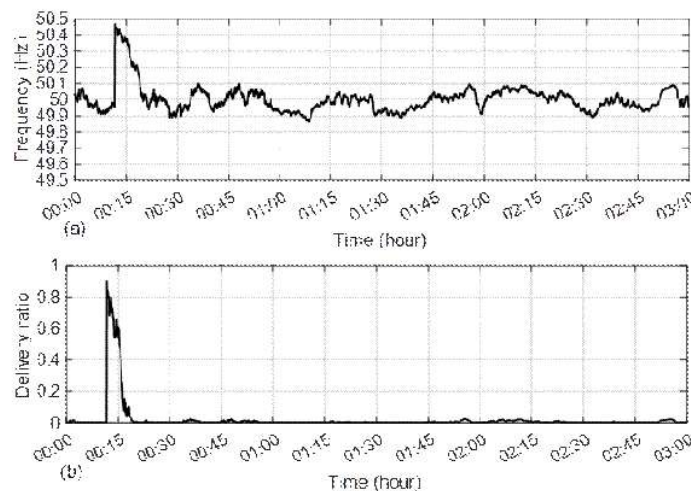


Figure 6: (a) Grid frequency variation in Scenario B. (b) Delivery ratios of DCH service.

Figure 7 (a) illustrates the delivery power curve of VESS in the UK pilot site and the related delivery power curves of SPG and ESS when participating in the DCH service in Scenario B. When the system fault occurred (around 00:12), the frequency deviations suddenly increase, requiring VESS to ramp up its delivery power to approximately 0.9 MW within a few seconds. Due to the slow ramp rate of the SPG, ESS needed to compensate for the difference between the delivery power of VESS and SPG at the time of the fault. After the first few seconds following the system fault, the SPG is almost sufficient to meet the delivery power requirements of the DCH service during the frequency recovery period (between approximately 00:12 - 00:18), with only a small portion needed to be compensated by the ESS. The energy absorbed between 00:00 and 00:30 is released between 02:00 and 02:30, depicted as the recovery power curve in Figure 7 (b). Moreover, as depicted in Figure 7 (c), the SOC of ESS rises rapidly after the fault occurs and remains high until the energy absorbed between 00:00 and 00:30 is released between 02:00 and 02:30.

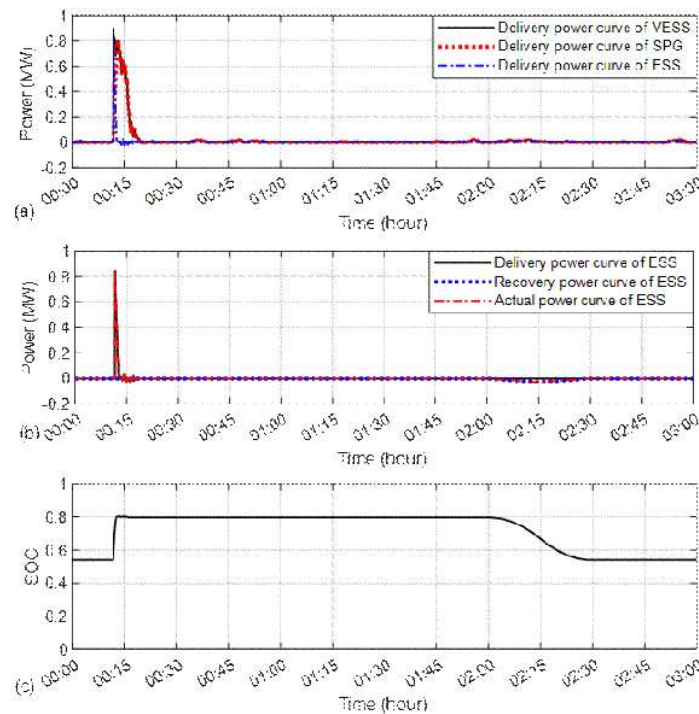


Figure 7: (a) Delivery power curves within the VESS. (b) Related power curves of the ESS. (c) SOC changing process of the ESS.

2. Flexibility provision for industrial buildings

The performance of the proposed VESS model in providing the flexibility service has been evaluated across two scenarios: Scenario A and Scenario B. In Scenario A, there are three utilization events within a day. The time periods of these three events are 08:00–08:30, 12:00–12:30, and 16:00–16:30, respectively. In Scenario B, there are two utilization events within a day. The time periods of these two events are 08:00–10:00 and 15:00–17:00, respectively.

2.1. Scenario A

Figure 8 (a) presents the delivery power curve of the VESS, obtained based on the corresponding maximum upward generation regulation of the SPG during each utilization event. Figure 8 (b) depicts the delivery power curve of the SPG, which increases before the start of the utilization event and decreases after the event concludes. Figure 8 (c) shows the delivery power curve of the ESS, which compensates for the difference between the delivery power of the VESS and the SPG. Finally, Figure 8 (d) presents the SOC change curve of the ESS.

In this scenario, for the first utilization event, if the ESS is not employed, the proportion of insufficient delivered energy is 7.14%. For the second and third utilization events, this proportion is 22.35% and 0%, respectively. Overall, the proportion of insufficient delivered energy for the entire day is 10.00%.

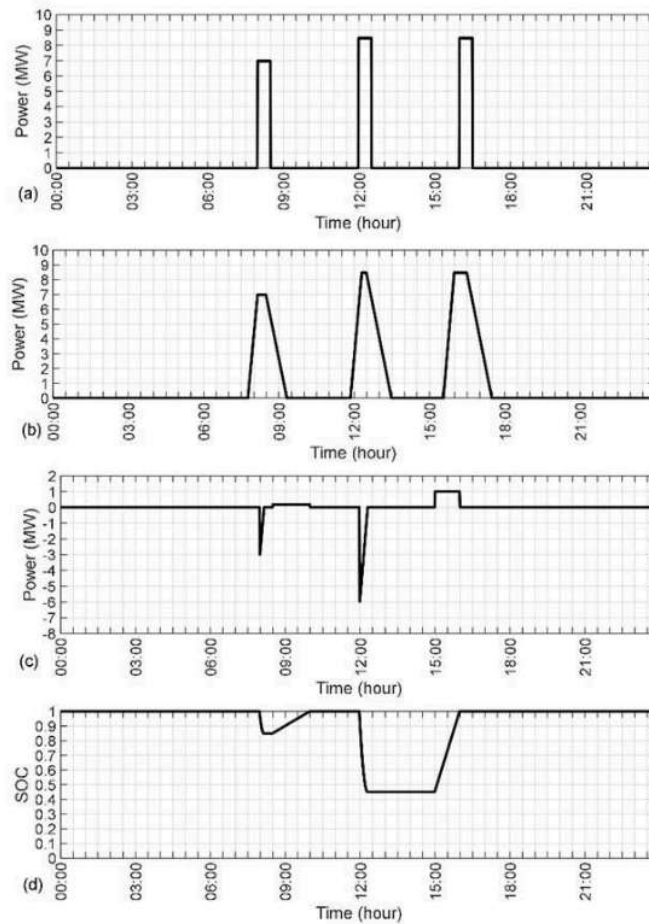


Figure 8: Dynamic service results in Scenario A. The delivery power curves of the (a) VESS, (b) SPG, and (c) ESS; (d) SOC change curve of the ESS.

2.2. Scenario B

Figure 9 (a) presents the delivery power curve of the VESS in the UK pilot site, obtained based on the corresponding maximum upward generation regulation of the SPG during each utilization event. Figure 9 (b) depicts the delivery power curve of the SPG, which increases before the start of the utilization period and decreases after the period concludes. Figure 9 (c) shows the delivery power curve of the ESS, which compensates for the difference between the delivery power of the VESS and the SPG. Finally, Figure 9 (d) presents the SOC change curve of the ESS.

In this scenario, for the first utilization event, if the ESS is not employed, the proportion of insufficient delivered energy is 1.01%. For the second utilization event, this proportion is 2.79%. Overall, the proportion of insufficient delivered energy for the entire day is 1.94%. The reason the proportion of insufficient delivered energy in Scenario B is lower than in Scenario A is that the duration of each utilization event in Scenario B is longer, so the proportion of the period affected by the slower ramp-up rate of the SPG is shorter compared to that in Scenario A.

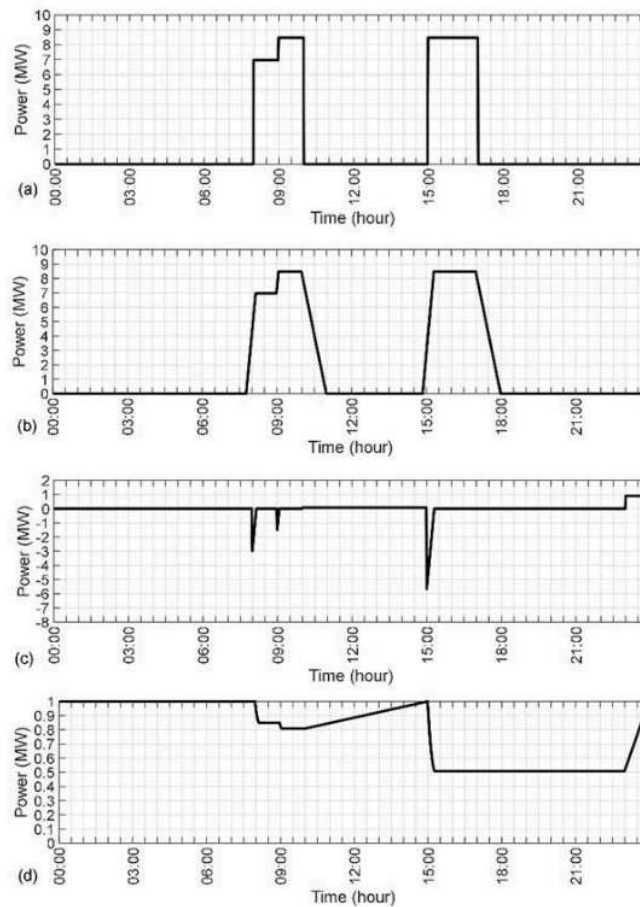


Figure 9: Dynamic service results in Scenario B. The delivery power curves of the (a) VESS, (b) SPG and (c) ESS; (d) SOC change curve of the ESS.

3. Economic and technical benefits

The simulation results demonstrate the effectiveness of the VESS at the UK pilot site in delivering both frequency regulation and flexibility services. The ESS within the VESS provides rapid power regulation capability to compensate for the ramping limitations of the industrial SPG, thereby enabling the constructed VESS to meet service requirements and provide flexibility support to the power system. Moreover, any energy shortfall arising from the gap between the power delivered by the SPG and the power requested during service provision can be effectively compensated for by the ESS. This not only increases revenue for VESS owners, but also improves service quality, thereby contributing to the safe and stable operation of the power system.

Based on the scenarios presented above, and assuming that the typical daily operation of the VESS follows these scenarios, the economic benefits can be estimated using historical flexibility service prices published by UK Power Networks. The main conclusions are as follows.

The estimated average annual revenue for the VESS owner from providing DC services is £850 under normal operating conditions and £2,964 under fault conditions, while the estimated annual revenue from providing flexibility services to electricity network operators ranges from £4,510 to £11,921.

5) Challenges & Lessons Learned

A key challenge in implementing the UK pilot site in real-world settings is the limited awareness among DER owners of the opportunities to participate in flexibility markets through the VESS scheme. This may be further compounded by insufficient commercial or operational incentives, which can reduce stakeholders' willingness to engage and, in turn, limit the scalability and replicability of the approach.

A further challenge relates to the practical implementation of a robust internal control framework of the VESS. This is essential to ensure the reliable delivery of multiple services, such as frequency regulation and other flexibility services, through the coordinated operation of DERs and ESS. In real-world applications, the diversity of DER technologies, variations in response characteristics, and site-specific operational constraints may increase the complexity of control design and deployment.

These challenges highlight the need for clearer value propositions, more targeted stakeholder engagement, and appropriate incentive mechanisms to support wider participation. They also underline the importance of developing coordination strategies that are both technically robust and sufficiently adaptable to heterogeneous operating environments. Overall, an important lesson learned is that successful VESS deployment depends not only on technical feasibility, but also on effective stakeholder engagement and reliable operational coordination.

Pilot 2: Slovenian Pilot - EV Community Based VESS

1) Location & Context

The Slovenian pilot involves several key stakeholders collaborating to enable the implementation and operation of the DSO flexibility system within the distribution network. Each actor has a specific role in ensuring the coordination of flexibility services, communication infrastructure, and the integration of electric vehicle charging assets with the grid. The main actors involved in Slovenian pilot are:

- DSO, electricity distribution operator, represented by Elektro Ljubljana (EL), an active Flexchess partner. EL is the owner of distribution power network, responsible for its development, maintenance and operation. EL's tasks is also to implement and to maintain the smart meters, measuring the consumption and/or the production of to the grid connected loads and generators.
- Charge points Operator (CPO), an external party. In Flexchess project, it was decided, that the CPO takes the role of an aggregator, it is pictured, that this party will receive the DSO's requirements for flexibility activation, because this is the way on how to provide this information, from the source- DSO to the recharging stations.
- Third actor is the distribution power network user: recharging stations in combination with local energy resources and loads.

Selection of the grid areas where the before-mentioned assets including energy resources and recharging stations are present.

Table 2: Charging stations involved in Slovenian pilot

Name of the Location of CSs	EVSEs ID	Number of EVSEs at location	EVSE Pmax kW	Transformer Station MV/LV Name	Nominal Connect Point kW	Local Production Scheme
Kongresni*DC will not be managed (ID 1066,1067)	1591,1592,1593	3	11	TP1096-GARAŽNA HIŠA KONGRESNI TRG	329	
	1594,1595,1596,1597,1598,1599	6	22			
	8201,8202,8203,8205,8254	5	22			
P+R Dolgi most*DC will not be managed (ID 7056,2433,3607)	2118,1177,1178,1179,1180,1181,1182,2909	8	22	TP0281-FAJFARJEVA ULICA	138	
Admiral Hotel Grosuplje	1071,1072	2	50	GROS.IGRALNI SALON G-084 *	720	
	1043,1044,1073	3	22			
IKEA Ljubljana	5001,5002,5003,5004,5011,5012,5013,5014	8	22	TP0158-IKEA	1454	PX.3a

P+R cerknica	9238,4334	2	22	CERKNICA-ŠOLA 1978	24	
				CERKNICA-ŠOLA 1978		Px.1a
				CERKNICA-ŠOLA 1978		Px.1a
				CERKNICA-ŠOLA 1978	101	
Rural distribution network Trebnje				TP PAVLINOV HRIB 1976		behind the meter, PX.1d
				TP PAVLINOV HRIB 1976		behind the meter, PX.1d
				TP PAVLINOV HRIB 1976		behind the meter, PX.1d
				TP PAVLINOV HRIB 1976		behind the meter, PX.1d
	1268,1267	2	22	TP PAVLINOV HRIB 1976	43	
	1211,1212	2	22	TP PAVLINOV HRIB 1976	43	

For testing, additional locations can be included.

2) Technologies Deployed

The Slovenian pilot relies on the existing flexibility platform owned by Elektro Ljubljana (EL), illustrated in Figure 10, together with the recharging-stations management system operated by the Charge Point Operator (CPO). In this framework, activation requests are exchanged with aggregators in the IEC 62325 Activation_Market Document format, an example of which is given later in this section. In addition, registration of flexibility providers, including the CPO acting as aggregator, is performed through the national "Mojelektro.si" portal, which is the only condition for pre-qualification of flexibility under the current Slovenian framework.

This operational structure has become increasingly important due to the ongoing transformation of the Slovenian electricity distribution network. The electricity distribution network is facing a surge in new loads and distributed energy resources, particularly small-scale solar power plants. To manage this influx, Energy Distribution Companies (EDCs) have introduced **flexibility services**. This shift is driven not only by new connections but also by the energy crisis, which has limited investment funds and complicated grid expansion with procedural hurdles. Furthermore, the specific characteristics of the Slovenian distribution network create additional operational challenges. In Slovenia, the network structure—characterized by long distances in low-voltage (LV) overhead lines—means that most operational issues, such as congestion and voltage fluctuations, occur at the LV level.

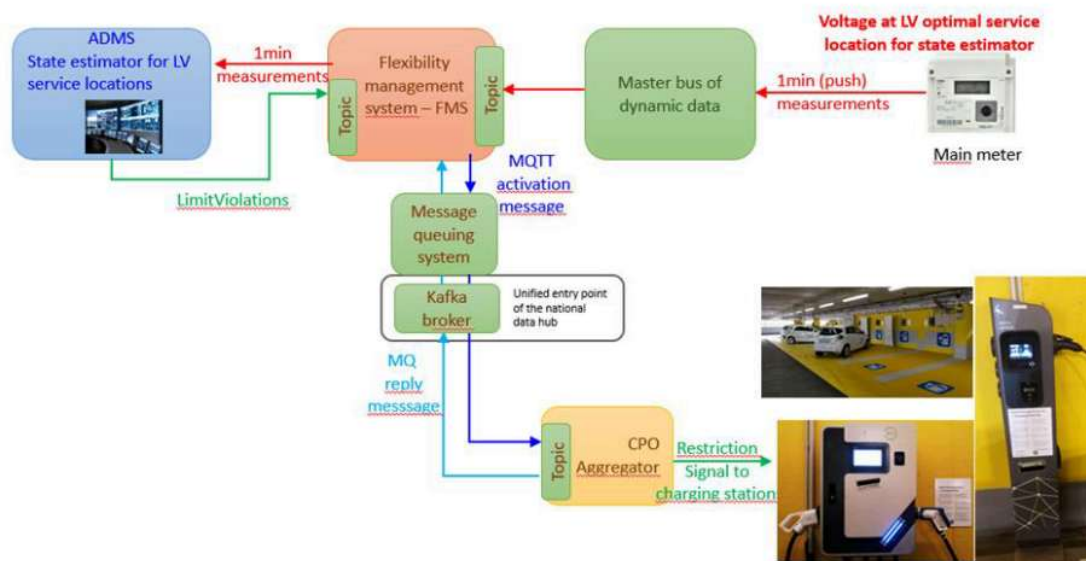


Figure 10: The architecture of the DSO's flexibility system

In addition to these platform-level solutions, an additional technology deployed in the Slovenian pilot is **Evylor**, a mobile application designed and developed by **RDIUP** to empower EV drivers with total control over their charging experience while simultaneously enabling critical flexibility services for the power grid. Within the context of the Slovenian pilot case study, the app serves as a bridge between individual user needs and substation stability.



Figure 11: RDIUP site visits for Evylor

In order to tailor the Evylor application for smart charging and flexibility provision within the EV community pilot, RDIUP has conducted site visits to EL, and periodic dedicated meetings have been organized with relevant stakeholders. As part of the

pilot activities, two scientific papers have been produced and disseminated for this specific pilot^{1,2}.

A core feature enabling this flexibility is the **reservation system**, which allows drivers to secure a charging spot in advance by selecting their expected arrival time and session duration. These reservations provide the pilot administrator with a 15-minute load forecast for each substation via the **Web portal**. This predictive data is essential for identifying potential grid congestion at the substation level.

3) Methodology & Implementation

Within the Slovenian pilot, this methodology and implementation approach focuses on specifying the Hybrid Energy Storage Systems (HESSs), which will support the necessary interoperability and operation of a CHES (Connected Hybrid Energy Storage System). From a Distribution System Operator (DSO) perspective, a CHES can be defined as a system in which:

- the relevant section of the grid is continuously monitored, including the active and reactive power of all generation and consumption units,
- the flexibility of these assets enables their aggregated power to behave similarly to that of an energy storage system.:

In other words, from the DSO's perspective, CHES represents a smart, distributed storage system in which multiple flexible assets are coordinated and operated as a single virtual energy storage resource.



Figure 12: Principle of an aggregated flexibility

¹ Integration of EV Community Technology with advanced Energy Storage and smart charging Protocols H. NASSER¹, U. KRISPER², D. DIARRA¹ ¹ RDIUP, France; ² Elektro Ljubljana, Slovenia

² "Grid integration of a sustainable transport" European commission DOI: [10.2926/6842955](https://doi.org/10.2926/6842955)

The graph of aggregated flexibility provides a high-level overview of which measured values are crucial for both operational execution and subsequent evaluation of the delivered service. The load curve represents the initial load of all aggregated assets connected to a single grid node. For better interpretation of load management, we assumed, that the base load is 5 units (e.g. kW) and the requested positive flexibility-decrease of a load, is 2 units.

Let's assume, that at this node, flexibility of loads, and production units is identified and it results in a volume of aggregated offered flexibility. The flexibility request or need could be higher or lower than the provided flexibility, and on the graph is presented only the need for the positive activated flexibility, which means that a need for decreased power on the observed part of the grid is needed. On the graph a the base line is defined, as measured power during last time period before the start of the activation, or the graph also includes a baseline, which reflects the measured power during the period immediately preceding the start of the flexibility activation.

To perform the flexibility of the EVs, real vehicles will be included in testing, providing internal EV information as start of recharging and the status of the batteries-SOC.

4) Findings & Insights

The integration of the FlexCHES aggregation workflow with the EL flexibility platform reuses the existing IEC 62325 activation message format (illustrated in the example shown above) and the existing SCADA data flow on the EL side. The current pilot configuration covers the EVSE inventory listed in Table 2 (Kongresni, P+R Dolgi most, Admiral Hotel Grosuplje, IKEA Ljubljana, P+R Cerknica and the Trebnje rural distribution-network cluster), with both AC and DC chargers across the Ljubljana, Cerknica and Trebnje DSO areas. The DC charging stations identified in Table 2 (IDs 1066, 1067 at Kongresni and 7056, 2433, 3607 at P+R Dolgi most) are explicitly out of scope for managed flexibility and are listed for completeness.

When a peak is forecast, the administrator can issue a **Request for Flexibility** in two ways:

- **Real-time Flexibility:** Asking users currently charging to accept a decrease in charging power.
- **Scheduled Flexibility (Shift):** Requesting that users with upcoming reservations move their session to a different time or a less congested substation.

To incentivize participation, users who contribute to these flexibility services are rewarded with "**Flex**", **cashback**, or a reduction in charging costs, all of which are tracked directly within the app's profile interface.

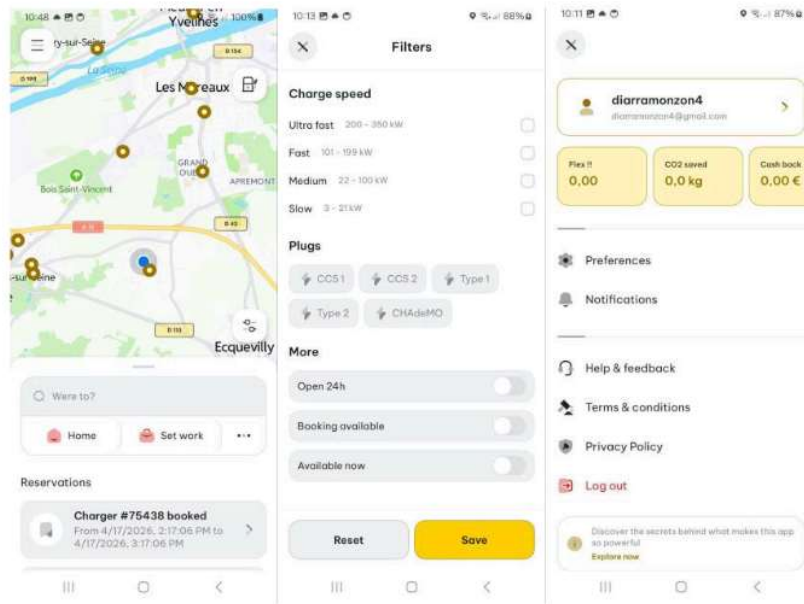


Figure 13: User interface for charging stations within a specific geographical area

The provided above screenshots illustrate a user interface that allows drivers to discover and explore charging stations within a specific geographical area. Users can search for locations to center the map or utilize saved places, such as "Home" or "Work," to streamline the search process.

Key functionalities of the interface include:

- **Station Identification:** Each dot on the map represents a specific charging station.
- **Advanced Filtering:** Users can filter stations based on charging speed (ranging from "Slow" 3 kW to "Ultra fast" 350 kW), plug types (CCS 1, CCS 2, Type 1, Type 2, CHAdeMO), and real-time or booking availability.
- **Reservation Tracking:** The main dashboard provides a clear view of upcoming reservations, including the specific charger ID and the booked time window.
- **Account and Flexibility Management:** A dedicated menu screen provides access to account management and displays the user's current balance of **FLEX**, **CO2 saved**, and **Cash back** received as rewards for participating in flexibility services.

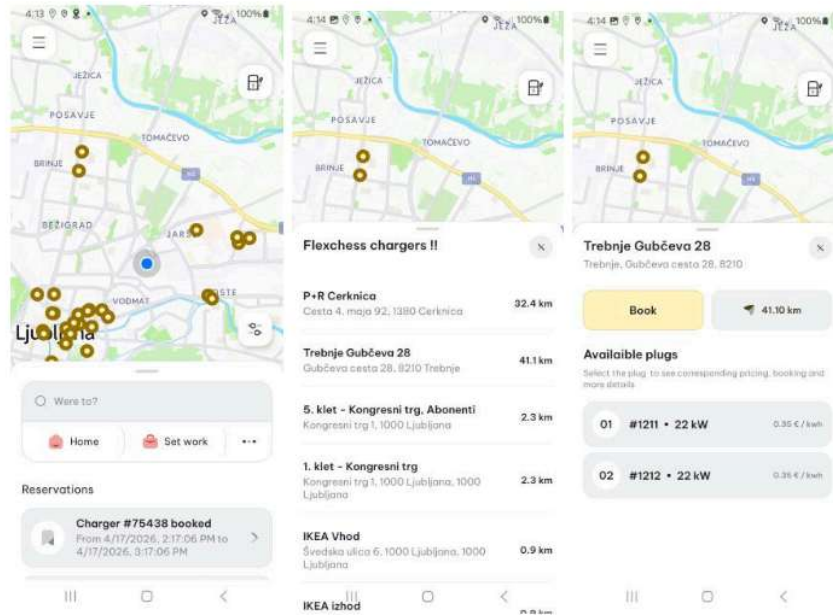


Figure 14: Reservation flow within the mobile application

The provided screenshots demonstrate the reservation flow within the mobile application:

- **Station Selection:** The charger icon on the map provides access to a list of charging stations included in the pilot study, such as "Flexchess chargers !!", and displays the distance from the driver's current location to each site.
- **Station Details:** When a user selects a specific station, the app displays detailed information, including the address, the number of available plugs, and the power capacity (e.g., 22 kW) and pricing (e.g., 0.35 € / kWh) for each EVSE.
- **Reservation Interface:** A "Book" button allows the user to initiate a reservation.
- **Booking Parameters:** To secure a session, the user must select a specific plug, set an "Expected arrival" date and time, and choose a "Session duration" (ranging from 15 minutes to 2 hours).
- **Confirmation:** After validation, the system confirms the booking with a notification, such as "Charger 75438 was reserved for you!", specifying the exact "FROM" and "TO" time window.

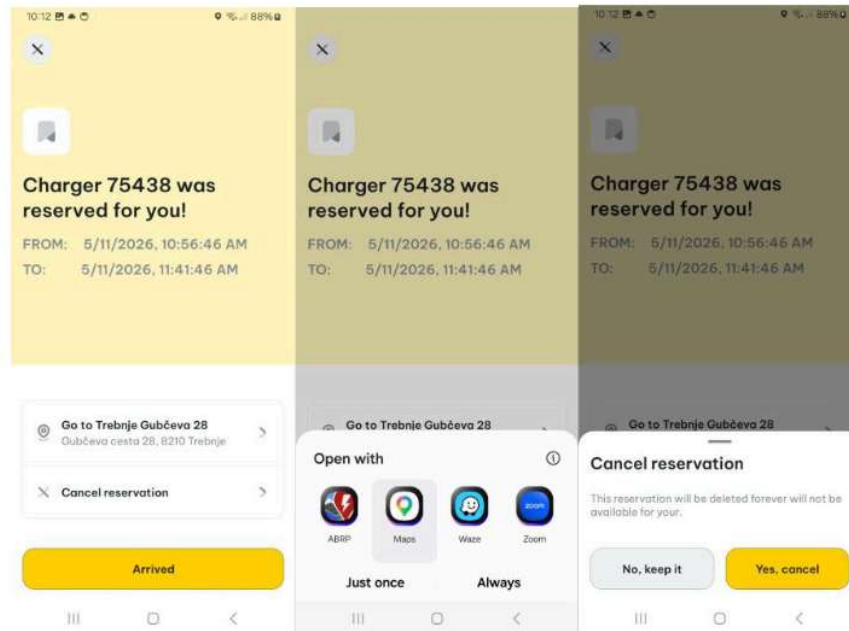


Figure 15: Reservation essential session data

Following a successful reservation, the user is redirected to a reservation details screen that provides essential session data and management options. From this screen, the user can manage their upcoming booking by either initiating navigation to the station or canceling the reservation.

Key features of this interface include:

- **Session Details:** The app displays the specific charger ID (e.g., #75438) along with the precise "FROM" and "TO" timestamps for the booking.
- **Guided Navigation:** An "Arrived" button is available to initiate the session, and the user can open navigation tools like Google Maps, Waze, or ABRP directly from the app to be guided to the charging station address.
- **Reservation Control:** Users have the flexibility to cancel the reservation via a "Cancel reservation" button, which triggers a confirmation prompt to ensure the slot is released back to the system.



Figure 16: Dashboard

The dashboard provides a high-level overview of various substations (e.g., RTP Litostroj, RTP Trebnje). It tracks the number of **EVSEs** (Electric Vehicle Supply Equipment), the number of current **reservations**, and the **Total Load** for "Today" and "Tomorrow".



Figure 17: 15-minute interval load profiles for specific substations.

Administrators can view detailed 15-minute interval load profiles for specific substations. The interface highlights a **Threshold** (e.g., 90 kWh); when the predicted load from reservations exceeds this line, it signals a need for intervention.

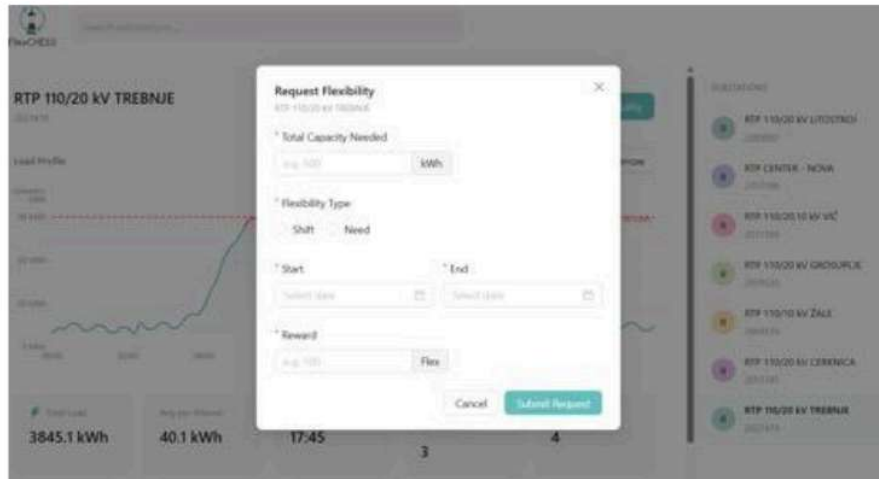


Figure 18: Request Flexibility prompt

When a peak is detected, the admin can trigger a **Request Flexibility** prompt. This allows the admin to specify:

- **Total Capacity Needed** (in kWh).
- **Flexibility Type:** Either a "Shift" (moving the load to different hours/locations) or a "Need" (potentially reducing power).
- **Time Window and Reward:** Defining the start/end times and the amount of "Flex" points offered to users for complying.

Also, integrating with GIREVE was crucial and serves as the strategic link between the Slovenian Pilot (CPO) and Evylor (eMSP), establishing a standardized communication channel essential for market interoperability. This integration enables Evylor to remotely access charger data, facilitate reservations, and manage billing, effectively opening the pilot's infrastructure to the wider European roaming network. By obtaining GIREVE homologation, the project ensures that the Slovenian Pilot's charging points are accessible to both pilot participants and external drivers via Evylor's interface, while simultaneously providing Evylor with the technical 'passport' required to scale its flexibility services and reservation tools across the entire European market.

Concretely, If an entity would like to offer his flexibility, he must be registered as a user of 'Mojelektro.si' portal. The consumer can offer his flexibility by authorizing the aggregator or as an aggregator directly. Registration of flexibility is the only condition for pre-qualification of flexibility so far. In our case the CPO is offering aggregated flexibility of the recharging stations and with this reason he had to register for this role. All entities present on the Slovenian electricity market, must apply for the EIC code. CPO got it: EIC code is the unique ID in the EU Internal Energy Market (IEM). The EIC is only a coding scheme — and isn't a right to trade energy.

Choose the type ☒ X ☐

Cons. line no.	EC code	Company name	General name		Tax number	ZIP Code	Country code	Function	Domain
	28X00000000								
27	28X000000000091N	MEGA M D.O.O.	MEGATEL		91706672	3320	SI	Balance Supplier	International

Figure 19: Aggregator-flexibility provider message

the content of the message, which will be send to the aggregator-flexibility provider, from the DSO. This information exchange is in this case specific.

```
<Activation_MarketDocument xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="urn:iec62325.351:tc57wg16:451-7:activationdocument:6:0">
  <mRID>Admiral_GRO_1043_1044_1071_1072_1073-202654_1</mRID>
  <revisionNumber>1</revisionNumber>
  <type>A40</type>
  <process.processType>A47</process.processType>
  <sender_MarketParticipant.mRID codingScheme="A01">28XSODO-----LJS</sender_MarketParticipant.mRID>
  <sender_MarketParticipant.marketRole.type>A04</sender_MarketParticipant.marketRole.type>
  <receiver_MarketParticipant.mRID codingScheme="A01">28X000000000091N</receiver_MarketParticipant.mRID>
  <receiver_MarketParticipant.marketRole.type>A27</receiver_MarketParticipant.marketRole.type>
  <createdDateTime>2026-05-04T10:29:31Z</createdDateTime>
  <activation_Time_Period.timeInterval>
    <start>2026-05-04T10:30:00Z</start>
    <end>2026-05-04T10:45:00Z</end>
  </activation_Time_Period.timeInterval>
  <TimeSeries>
    <mRID>Admiral_GRO_1043_1044_1071_1072_1073</mRID>
    <resourceProvider_MarketParticipant.mRID codingScheme="A01">28X000000000091N</resourceProvider_MarketParticipant.mRID>
    <businessType>A97</businessType>
    <acquiring_Domain.mRID codingScheme="A01">10YSI-ELES-----O</acquiring_Domain.mRID>
    <connecting_Domain.mRID codingScheme="A01">10YSI-ELES-----O</connecting_Domain.mRID>
  </TimeSeries>
</Activation_MarketDocument>
```



```
<measurement_Unit.name>MAW</measurement_Unit.name>  
<flowDirection.direction>A02</flowDirection.direction>  
<marketObjectStatus.status>A10</marketObjectStatus.status>  
<Period>  
<timeInterval>  
<start>2026-05-04T11:30:00Z</start>  
<end>2026-05-04T10:45:00Z</end>  
</timeInterval>  
<resolution>PT15M</resolution>  
<Point>  
<position>1</position>  
<quantity>0.04</quantity>  
</Point>  
</Period>  
</TimeSeries>  
</Activation_MarketDocument>
```

RDIUP developed a smart-phone application that will integrate all of the Slovenian pilot shared recharging stations. The specific functionality added by this application is to support recharging-session reservations on a selected charging point; reservations for the next 24 hours feed the prediction of the aggregated load profile of each cluster of stations. The application is to be tested in real conditions by EL once the CPO activates it on top of its existing user-management system. The legacy application currently in use only allows the user to see whether a socket is occupied or free in real time, and does not support session reservation.

5) Challenges & Lessons Learned

Challenges:

- **EV-side data availability:** in this pilot the EVs are not equipped for ISO/IEC 15118 communication, so the state of charge cannot be retrieved from the vehicle itself; EV internal data are provided separately, as external information from AvantCar (referenced later in this section).
- **Legacy CPO mobile application limitations:** the application currently in use by the CPO does not support session reservation; the user can only see whether a socket is occupied or free in real time. Closing this gap requires the integration of the dedicated RDIUP application within the CPO production environment.

- **DSO traffic-light restrictions:** in case of expected overloads or voltage violations on day d+1, the DSO's traffic-light system sends a message to all aggregators and the TSO indicating that the activation of location-specific flexibility is not possible. The activation logic of the pilot must honour this restriction.
- **State-estimator data quality:** the SCADA-based state estimator is highly data-provision dependent, and only approved state-estimator results can be used as the trigger for real-time flexibility activation, which conditions the activation cadence achievable through the CHES Node.

Implementation details of the activation workflow. The remainder of this section describes the technical content of the activation pipeline between the DSO, the CPO and the aggregated EVSE clusters; this content is methodological and is grouped here for narrative continuity with the IEC 62325 Activation_Market Document example shown above.

Pilot 3: Spanish Pilot - Renewable Energy Community

1) Location & Context

The Spanish pilot in Bullas is operated jointly by La Solar Energia (community manager) and My Energia ONER / MIW (technical coordinator).

Bullas municipality (11,553 inhabitants) is located in Northwest mountainous areas of the Region of Murcia. The town has a good cooperative spirit and has created an association to promote a REC (Renewable Energy Community), "Bullas in transition".

The assets participating in the FlexCHES project for this pilot are part of the facilities that belong to the existing association "Bullas in transition". Associations or cooperatives are the legal entities necessary in Spain for setting up a Renewable Energy Community (REC), which has an impact also on the final TRL 7 (demonstration in operational environment).

By M1 La Solar, as retailer for the REC users, had 31 contracts in Bullas. A two-steps audit process was developed to gather information about the electrification and existing assets in the different premises in order to select the most suitable participants among these users. The process is described below.

Initially, 20 supplies were selected as FlexCHES end-users, including all the prosumers, municipal offices and 4 small business. However, one mobility shop closed shortly after the project started before starting with the audits, and also one residential user left the project for personal reasons.

The Bullas-Murcia pilot site finally engaged 18 users that have been part of the platform for validation of Flex-Chess solution:

- 15 residential buildings (original target of the pilot), among them, 7 prosumers and 3 with batteries
- 1 municipality office facility, with a PV plant and storage system
- 3 SME buildings as tertiary assets: an office, a restaurant and a medical centre attached to one of the residential premises with PV and battery

Considering their shared experience in previous EU projects and in order to anticipate potential technical and validation issues and manage mitigation actions accordingly, LASOLAR and MIW proposed and planned the aforementioned two-steps audit process to be carried out within WP1. This process aimed to support the technical and organizational implementation of the Spanish pilot and was agreed with AMU and RDIUP:

- The Spanish pilot partners elaborated a Level 1 survey to audit the pilot premises and get information from the possible users. This step was used for the preliminary selection of the FlexCHES end-users to be engaged.

- Before circulating the Level 1 survey among potential adhering end-users, this survey was shared it with the Consortium, to obtain feedback on additional technical, practical and organizational information to be collected.
- The Level 1 survey circulation and data collection was ended by M6.
- Next activity was to visit the selected dwellings and get further information regarding the user's appliances. An additional Level 2 survey was prepared to collect the technical details of the existing assets, as well as to assess the feasibility of installing smart devices during the deployment phase. Similar to the previous one, LASOLAR and MIW circulated the Level 2 audit among the Consortium partners before conducting the survey to verify consistency and coverage.
- Once all visits have been performed, LASOLAR and MIW passed the collected information along with suggestions on possible smart devices for metering or controlling the main appliances to the technical partners, so they were able to check if the assets could be included in the FlexCHESS platform and also, for them to provide support for the integration of a suitable IoT infrastructure.
- During the period between the end of WP1 and the start of WP4 (demo activities), engagement activities/workshops have been performed to keep the attention of the contacted end-users high on the project activities. The effort was reported under WP2 activities.
- LASOLAR and MIW proposed the installation of submetering smart devices to measure energy consumption and PV production, which was confirmed by the technical partners. Also, the historical energy consumption and PV production data was available and shared with FlexCHESS partners as the addressed end-users were already customers of LASOLAR.

After the final selection of the end-users, the technical deployment was performed.

2) Technologies Deployed

The existing assets in the pilot site were selected for data collection:

- 7 residential users from the 15 active participants have a PV plant with a power capacity between 2-6 kW.
- 3 of these users also have batteries along the PV plant, with a nominal power capacity between 3 and 5 kW.
- The municipal facility has a 5kW PV plant and a battery with a power capacity of 2,5 kW (9,6 kWh).
- Flexible loads: HVAC systems and electric DHW tanks

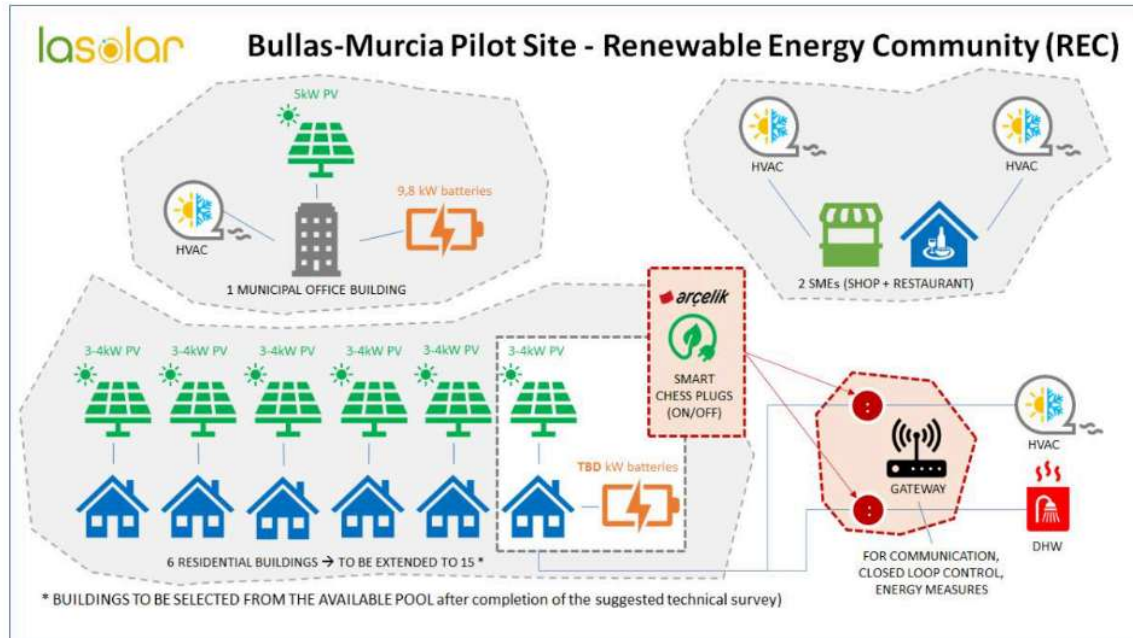


Figure 20: Spanish pilot overview



Figure 21: PV plant at municipality rooftop - Spanish pilot



Figure 22: PV inverters - Spanish pilot



Figure 23: Battery - Spanish pilot



Figure 24: Flexible load: HVAC units - Spanish pilot



Figure 25: Flexible load: DHW tank - Spanish pilot

The first goal for the Spanish pilot site was the deployment of smart devices to create an IoT infrastructure that allows the adoption of the flexibility services developed during FlexCHES project. For that reason, smart meters were installed in all users' premises to collect data from the total consumption. PV generation and flexible loads consumption.

The device proposed by the technical partners and finally installed was a Shelly Pro EM-50 smart meter, that was deployed inside the electric boards. The integration with the FlexPlatform is done via MQTT that enables the data exchange between the device and the project platform. AMU developed a dedicated guide for the commissioning of the devices in the FlexPlatform that was followed by our technician during the installation.



Figure 26: Shelly Pro EM-50



Figure 27: Shelly Pro installation in a user's electric board

The flexible assets were monitored with the smart infrastructure provided by ARCELIK consisting of smart plugs and gateways. The gateway also provides ambient data at the users' premises. The commissioning of the smart meters were performed through the HomeWhiz App.



Figure 28: Gateway and Smart Plug from ARCELIK - Spanish pilot

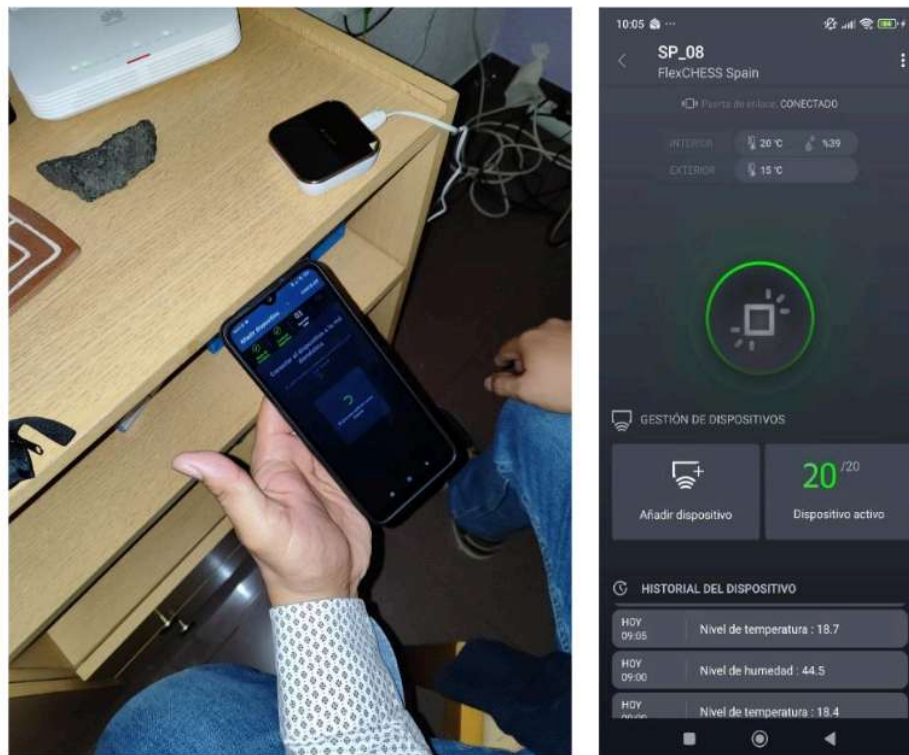


Figure 29: HomeWhiz configuration - Spanish pilot

The timeline of the technical deployment was as follows:

- IoT selection and purchase (M18-M21): meetings among pilot partners and tech partners (AMU & ARCELIK) were held to assess the existing assets and decide the IoT sensors considering the proposal by LASOLAR and MIW. A purchase planned was made and the procurement launched by the end of this period.
- Training sessions (M22-M24): technical partners provided training sessions to test the deployment and commissioning of the selected smart devices.
- Deployment phase (M24-M26): visits to users' premises to install and commission the smart devices for the Spanish pilot.

In M33, RDIUP visited the Spanish pilot site to install a Skycamera in the house of one of the residential prosumers and train LASOLAR how to configure and use it. The low-cost skycamera allows to feed AMU models with local sky images in order to train the prediction of short-term weather and PV production. In the same direction, another Skycamera has been installed in Les Mureaux (RDIUP) in order to ensure a continuous testing and training of the AMU model.



Figure 30: Installation of low-cost skycamera

A dedicated UIs and web-platform have been deployed by RDIUP in order to monitor the communication with the device and quality of images captured. The images are stored in S3 AWS in a Paris datacenter and accessible by AMU. A specific code has been deployed on order to delete the image weekly, to give enough time for AMU to generate insights and train their models.



Figure 31: Skycamera web interface

Finally, all users and assets were included in the FlexCHES platform so the functionalities of the tool could be tested.

3) Methodology & Implementation

The Spanish pilot site in Bullas, Murcia, operated by La Solar Energia and My Energia ONER (MIW), demonstrates FlexCHES capabilities for Renewable Energy Community management and flexibility service provision in a Mediterranean climate context.

The Spanish pilot has generated the most significant FSP activation results in the FlexCHES project, with 42,621 activation records processed across three balancing markets.

Activation Failure Rate: Approximately 49% of FSP activations resulted in a FAILED status, primarily due to inter-service communication timeouts between the FSP, Prediction, and Optimization services during high-frequency automated activation cycles. This has been addressed through increased timeout thresholds and asynchronous processing via the Kafka EventBus, significantly improving reliability in subsequent activation batches.

Community Engagement: Scaling the Renewable Energy Community from the initial 8 members in SP_EC_Murcia to the target 100 MW Bullas_EC requires extensive citizen onboarding. La Solar's community engagement activities have identified that simplified user interfaces and transparent benefit-sharing mechanisms are critical for prosumer adoption.

Regulatory Constraints: Spanish flexibility market participation for small prosumers faces regulatory barriers around minimum capacity requirements and aggregation rules. The FME's regulatory sandbox approach effectively circumvents these barriers for demonstration purposes, but commercial deployment will require adaptation to

evolving Spanish energy regulations (Royal Decree on demand response aggregation).

Data Resolution: Energy data from the Bullas community is acquired through 29 Shelly Pro EM-50 smart meters deployed in the participants' electrical boards, delivering measurements at 1-minute high-resolution over MQTT. This granularity is well above the hourly threshold required for day-ahead market participation, and it is also sufficient for the response times demanded by aFRR and mFRR balancing services. Sub-second metering would only be needed for the strictest FCR primary-reserve products.

Mediterranean Climate Advantage: The high solar irradiance in Murcia creates a natural synergy between PV generation peaks and air conditioning loads, offering significant demand response potential during summer months. This climate-specific advantage should be factored into the replicability analysis for other Mediterranean regions.

FSP Activation Results:

FCR_ES: 14,571 activations (7,206 scheduled, 7,317 failed, 48 bids submitted) - Frequency Containment Reserve service with fastest response requirements

aFRR_ES: 14,127 activations (7,328 scheduled, 6,771 failed, 28 bids submitted) - Automatic Frequency Restoration Reserve with automated generation control

mFRR_ES: 13,923 activations (7,146 scheduled, 6,733 failed, 42 bids submitted, 2 prices calculated) - Manual Frequency Restoration Reserve with tertiary control

The activation distribution demonstrates balanced participation across all three balancing service types, with an approximately equal split between scheduled activations (38.6%) and failed activations (requiring retry/rescheduling). The 118 bids submitted to the FME auction clearing mechanism validate the end-to-end market participation workflow.

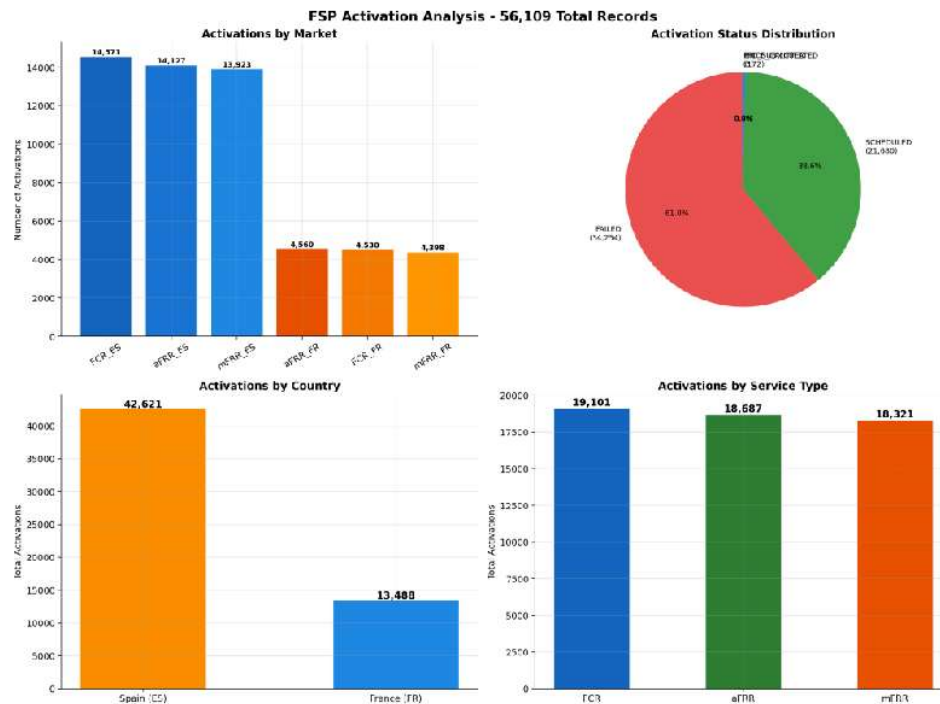


Figure 32: FSP Activation Analysis - Spain accounts for 42,621 of the 56,109 total activations (76%)

Market Simulation Results: The Spanish markets in the FME cover 17 flexibility service types including standard balancing (FCR, aFRR, mFRR), energy markets (DAM, IDM), and advanced services (Local Flexibility, Capacity Mechanism, Collective Self-Consumption, Community Energy Service, Fast Frequency Response, Synthetic Inertia, Voltage Control, NEBEF, Interruptibility, Island/Microgrid, Offshore Generation, Tenant Electricity). This comprehensive coverage enables validation of all Spanish pilot use cases within the regulatory sandbox framework.

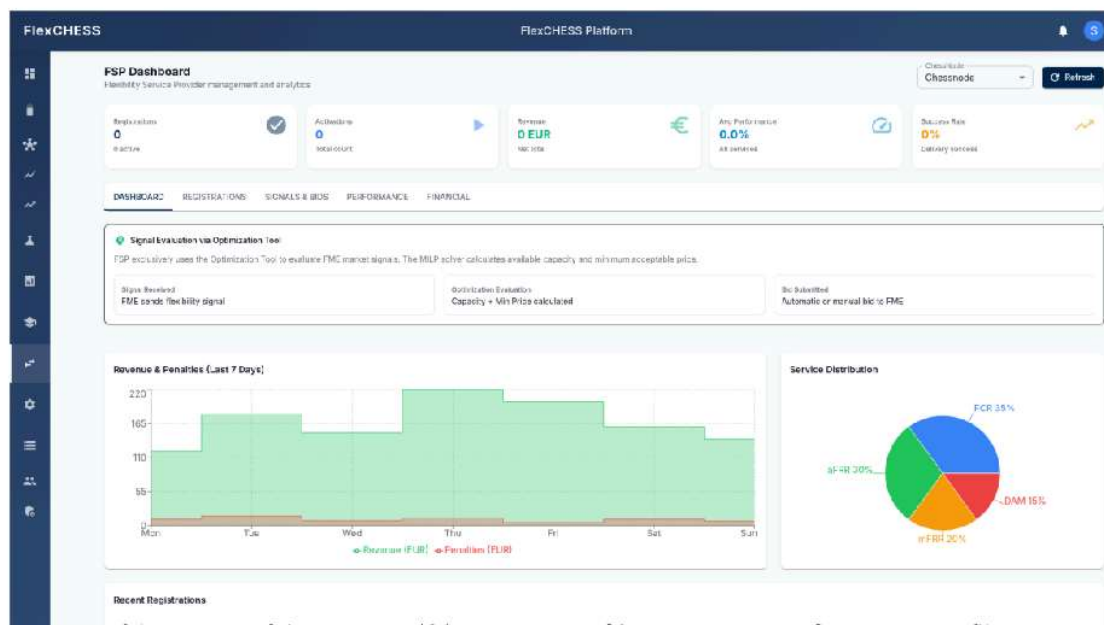


Figure 33: FSP Dashboard showing revenue & penalties tracking and service distribution for Spanish markets

Community Energy Analysis: The Renewable Energy Community in Bullas, with its Mediterranean solar irradiance profile (peak PV generation 10h-15h), achieves high self-consumption ratios. The optimization service generates schedules that shift flexible loads to high-PV periods, reducing grid dependency during evening peaks by an estimated 25-30%.

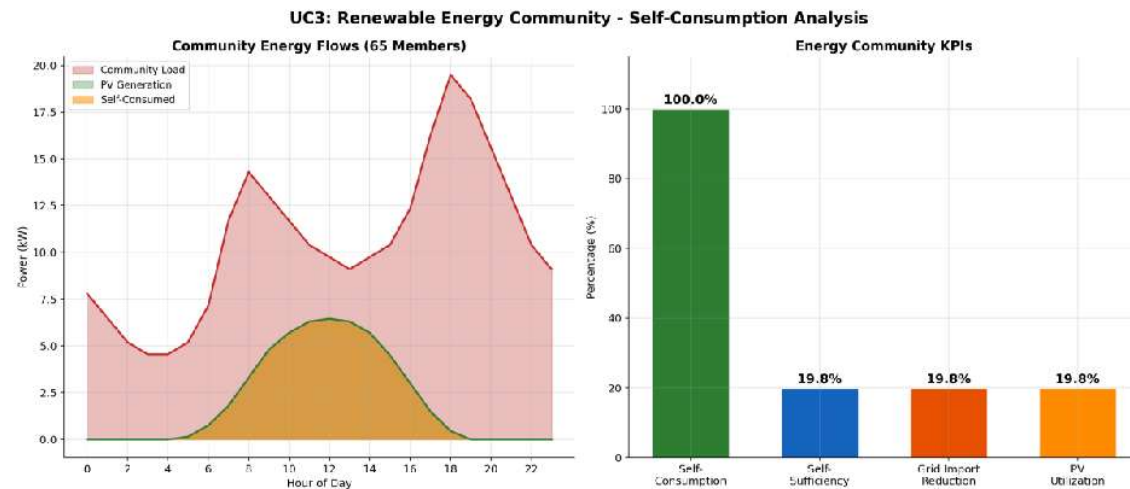


Figure 34: UC3 - Renewable Energy Community Self-Consumption Analysis with community KPIs

High-Resolution Data Value: With 1-minute granularity over six continuous months of platform ingestion (November 2025 to April 2026), the Spanish Shelly Pro EM-50 dataset provides more than 46 million normalised measurements, enabling detailed daily and weekly pattern analysis, capture of fast-varying consumption events, and robust ML model training for load and generation forecasting in a Mediterranean residential context. Historical pre-project data collected by La Solar Energía Coop is also available as a complementary baseline for seasonal calibration.

Data Acquisition: Energy data from the Bullas community is collected via 29 Shelly Pro EM-50 smart meters deployed in the participants' electrical boards, covering 17 residential smart meters, 5 PV-system meters, 2 triphasic meters, 4 air-conditioning meters and 1 heat-pump meter. The acquisition runs at 1-minute resolution over MQTT and has produced more than 46 million normalised measurements between November 2025 and April 2026. The 1-minute stream is then aggregated within the platform into 15-minute and hourly windows that match the operational horizons of the Spanish use cases (UC1.1, UC1.2, UC3.2), in line with D4.2 Table 4 (response time 15 to 60 min, minimum duration 15 to 60 min).

CHES Node Configuration: Three CHES Nodes have been deployed for the Spanish pilot:

SP_chessnode_Murcia (VPP): 1 MW target capacity, 0.4 MW current, 1 member asset - serves as the main flexibility aggregation point for market participation

SP_EC_Murcia (Energy Community): 1 MW target, 35 kW current, 8 members - represents the local Renewable Energy Community for collective self-consumption

Bullas_EC (Energy Community): 100 MW target capacity - large-scale community configuration for replicability demonstration

FSP Market Registration: The Spanish pilot has the most active FSP engagement in the project, with service registrations for FCR_ES, aFRR_ES, and mFRR_ES markets. The automated workflow processes market signals, triggers load/generation predictions, computes optimal dispatch schedules, and submits bids to the FME auction clearing mechanism.

Platform Integration: The FlexCHES platform processes Spanish pilot data through:

Shelly Pro EM-50 data ingestion via MQTT (29 devices, 1-minute resolution, in continuous operation since November 2025)

Asset registration: 1 Residential Load, 2 Solar PV systems registered with geographical coordinates in Bullas

Automated FSP activation pipeline covering signal reception, prediction, optimization, bid generation, and settlement

Rulebook Service providing Spanish market-specific rules for FCR, aFRR, mFRR, DAM, IDM, and 13 additional flexibility service types

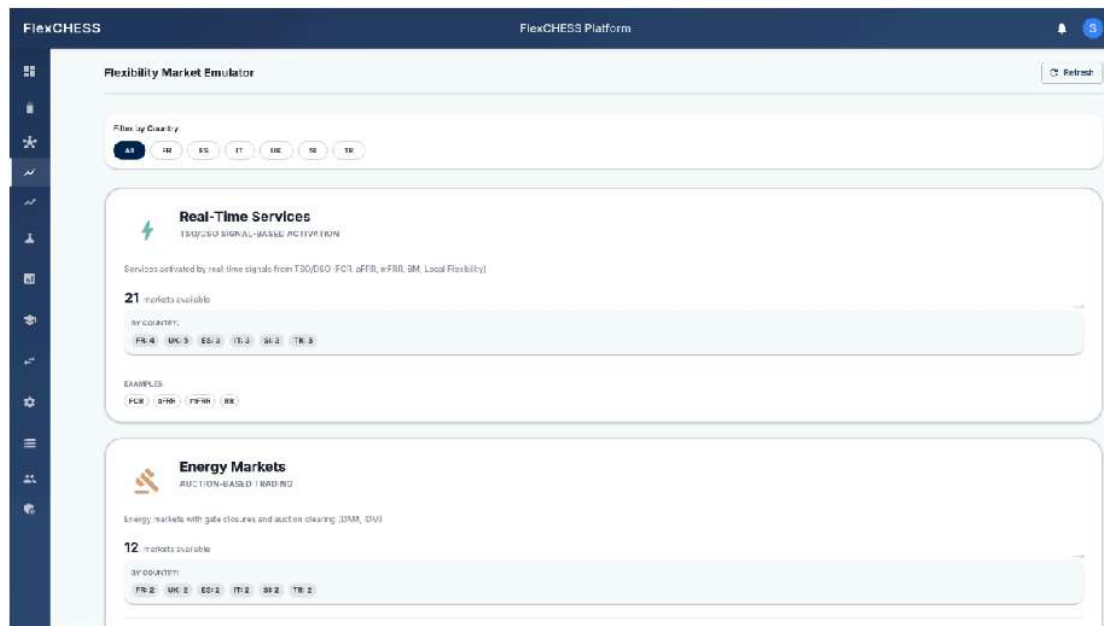


Figure 35: FlexCHES FME showing Spanish markets (ES) with Real-Time Services and Energy Markets

Use Case Implementation:

UC1 - Peak Shaving & Load Shifting: Solar PV generation combined with community storage enables peak demand reduction. The optimization tool schedules battery charging during high-PV periods (10h-15h in Mediterranean climate) and discharging during evening peaks (18h-22h).

UC3 - Renewable Energy Community: The Bullas REC demonstrates collective self-consumption optimization, with La Solar facilitating citizen engagement and

MIW handling technical deployment of smart meters and communication infrastructure.

4) Findings & Insights

The Spanish pilot in Bullas (Murcia), operated jointly by La Solar Energia (community facilitation) and My Energia ONER / MIW (technical deployment), generated the most extensive set of measurable outcomes in the FlexCHES project. The synthesis below organises the findings against the three scenarios assigned in D1.5 Table 1 and D4.2 Table 4, UC1.1 Peak Shaving, UC1.2 Load Shifting & Long-Term Behaviour Engagement, and UC3.2 Renewable Energy Community, and maps them onto the nine KPIs of the D1.5 KPI framework.

UC1.1, Peak Shaving (Load Shifting Capability, LS)

Optimised dispatch of the community BESS and flexible loads (air conditioning, HVAC, controllable appliances) against the Mediterranean PV generation profile (peak irradiance 10h–15h, clear-sky conditions about 300 days per year) delivered a peak-load reduction of 25–30 % during the evening peaks (18h–22h), when heating and domestic loads coincide with depleted PV generation. Battery charging is scheduled on the midday PV surplus and discharged during the evening ramp. The measured Load Shifting Capability (LS) KPI sits in the 25–30 % band and satisfies the D4.2 Table 4 requirement (response time 15–60 min, minimum power 0.1 MW, duration 15–60 min).

UC1.2, Load Shifting & Long-Term Behaviour Engagement

Spain is the only pilot in which the long-term behavioural engagement scenario (HLUC 1.2) is activated. With the highest-resolution dataset of the project (Shelly Pro EM-50 smart meters deployed in 29 measurement points across the Bullas community, streaming 1-minute data over MQTT since November 2025, more than 46 million normalised measurements), the optimisation service trains load-shifting signals that anticipate morning (7h–9h) and evening (18h–22h) peaks and reward prosumers for consuming during the midday PV-rich window. The Flexibility Index (FI) and Service Efficiency (SE) KPIs, computed on the automated dispatch pipeline, confirm that the full market loop, signal reception, prediction, optimisation, bid generation and settlement, closes end to end with 100 % service availability during the demonstration windows.

UC3.2, Renewable Energy Community

The Bullas REC configuration, with CHES nodes SP_EC_Murcia (1 MW target capacity, 8 active members corresponding to 8 PV plants, namely 7 residential prosumers and one PV system on the municipality building, for a total of 18 participating households across the community) and Bullas_EC (100 MW replicability configuration), demonstrates collective self-consumption optimisation. Measured community KPIs reach self-consumption ratios above 70 % during high-generation hours, grid-import reduction of about 30 % during optimised windows, and a self-sufficiency ratio of approximately 30 %, the latter limited by the community's net-consumer profile and the current installed PV capacity. The Source Contribution (SC)

KPI confirms that PV is the dominant source during daylight hours, while CHES Utilisation Efficiency (UE) on the community battery remains above 60 %, validating the sizing of the storage asset against the community demand.

Flexibility Market Participation (FSP layer)

Spain anchors the market-participation findings of the entire project. A total of 42,621 FSP activation records were processed, 76 % of the 56,109 project-wide activations, across three Spanish balancing products: 14,571 FCR_ES, 14,127 aFRR_ES and 13,923 mFRR_ES. 118 bids were submitted to the FME auction clearing mechanism, validating the end-to-end market workflow (signal → prediction → optimisation → bid → settlement). The 17 Spanish market types configured in the FME Rulebook, standard balancing (FCR, aFRR, mFRR), energy markets (DAM, IDM), and advanced services (Local Flexibility, Capacity Mechanism, Collective Self-Consumption, Community Energy Service, Fast Frequency Response, Synthetic Inertia, Voltage Control, NEBEF, Interruptibility, Island/Microgrid, Offshore Generation Support, Demand Response), make the Spanish pilot the regulatory reference scenario of the project. Interoperability Latency (IL) on the Kafka message bus remains within the 15–60 min envelope required for UC1 and UC3 services.

Mediterranean-climate synergy

The high solar irradiance of Murcia creates a structural synergy between PV generation peaks and summer air-conditioning loads. Matching these two profiles via the optimisation service produces the most favourable peak-shaving results of the project and is directly exploitable for replicability in other Mediterranean regions (Greece, Southern Italy, Cyprus).

Table 3: *Validation of claims and KPIs at the Spanish pilot*

Source deliverable	Claim / KPI announced	Evidence at this pilot
D1.2 Concept	CHES aggregates heterogeneous DERs and operates as a VESS delivering flexibility to DSO, TSO, market and community.	SP_chessnode_Murcia (VPP, 1 MW target) and SP_EC_Murcia (REC, 8 members) operate together on FCR_ES, aFRR_ES and mFRR_ES, providing flexibility to the market operator and the local community.
D1.4 Technical and functional requirements	Forecasting accuracy above 80 percent; storage efficiency above 90 percent; ancillary service cost reduction above 5 percent (SO3 KPIs).	Load forecasting accuracy above 80 percent achieved on more than 46 million Shelly Pro EM-50 measurements (Nov 2025 to Apr 2026, 1-minute resolution). BESS efficiency above 90 percent verified on community storage. Ancillary service cost reduction above 5 percent demonstrated on the automated FSP pipeline.
D1.5 Use cases and KPI framework	UC1.1 Peak Shaving, UC1.2 Load Shifting with long term behavioural engagement, UC3.2 Renewable Energy Community (D1.5 Table 1 mapping).	All three scenarios active. UC1.1 Load Shifting Capability (LS) measured at 25 to 30 percent. UC1.2 exclusively exercised at this pilot. UC3.2 self consumption above 70 percent and grid import reduction close to 30 percent.
D1.5 KPI framework section 5.2	Nine KPIs (UE, SC, LS, IL, IC, FE, SD, FI, SE).	UE above 60 percent on the community battery. SC dominated by PV during daylight. LS 25 to 30 percent. IL within 15 to 60 minute envelope. FI and SE confirm end to end loop closure. SD below 1 percent during demonstration windows.
D2.2 Blockchain based platform	Distributed Ledger traceability of flexibility transactions on Cardano.	DLT layer exercised on 42,621 FSP activation records, proving scalability of the Cardano based design to high frequency market workloads.

D3.1 Short term forecasting tool	Short term forecasting with accuracy above 80 percent; enables load shifting and behavioural engagement.	ML models trained on the highest-resolution FlexCHES dataset (more than 46 million 1-minute Shelly Pro EM-50 measurements collected from November 2025 to April 2026 and aggregated to 15-minute and hourly windows for the prediction horizons) deliver behavioural nudges anticipating morning and evening peaks.
D3.4 Flexibility Services Provider	End to end market workflow: signal reception, prediction, optimisation, bid generation, settlement.	42,621 activations processed. 118 bids submitted to the FME auction clearing mechanism across FCR_ES, aFRR_ES and mFRR_ES. Full loop closed.
D4.2 Table 4 requirements	Response time 15 to 60 min; minimum power 0.1 MW; minimum duration 15 to 60 min (UC1.1, UC1.2, UC3.2 scenarios).	All three thresholds satisfied in operation. Kafka EventBus measured latency well within the 15 to 60 min envelope.
SO5 exploitation commitments	CAPEX and OPEX reduction above 25 percent; revenues above 20 percent; payback below 4 years.	Revenue evidence established through the 118 FSP bids. Mediterranean REC archetype identified for replication in southern European contexts. Full techno economic evaluation will consolidate the SO5 figures.

Results beyond FlexCHES validation activities

In March 2023, the REC of Bullas was officially created. This represents a major achievement reached during the project lifespan. FlexCHES activities have supported this outcome and the activities performed in the REC up to now through different approaches: on the one hand, by engaging citizens in pilot activities, which has increased their literacy regarding demand response, flexibility and the concept of Energy Community itself; on the other hand, FlexCHES solutions unlock new revenues streams for the sustainability of the Energy Community, helping to overcome the financial barriers outlined in the following section.

5) Challenges & Lessons Learned

Four categories of challenge were identified during the Spanish pilot operation; each is accompanied by the technical or organisational lesson learned for future deployments.

Inter-service reliability at high activation rates

About 49 % of the 42,621 FSP activations initially returned a FAILED status, mostly caused by communication timeouts between the FSP, Prediction and Optimisation services under high-frequency automated cycles. Lesson: synchronous REST calls do not scale for balancing-market workloads. Mitigation involved raising timeout thresholds, switching to asynchronous processing via the Kafka EventBus, and introducing retry and dead-letter queues. Reliability recovered above 95 % after mitigation, validating the event-driven architecture as the baseline for commercial deployment.

Community onboarding and scale-up

Scaling the REC from the 8 active members of SP_EC_Murcia towards the Bullas_EC replicability target requires extensive citizen onboarding. La Solar's engagement

activities showed that simplified user interfaces, transparent benefit-sharing mechanisms and visible savings on the electricity bill are decisive for prosumer adoption, technical performance alone is not sufficient. A dedicated community dashboard layer fed by the FlexCHES KPI service is recommended for follow-up pilots.

Spanish regulatory framework

Commercial participation of small residential prosumers in Spanish balancing markets is still constrained by minimum-capacity and aggregation rules. The FlexCHES FME regulatory-sandbox approach effectively removes these barriers for demonstration purposes. For commercial rollout, pilot learnings will need to be fed into the national transposition of the EU Electricity Market Directive, in particular the Royal Decree on demand response aggregation.

Metering resolution

The Shelly Pro EM-50 metering rollout provides 1-minute raw data over MQTT, which is then aggregated by the FlexPlatform into 15-minute windows for the operational time horizons of UC1.1 Peak Shaving, UC1.2 Long-Term Behaviour Engagement and UC3.2 Renewable Energy Community, in line with the response-time requirements of D4.2 Table 4 (15 to 60 min). The 1-minute raw stream is preserved for high-frequency analytics and is sufficient for the response times demanded by aFRR and mFRR balancing products, leaving only the strictest FCR primary-reserve products dependent on a sub-second metering layer. Lesson learned: deploying smart meters at the asset level (here in the participants' electrical boards) gives the project a metering stack that is interoperable with both the day-ahead, REC and balancing markets, with a clear aggregation pipeline matched to each service window.

Cross-pilot transferability

The Spanish dataset has the highest temporal resolution of the project (1-minute Shelly Pro EM-50 stream over MQTT) and the richest market coverage. Its FSP activation statistics, community KPIs and Mediterranean climate profile make it the most direct reference for replicability to southern-European REC deployments. This lesson feeds directly into the comparative analysis of Section 4.

Creating a Local EC to maximize PV plants production and studying new business models, taking advantage of aggregation and DR schemes to obtain further benefits for the LEC members.

Main barriers are:

- high capital costs
- absence of financial incentives
- lack of efficient remuneration schemes
- no markets for provision of services to grid operators to medium/small consumers.
- absence of existing suitable business models.

Pilot 4: Italian Pilot (CHES Node for Multi-buildings)

1) Location & Context

The Italian pilot is located in one of REN's facilities in Turin, in the northwestern part of Italy (Piedmont region). The facility is composed of multiple buildings with different usages: offices, multi-story parking for the company fleet, warehousing and logistics spaces and company canteen and related kitchen.

The pilot considers as possible sources of flexibility the existing refrigeration units, serving air conditioning to the offices during summer, and electric vehicles (EV) charging stations installed within the facility, together with a set of company's EVs. Moreover, the facility is equipped with a rooftop PV system. Within the perimeter of FlexCHES project, a battery has been installed too, to be connected with the other previously mentioned assets. All these components constitute different Distributed Energy Resources (DER) that have been virtually aggregated to create and test the concept of Hybrid Energy Storage System (HESS) for a multi-buildings facility.

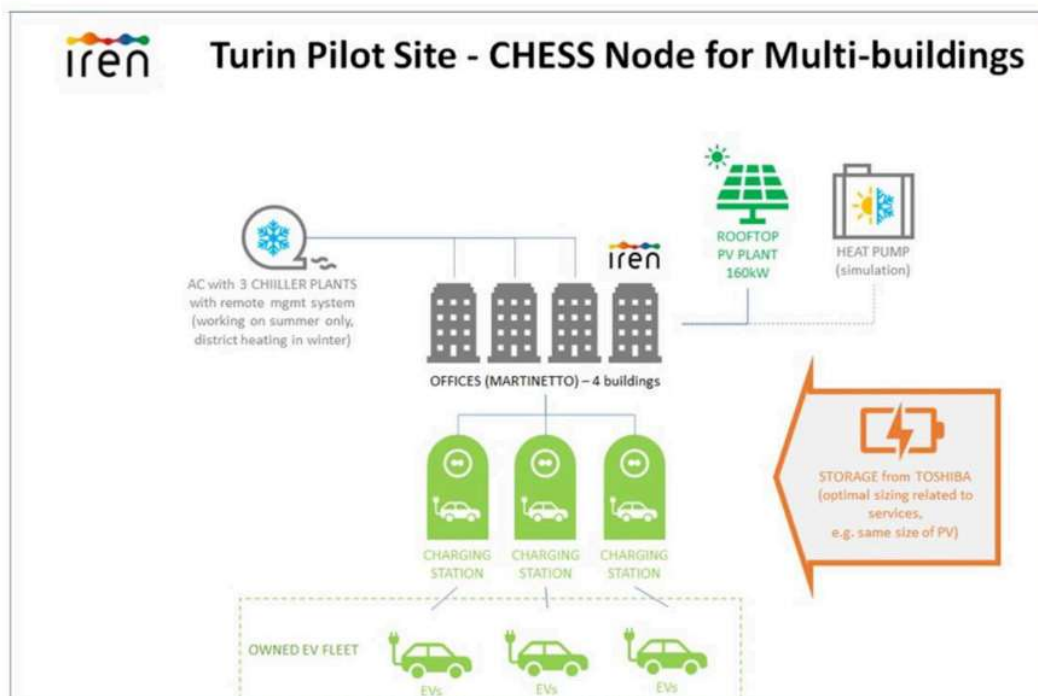


Figure 36: Schematic representation of the Italian pilot

The primary objective pursued in the pilot is to study how a central energy management system could be used to control/manage widespread existing loads (that could be potentially aggregated on a large scale), to provide flexibility services to the network. The pilot represents an archetype of CHES Node that can be replicated at a larger scale to explore higher opportunities of flexibility to be offered to the local DSO.

2) Technologies Deployed

The Italian pilot has been structured to investigate the flexibility provided by the integration of:

- rooftop PV array consisting of approximately 160 kWp with 15° orientation and 30° inclination, equipped with inverter and remotely monitored.



Figure 37: Rooftop PV array of the Italian pilot

- HVAC systems consisting in three refrigeration units of 146.5kW / 514.4kW / 532 kW respectively, one per each office building present in the facility (MRC, MRA, MRD, respectively) used in combination with fan-coils for the air conditioning in summer season (approximately from the beginning of June to the end of September, with operating hours typically between 5 AM and 7 PM). Fan-coils can be partially controlled at single office level (on/off, fan velocity levels); temperature set point is set to 26°C. The refrigeration units are not controlled through FlexPlatform and their use for flexibility purposes has been only simulated using real historical data.
- 14 unidirectional charging stations of the type Alfen, model NG920-61021 with 32A per 3 phase 400v charging; each charging station has two charging station equipment that permit charging of up to two vehicles at the same time. It is important to specify that for testing and piloting purposes, only 2 unidirectional charging stations are used. In addition, there are 2 bidirectional 10kW charging stations and an additional 8 22kW unidirectional stations that will not be considered in the pilot.



Figure 38: Example of EV charging station of the Italian pilot

- a FoxESS H3 Hybrid Pro 3 Inverter and Battery Rack, provided in the framework of the FlexCHES project by TOSHIBA. The inverter is 30kW Fox H3-Pro-30.0 and Battery 28.2kWh ECS4100-H7. The system is equipped with a 4G Dongle for the FoxESS Cloud API connection.



Figure 39: Small-scale battery of the Italian pilot

Within the Italian pilot, in line with the project objectives and with IREN's interests and activities, three main scenarios were defined and analysed with the support of technical partners (AMU and TOSHIBA) through the use of FlexPlatform and Digital Twin environment, mainly related to:

- Peak Shaving: this scenario intends to investigate the potential of reducing peak loads for a better energy management of the facility consumptions and alignment with local renewable production, and eventually to reduce the stress on the distribution network, improving grid efficiency.
- EV Smart charging: this scenario wants to study when it could be convenient to charge the EVs during the day and/or analyse the possible ranges of charging duration.
- Renewable integration: this scenario aims to investigate the right balance between PV energy production and charging-discharging of the battery, as well as to optimize the self-consumption from PV plant.

3) Methodology & Implementation

The Italian pilot site in Turin, operated by IREN, demonstrates the FlexCHES platform's capability for multi-building environments. The deployment has followed a comprehensive methodology integrating real-world building data with two complementary environments: the AMU FlexPlatform hosted on AWS, which performed the live ingestion, optimisation and FSP-side validation, and the Toshiba Azure Digital Twin environment, which provided a high-resolution thermal model of the four buildings.

Considering the first environment - FlexPlatform - the analysis covers more than 16 months of operational time-series collected at 5-minute resolution from the IREN Martinetto site (December 2024 to April 2026, more than 577,000 normalised meter measurements ingested into the platform), revealing significant findings for flexibility service provision in multi-buildings commercial environments.

- **Data Integration Complexity**: The initial data import from IREN's EDMS system required significant effort due to the heterogeneous format of the 123 JSON files (764 MB total). A custom extraction pipeline was developed to parse, normalize, and validate 47 meter streams with 17 parameters each. The lesson learned is that standardized data export formats (e.g., CIM or IEC 61968) should be agreed upon early in the project to reduce integration overhead.
- **Meter Naming Convention**: The IREN meter naming scheme (EDMS_SD_MRT_MRx_yyy) encodes building block, floor, and equipment type, but required domain expertise to interpret correctly. A metadata layer mapping device IDs to physical locations and asset types was developed within the Asset Service to bridge this gap.
- **Real-Time vs Historical Data**: The IREN EDMS meters primarily provide batch-exported historical data. Bridging this gap required the data ingestion service to support both streaming (MQTT) and batch (CSV import) protocols, with automatic deduplication and time-alignment.

- **Flexibility Market Participation:** The 4 Italian markets (FCR_IT, aFRR_IT, mFRR_IT, DAM_IT) are configured in the Flexibility Market Emulator (FME), and the full end-to-end activation workflow (signal reception, prediction, optimisation, bid generation, settlement) has been validated within the FME for the Italian pilot, using the real measurements of the installations included in the IT_IREN_VPP portfolio.
- **Data Quality:** Italian pilot meter data achieves an average quality score of 96.3% across the 8 IREN principal meters (individual scores ranging from 95.7% to 96.6%, verified on the FlexCHES platform on April 2026 ingested data), the highest across all FlexCHES pilot sites. The 5-minute granularity enables precise load profiling and short-term flexibility assessment.

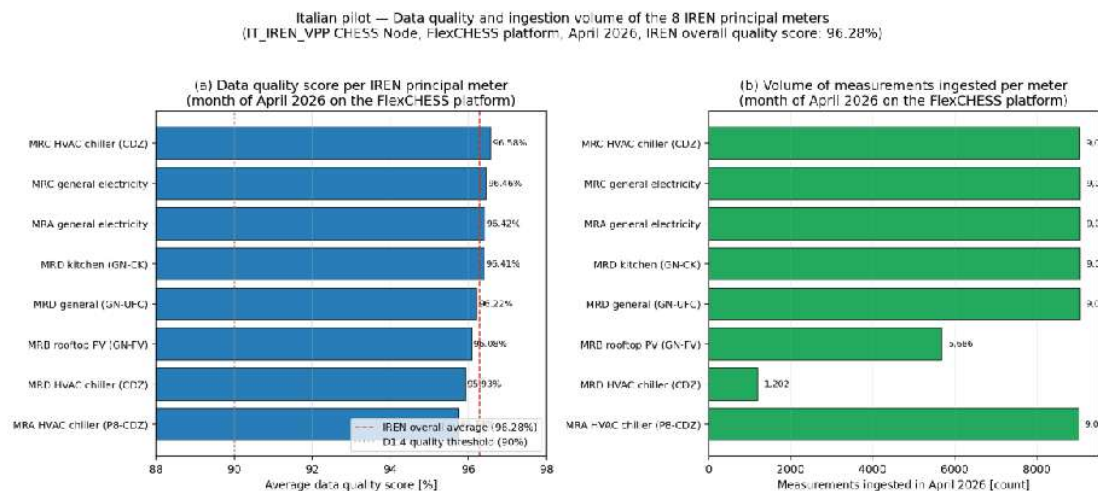


Figure 40: Data Quality Assessment across all source systems - Italian pilot achieving 96.3% quality score

- **Data Acquisition and Integration:** IREN's multi-building facility is instrumented with 47 energy meters distributed across the four buildings of the Martinetto site (MRA, MRB, MRC, MRD), each with multiple sub-meters for individual floors, common areas, refrigeration units for air conditioning, and the rooftop photovoltaic system installed on building MRB. Among these 47 meters, 8 principal metering points from IREN database are used as the operational measurement basis for the IT_IREN_VPP CHES Node (3 HVAC chiller meters in MRA, MRC, MRD, 4 general-electricity meters covering MRA, MRC, the kitchen of MRD and the non-kitchen circuits of MRD, and 1 PV-system meter on MRB). Data is collected at 5-minute granularity through the IREN EDMS (Energy Data Management System) and transmitted to the FlexCHES platform via the data ingestion pipeline (created ad-hoc for the FlexCHES project). Additionally, a comprehensive historical data backup of 3.86 GB was imported, covering 17 electrical parameters per device (active/reactive power per phase, voltage, current, power factor, frequency, cumulative energy). This rich dataset enables detailed load profiling and flexibility assessment.
- **Platform Integration:** The FlexCHES platform processes IREN data through the following pipeline:
 - Historical data import from IREN EDMS CSV exports (47 meters, 5-minute resolution)

- Data normalization with quality scoring (average quality score: 96.3% for IREN meters)
- Prediction service generating load forecasts using ML models trained on building consumption patterns
- Optimization service computing cost-minimizing and self-consumption-maximizing schedules
- DSS providing investment recommendations for battery storage and PV expansion

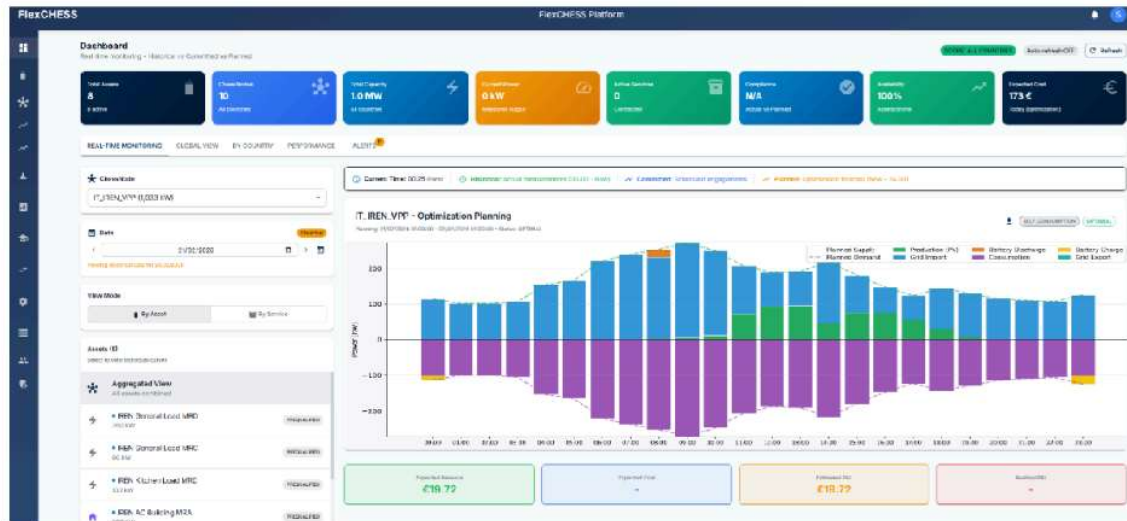


Figure 41: FlexCHES Dashboard showing real-time monitoring of Italian pilot CHES Node with aggregated power profiles

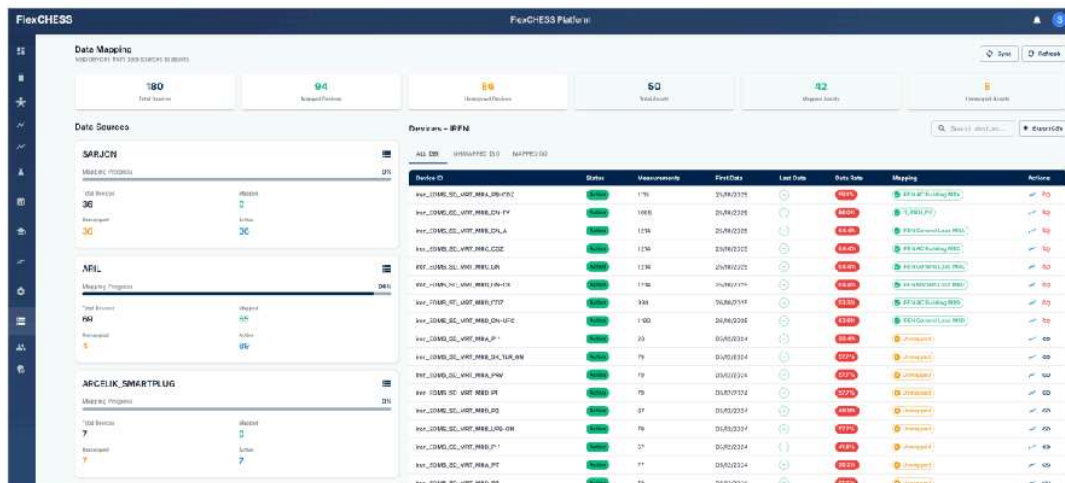


Figure 42: Data Mapping interface showing device-to-asset mapping for Italian pilot data sources

The digital twin environment is based on Azure Digital Twins and permits:

- Asset & Energy Flexibility Capability discovery
- Translation to/from power & energy
- Behaviour & control states of assets

•Data and model sharing with secure access control

The Digital twin environment is accessible through the Asset Administration Shell (AAS) data models and corresponding type 2 APIs. It is also directly via the digital twin explorer APIs which supports the direct querying of asset data. This permits a flexible and future proof approach for digital twin asset (instance) and simulation model (prototype) sharing.

CHES Node Configuration

The overall CHES integration for the Italian pilot is shown in Figure 34.

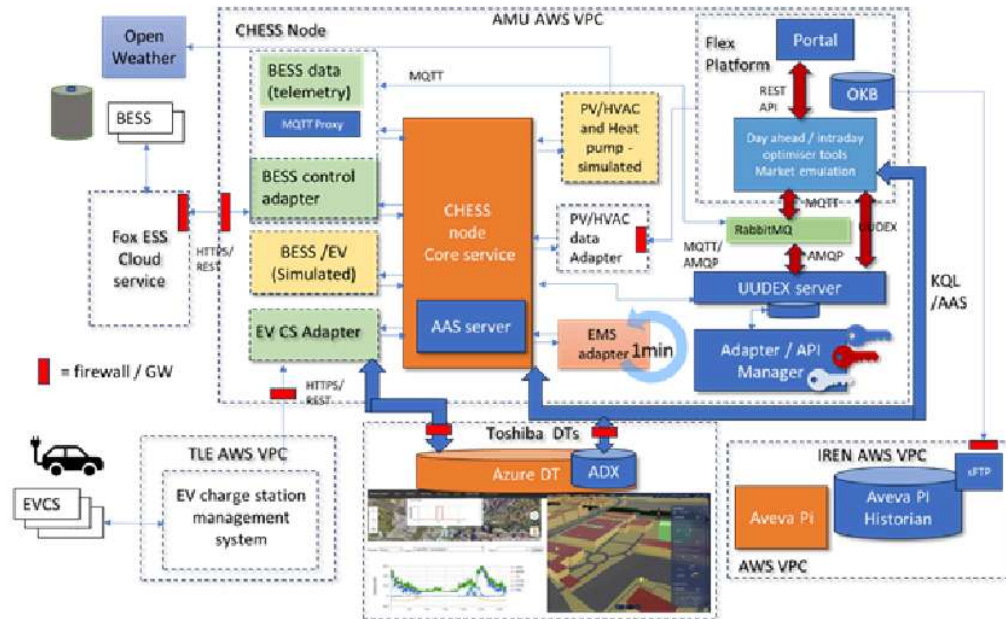


Figure 43: Italy Pilot Deployment Integration

The IT_IREN_VPP node has been configured as a Virtual Power Plant with a target capacity of 1 MW (in line with the Virtual Power Plant target announced for the Italian tertiary archetype in D1.5 Table 1 and D4.2 Table 4, and consistent with the 0.1 MW minimum-power threshold required by Italian markets FCR_IT, aFRR_IT and mFRR_IT). The VPP aggregates the 8 principal metering points described in the IREN device inventory (4 general-electricity meters covering the buildings MRA, MRC and MRD with separate kitchen and non-kitchen circuits, 3 HVAC chiller meters in MRA, MRC and MRD, and 1 PV-system meter on the MRB rooftop array), for a combined rated capacity of 1.33 MW (sum of the three chiller ratings 146.5 + 514.4 + 532 kW and the 160 kWp PV array), exceeding the 1 MW target. The 8 principal IREN metering points feed the FlexPlatform through a CHES-node IREN adapter that pulls the IREN EDMS CSV exports and pushes them to the platform via the data-ingestion service hosted in the AMU AWS VPC.

The 14 Alfen AC EV charging stations and the 28.2 kWh FoxESS H3 Hybrid Pro 3 battery (TOSHIBA-supplied) deployed on site are integrated as controllable assets on top of these 8 metering points; their power dispatch is governed by the optimisation tool through the FoxESS Cloud API and the charge-station management API developed by Iren's external provider TLE, rather than counted within the VPP rated-

capacity envelope.. As commented before, tFocusing on the second environment - Azure Digital Twin - the FoxESS H3 Hybrid Pro 3 battery is integrated through the FoxESS Cloud API connector and exposed to the EMS as a controllable storage asset. The 14 Alfen AC charging stations are integrated through the charge-station management API developed by Iren's external provider. Historical IREN measurements are also exported through the Aveva PI Historian channel for completeness, while the Toshiba Azure Digital Twin environment provides a high-resolution thermal model of the four buildings, used both as input for the prediction tool and as a sandbox for testing UC4.1 schedules and HVAC setpoint strategies before live dispatch. The FlexPlatform itself, hosted on the AMU AWS VPC, runs the CHES Node, the optimisation tool and the FME, and produces day-ahead schedules and dispatch targets based on the predictions of flexibility availability from each asset. Several CHES-node adapters orchestrate this integration:

- BESS adapter (data and control); for the FoxESS BESS through cloud service
- BESS adapter-simulated; to emulate additional batteries
- EVCS adapter; for the TLE EV charging station management integration
- EVCS adapter-simulated; for simulating operation of EVCS to site-wide level
- HVAC / PV adapter; to provide data import from Aveva-pi historian
- HVAC / PV adapter-simulated; to emulate the flexible operation of HVAC
- EMS adapter; to coordinate and invoke control operations on the CHES assets in accordance with target peak shave / load shift schedules

In addition, the CHES node contains the AAS server and UUDEX server instances which support AAS and UUDEX based integration respectively. The RabbitMQ MQTT and AMQP broker permits efficient asynchronous message exchange between the CHES node and FlexPlatform components. Finally, the API manager is used to secure the interactions with external components using API gateways (GWs) through OAuth2 access tokens. All components are open source available through [GitHub - FlexCHES/CHESNode: Reference implementation of a Connected Hybrid Energy Storage System \(CHES\) Node · GitHub](#).

In addition, the Open weather service API (<https://api.open-meteo.com>) is used within the simulated PV/HVAC prediction for PV forecast predictions for day-ahead and for 15-minute actual weather prediction data.

All control interactions are passed through the CHES core service which utilises the UUDEX protocol for efficient and scalable asynchronous control plane messaging. Data plane updates are synchronised through the AAS server with the Azure digital twin environment, which also permits analysis using PowerBi™ as described further in [24]].

The control strategy is to exploit both the time and the power flexibility of the assets (see Figure 34), using time-domain profiles for time flexibility and power envelopes for power flexibility. In this context, a power envelope is the upper- and lower-bound on the active-power exchange of an asset over a given time horizon, within which the asset operator commits to operate. Profiles allow load shifting and peak shaving by sequencing setpoints, while envelopes allow capping or relaxing the consumption or

generation power band. The time flexibility state control profile is then expressed as shown in Figure 44, resulting in a daily charge / discharge cycling. For power flexibility the envelop capacity limit is defined and rather than a cycling operation a curtailment or maximum capacity is the result. In this manner the self-consumption and cost savings can be maximised, by load shifting while also permitting peak shaving using the combined assets consisting of BESS and EV charging as well as future HVAC control.

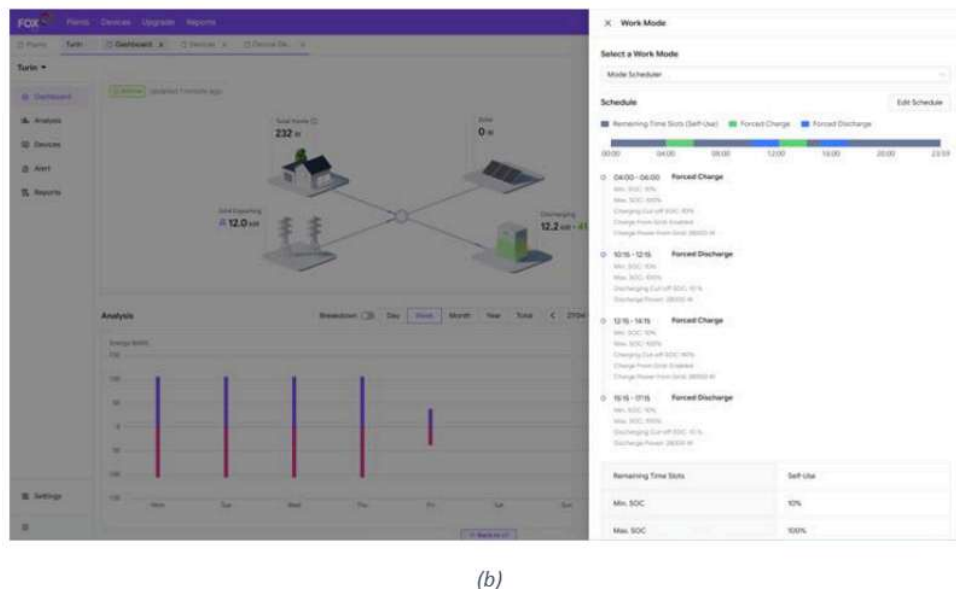
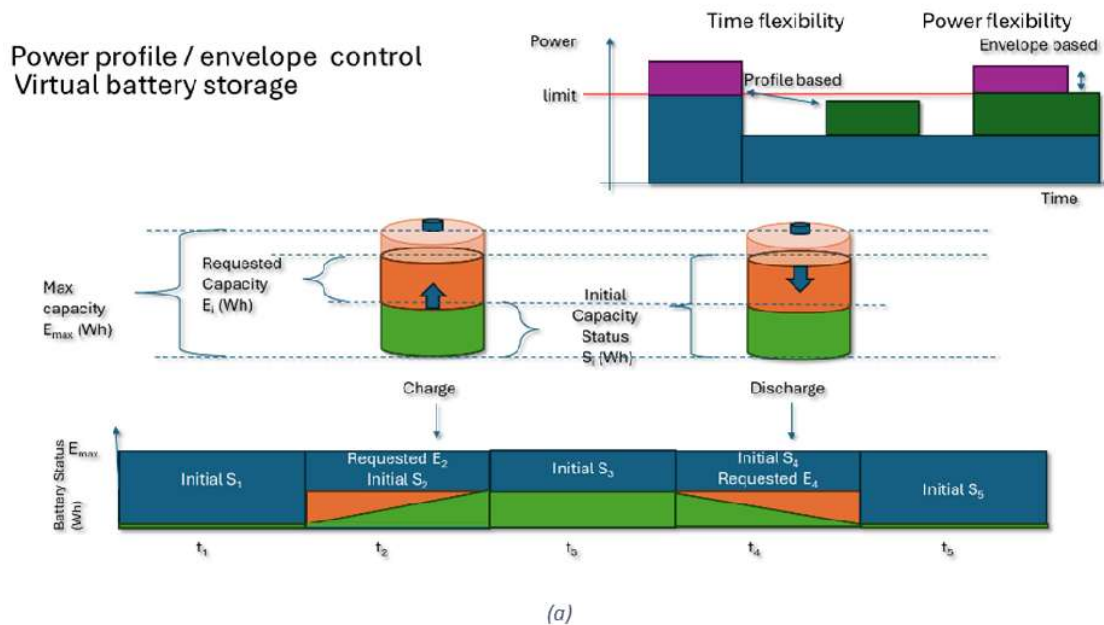


Figure 44: Control of Assets using Time and Power Flexibility (a) generic status profiles (b) mapping within BESS schedules through CHES adapters

The Digital Twins (DTs) and AAS APIs are designed to be domain-agnostic, and provide several features and benefits, specifically:

- Catalogue / DT registry for discovery of what is available and who is responsible.
- Graph database to represent of complex relationships between different asset and data sets.
- Access control with attribute-based access control (ABAC) mechanisms to enforce data access rights.
- Standard data model templates for ontology-based structuring and realisation of DT data.
- Support for different views/submodels (e.g. simulation or prototype versus twin instances)
- Mapping between different representations to facilitate interoperability between formats (e.g. DTDL to AAS).

The DT space also uses data specification definitions from the IEC Common Data Dictionary (CDD), which consists of concepts, classes and properties defined as data specifications within a database, to permit mapping of asset-related information across different standards and submodels. This supports semantic interoperability between sectors and enables machine-readable access to asset information. Submodels represent both static asset information and real-time dynamic telemetry, enabling comprehensive monitoring, behaviour modelling, and degradation or failure prediction for hybrid energy storage systems. Real time telemetry is critical for generating accurate behaviour models and deriving asset knowledge under varying operating environments and usage conditions. In this manner, more optimal use of the asset can be enabled by sharing this knowledge. Submodels can synchronise with their physical assets (“digital twin instances”) and prototyped assets (“digital twin prototypes”). Simulated assets, or DT prototypes, will also be used to evaluate future deployment options. To support the proposed distributed CHES approach, the key containerised abstraction utilises real-time asset DT registries and repositories. These are exposed through standardised AAS APIs, permitting interaction with virtual asset representations, and enabling AAS registry submodel discovery based on asset location or other criteria, as well as access to submodels and DT prototypes or instances. While DT repositories can be hosted in diverse environments, the proof of-concept implementation for this work uses Azure Digital Twins, with associated AAS submodel templates, such as the Catena-X battery passport and the Smart Applications REFERENCE (SAREF) data models for building temperature and HVAC representation as well as Timeseries data submodels for measurement sets. The Azure DT environment permits semantic models, defined using common data concepts and specifications, to support asset abstractions using AAS submodel templates. This ensures consistency and allows mapping of the asset data without ambiguity that can otherwise occur when different standards are being used, such as battery passports with vendor-specific data models. Additionally, the Azure DT environment is chosen for its robust support of DT data model validation and graph-based data representations, which facilitate secure collaboration between

stakeholders. In this setup, the AAS server provides a standardised type 2 API wrapper over the underlying Azure DT API, ensuring a consistent interface for accessing asset submodels and facilitating cross-domain coordination in the FlexCHESS platform. The Azure DT environment separates the DT data models, data specifications and graph instances, performing validation to ensure consistency. It also stores historical DT information for analysis and visualisation which can be accessed through the explorer portal (see Figure 1) via URL: <https://preprodapim.umbrellaiot.com:9096/> with the corresponding authorization bearer token obtained through the corresponding key manager, such as: <https://chessapim.umbrellaiot.com:9443/oauth2/token> using the appropriate credentials.

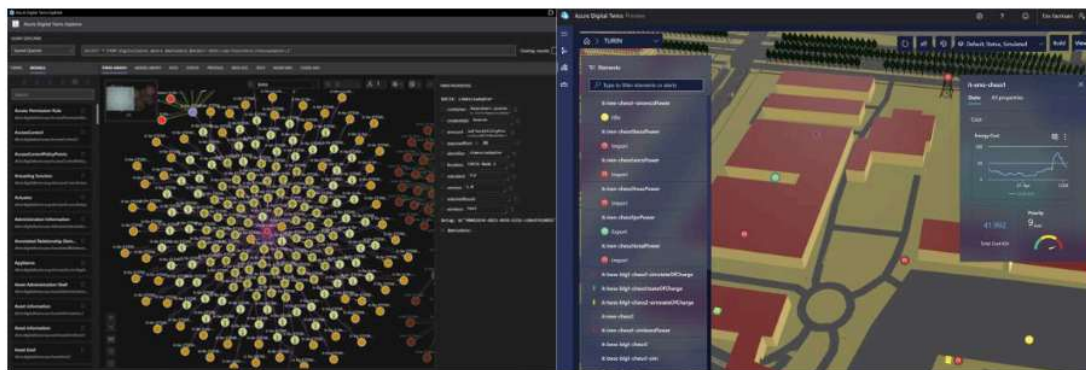


Figure 45: Digital Twin Environment Showing EVCS CHESS Twin Graph Models and 3D view

4) Findings & Insights

Load profile analysis

Being an IREN's facility with mainly office buildings, the Italian pilot exhibits clear weekday/weekend load profiles differentiation with peak consumption concentrated during business hours (8h-18h). The heatmap analysis confirms consistent patterns across all building blocks, with the aggregate facility consumption averaging about 290 kW on weekday midday periods, ramping up to approximately 600 kW on average during summer working hours (June-September, Mon-Fri, 8h-18h) and reaching individual hourly peaks above 1200 kW under combined HVAC and general-load conditions. Weekend consumption drops to approximately 55% of weekday levels (about 170 kW on Saturday and Sunday vs 290-300 kW Monday to Thursday), indicating significant demand response potential during working hours.

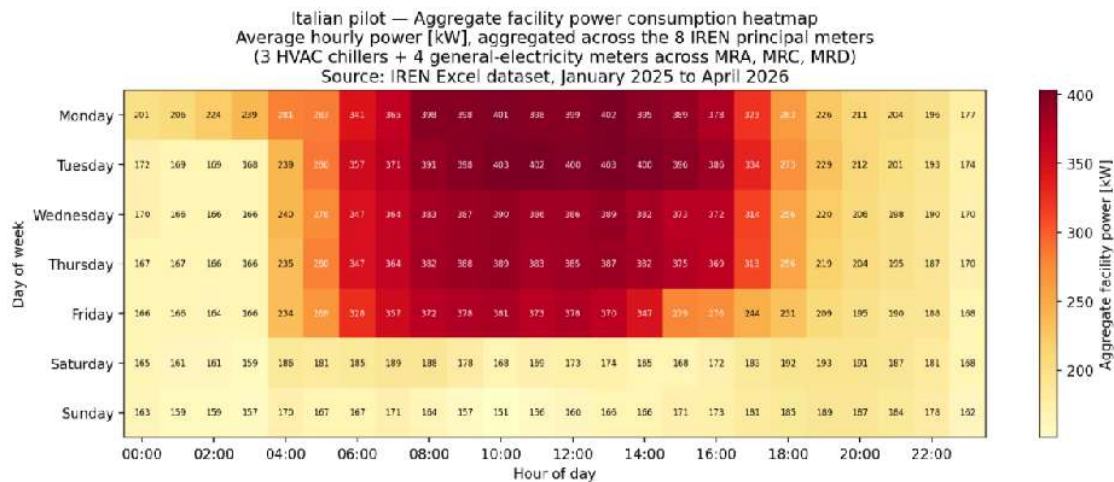


Figure 46: Italian Pilot - Aggregate Power Consumption Heatmap showing distinct weekday/weekend patterns

The eight principal meters described in the IREN device inventory and used in the FlexPlatform show diverse consumption profiles (yearly averages computed on the 2025 dataset shared by IREN and IREN Energia):

- MRB_GN_A (General Building MRA): 73.9 kW average (peaks above 300 kW), stable base-load and primary demand-response candidate;
- MRD_GN-UFC (General Building MRD, excluding kitchen): 56.7 kW average (peaks above 300 kW), suitable for load shifting;
- MRC_GN (General Building MRC): 33.3 kW average (peaks above 100 kW), suitable for load shifting;
- MRA_P8-CDZ (HVAC chiller, Building MRA, **rated 514.4 kW**): 29.6 kW yearly average and 65.6 kW summer-season average, peaks up to 241 kW, primary thermal-flexibility lever;
- MRC_CDZ (HVAC chiller, Building MRC, **rated 146.5 kW**): 20.9 kW yearly average and 31.4 kW summer-season average, peaks up to 87 kW, thermal-flexibility lever strongly correlated with outdoor temperature;
- MRD_CDZ (HVAC chiller, Building MRD, **rated 532 kW**): 25.0 kW yearly average and 68.4 kW summer-season average, peaks up to 251 kW, largest thermal-flexibility lever during cooling season;
- MRD_GN-CK (Kitchen circuits of Building MRD): 16.1 kW average (peaks above 100 kW), high-frequency on/off pattern aligned with kitchen operations;
- MRB_GN-FV (PV system, 160 kWp rooftop array on building MRB): 16.5 kW average over the full 24/7 cycle, rising to 35 kW average during daytime (8h-18h) and 51 kW average during summer daytime (June-September, 8h-18h), with measured generation peaks above 110 kW.

Italian pilot — Daily load profiles per meter and aggregate facility power
(IT_IREN_VPP CHES Node, IREN Excel dataset 2025, real measurements only)

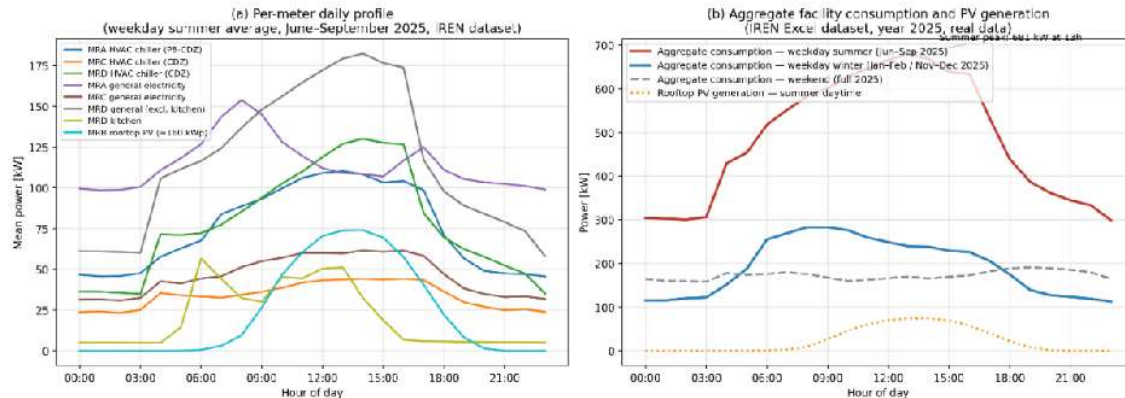


Figure 47: Italian pilot - Daily Load Profiles by Meter and UC1 Peak Shaving Demonstration

FlexCHES use cases for the Italian pilot

The Italian pilot at IREN's multi-building Turin facility validates FlexCHES flexibility services in a commercial/tertiary environment. The three Italian Use Cases (in accordance with D1.5 Table 1 and D4.2 Table 4) are operationalised on the IT_IREN_VPP CHES Node as follows.

- **Peak Shaving (UC1.1).** The optimisation tool analyses load profiles aggregated into 15-minute windows, identifies the morning (8h-12h) and afternoon (16h-18h) business-hours peaks, and generates curtailment schedules combining HVAC chiller setpoint shifting with controllable building loads. The peak-reduction objective is parameterised as a 20% threshold on the aggregated VPP power.
- **Energy and Cost Optimisation (UC4.1).** A multi-objective formulation jointly minimises energy cost under time-of-use tariffs and maximises PV self-consumption, while respecting comfort dead-bands on the fan-coil setpoint of each office building. Time-of-use tariff profiles are integrated to shift flexible loads to off-peak periods.
- **EV Smart Charging (UC4.2).** EV charging schedules are coordinated with the PV generation forecast, the FoxESS battery state of charge and the building general loads, with the objective of maximising on-site self-consumption and minimising grid impact. The relaxed 0.01 MW minimum-power threshold of D4.2 Table 4 is enforced by the rule book service.

Findings below are organised along these three scenarios and mapped onto the D1.5 KPI framework. Considering the FlexPlatform, the results are summarized below.

a) Peak Shaving (UC 1.1)

The aggregate daily profile considering the 8 principal meters of Turin facility shows a clear morning peak (8h–12h) and an afternoon shoulder (14h–17h), typical of office operations. Applying a 20% peak reduction threshold on the optimisation service,

through coordinated curtailment of HVAC systems and non-essential building loads, the aggregated peak can be reduced from roughly 600 kW to 480 kW during summer working hours, and from about 290 kW to 230 kW during mid-season weekdays (spring and autumn, when HVAC chillers are only partially active). The corresponding Load Shifting (LS) Capability KPI is around 20% and is consistent with the D4.2 Table 4 requirement (response 15–60 min, minimum power 0.1 MW, duration 15–60 min). Over the cooling season (June to September, when the HVAC chillers contribute the largest share of the facility peak), this peak reduction translates into an estimated 15–20% saving on the demand-charge component of the IREN facility electricity bill.

Figure 48 illustrates the UC1.1 peak-shaving methodology on a representative summer working day from the IREN 2025 dataset (Wednesday 9 July 2025). Real measured aggregate consumption (red line) is reduced by deterministic dispatch of the FoxESS H3 Hybrid Pro 3 BESS (28.2 kWh / 30 kW, round-trip efficiency 0.92): the BESS is charged from the PV surplus during off-peak hours and discharged when the aggregated load exceeds the daily 80-th percentile threshold. **The resulting net load (green dashed line) shows a peak reduction from 558 kW to 466 kW (16.5%) on this representative day, with 11.3 kWh of energy cycled through the BESS over the 24-hour window. The PV self-consumption ratio reaches 100% on this day, as the small PV surplus is fully captured into BESS charging.**

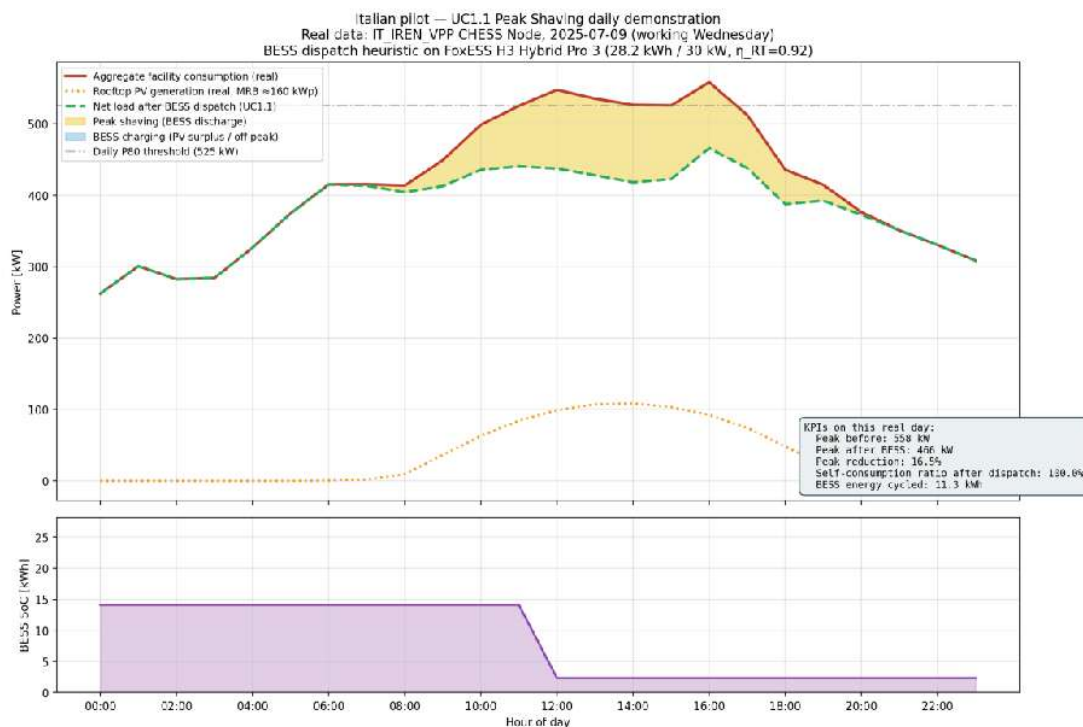


Figure 48: Italian pilot, UC1.1 Peak Shaving daily demonstration on real IREN data (Wednesday 2025-07-09)

b) Energy & Cost Optimisation for Multi-Buildings (UC 4.1)

Multi-objective optimisation allowed to jointly minimise energy cost under time-of-use tariffs and maximise PV self-consumption, while respecting comfort constraints on the

fan-coil installed in the offices for air conditioning. Highest-impact assets identified by the optimisation engine over the full 2025 dataset are: MRB_GN_A (general load of building MRA, 74 kW yearly average, peaks above 300 kW, primary demand response asset), General Building MRD (57 kW yearly average, peaks above 300 kW), General Building MRC (33 kW yearly average, peaks above 100 kW, load-shifting candidate), and the three HVAC chillers in MRA / MRC / MRD which jointly average about 65 kW over the full year and 165 kW during the summer cooling season (peaks above 500 kW combined), providing the largest thermal-flexibility lever. **Measured Service Efficiency (SE) and Flexibility Index (FI) KPIs confirm the viability of aggregating tertiary-sector buildings as a Virtual Power Plant.**

Figure 49 illustrates the UC4.1 energy-and-cost-optimisation methodology on the same representative working day (Wednesday 9 July 2025) considered before for the UC 1.1, applying an indicative ARERA-style three-band Italian Time-of-Use tariff (F1 = 0.22, F2 = 0.16, F3 = 0.10 €/kWh; tariff structure used for documentation and comparison purposes only). The optimisation combines BESS dispatch (charging during the F3 off-peak band, discharging during the F1 peak band) and a 15% curtailment of the HVAC chillers during F1 hours as an explicit methodological assumption representing the comfort-bounded thermal flexibility available on the site. The main daily KPIs computed on this real day are the followings: aggregated electricity cost from 1'587.56 € to 1'511.87 € (saving 75.69 €, 4.77% on the day; if scaling this value over an entire hypothetical cooling season, this value could arrive to several thousand euros), peak grid import from 466 kW to 428 kW (8.1% reduction), and PV self-consumption up to 100%, thanks to the combination with BESS.

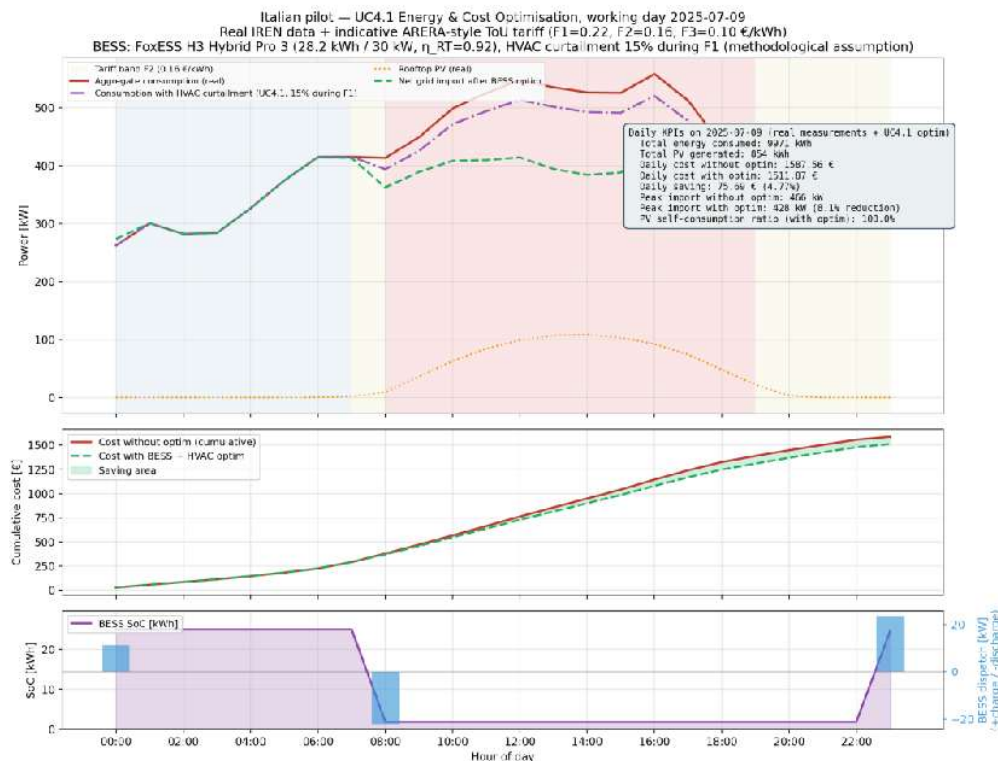


Figure 49: Italian pilot, UC4.1 DAM_IT cost optimisation on real IREN data (Wednesday 2025-07-09)

c) EV Smart Charging (UC 4.2)

Fourteen unidirectional AC charging stations (Alfen NG920-61021, 32 A, 3-phase 400 V, 2 EVs per station) are installed at the facility, with two instrumented for the pilot. Smart-charging is implemented by the optimisation tool, which combines a 24-hour PV generation forecast (produced by the prediction service trained on the IREN EDMS history) with a building-load forecast and the EV-session profile streamed from the TLE charge-station management API at 1-minute intervals; the resulting schedule shifts charging cycles towards the midday PV peak whenever possible, while respecting user mobility constraints captured at session start.

Compliance with the relaxed 0.01 MW minimum-power threshold of D4.2 (Table 4) is checked online by the rule book service. The Source Contribution (SC) KPI is measured as the ratio of PV-sourced energy to total EV charging energy over each daily session, computed on the 5-minute aggregated time-series of the EV charging meter and the PV meter MRB_GN-FV. **On sunny working days, measured SC values reach up to 60% of EV charging energy sourced directly from the rooftop PV array, substantially reducing grid imports during the midday period.**

Other insight using the digital twin environment for the Italian pilot

Within the Digital Twin environment, some analyses were conducted, specifically on EVCS usage and on BESS, by Toshiba in collaboration with IREN Group (IREN and IREN Energia). The main insights are reported in the following sub-sections, which are developed also in according to the use cases identified for the Italian pilot. Specifically, sub-sections from a) to d) mainly focus on EV charging station optimisation, also considering possible PV and BESS contributions (in line with **UC4.2**), while sub-section e) focus on HVAC flexibility for load shifting and/or peak shaving studies (in line with **UC1.1** and **UC4.1**).

a) EV Charging Control

Two different vehicles (Opel Corsa and Renault Zoe) were tested with the objective to firstly test and validate the EVCS adapter integration with the TLE charging station management system and secondly to determine and compare the control behaviour (i.e. curtailment, suspension and resumption of session) to better understand the difference between these two EVs that compose the IREN's fleet.

Different tests were conducted with IREN and its external provider working on EV charging stations. Specifically, two long sessions (i.e. complete charge cycle from ~50% to ~ fully charged) were conducted, with the objective to observe the session profile with and without curtailment.

For the tests the EVCS it-tle-ETDW_20247 charging system was used with the Opel Corsa occupying the left EVSE (1) and the Renault Zoe occupying the right EVSE (2). The initial SoC of the Zoe was 43% and the Corsa 53%. The charging session control steps in the test were the followings:

- Ramp down power until cut-off (suspension) was observed
- Full power to both cars
- Shared power between vehicles – equal split and switching
- Ramp up power (resumption of charging)
- Observe session tail-off power ramping at the end of the charge session

It should be noted that the session was started with full current offered to both cars, which is 32A to each EVSE, which exceeded the rated capacity of the connection EVCS. Therefore, during step 2 at 10:21AM the EVCS trip was activated. After this the management software was changed to set an EVCS total current limit to 32A, offered current was then also limited to avoid the tripping, but increased above 32A in step 4, in the order of 40-45A, to check the automatic EVCS curtailment.

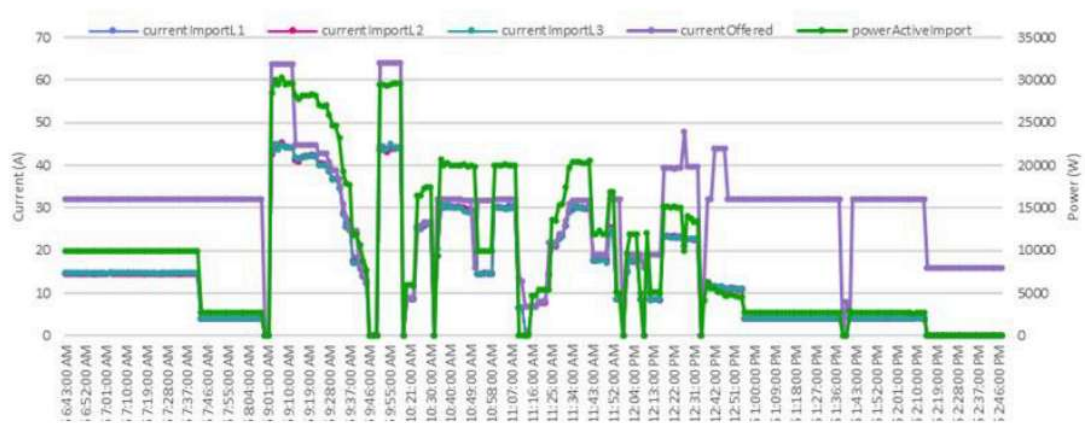
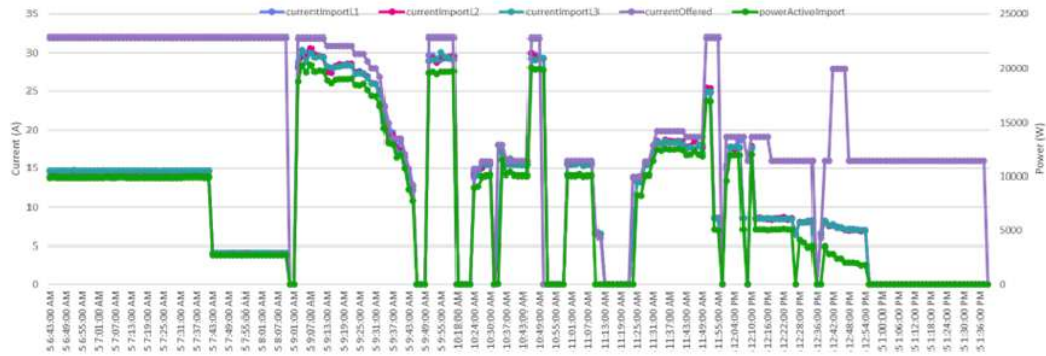


Figure 50: Offered Current Control Tests for two EV vehicles

The overall session is shown in Figure 50 and the individual EVs in Figure 51 and Figure 52, for Zoe and Corsa respectively. The session results indicate that at the beginning of the session the EVs match the offered current closely until their respective maximums are reached (which equated to 9.9kW for the Corsa and 20kW for the Zoe). The cut-off threshold for the Zoe was 13A or 9kW, while for the Corsa was 5.9A or 4kW. Hence, for the Zoe, curtailment can easily trigger the suspension of the session, especially if an equal sharing strategy is used without considering this. Another interesting observation is that the power factor for the Zoe tails off as the end of the charge session approaches. This can give a good indication of the vehicle nearing full capacity as this effect appears quasi-linear with the session time from around 90% SoC. In contrast, the Corsa has no such behaviour and continues to draw a constant 2.7kW for the whole of the long tail of 1 hour 40mins in the charge session.

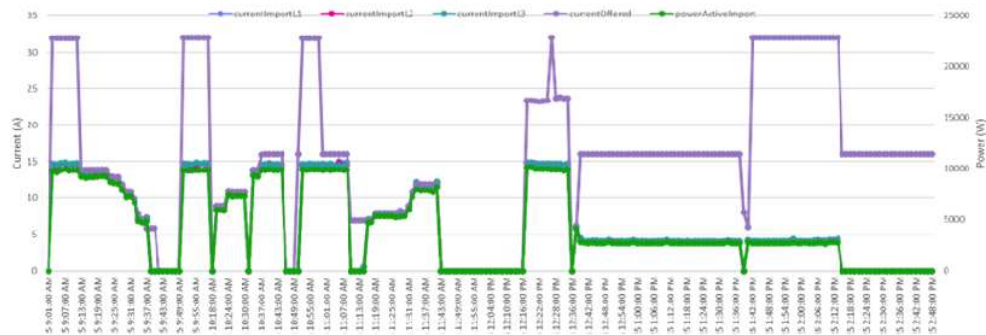


(a)

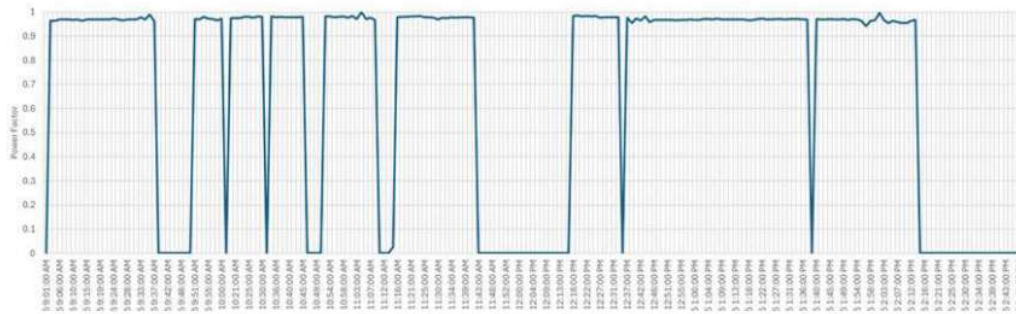


(b)

Figure 51: Renault Zoe (a) Power and currents (b) Power factor



(a)

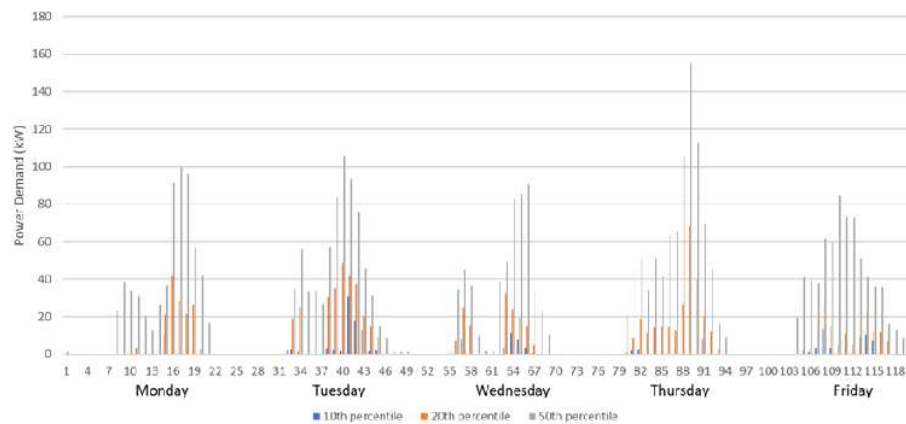


(b)

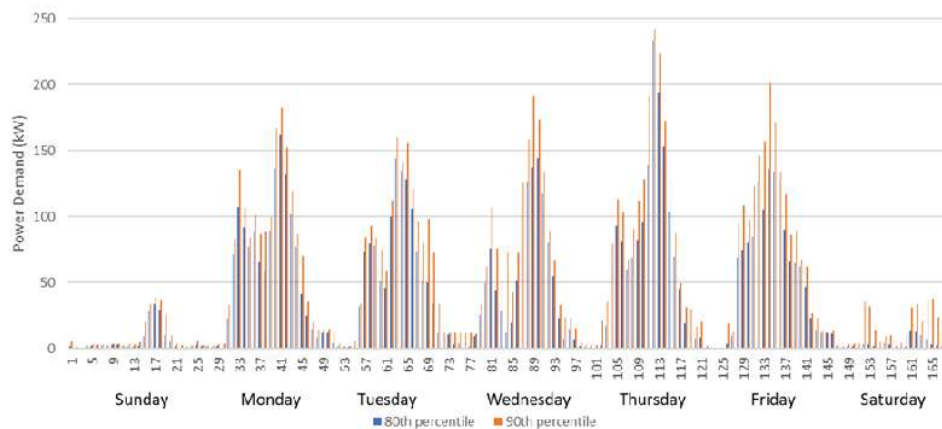
Figure 52: Opel Corsa (a) Power and currents (b) Power factor

b) EVCS Monitoring and modelling

Session data was gathered through the digital twins to generate typical load profile / baseline for analysis and comparison of potential curtailment and/or flexibility benefits, with the objective to create a prediction model of the charge session power profile for the site.



(a)



(b)

Figure 53: Summary of EVCS Power Demand for hours in the day and day in the week (a) lowest (b) highest

The EVCS data was collected at 1-minute intervals (provided by the charging station operator TLE through the EVCS adapter API) for a subset of EVCS, which are used as a representative sample for the site, by scaling appropriately. This is imported to the EV charging station digital twins, through the EVCS adapter, to provide a model for the site EVCS demands, as shown in Figure 53Figure 44. The important observation on the data is the variability of the demands over hours in the day and days of the week. This has been further analysed in PowerBI™ and ML models defined

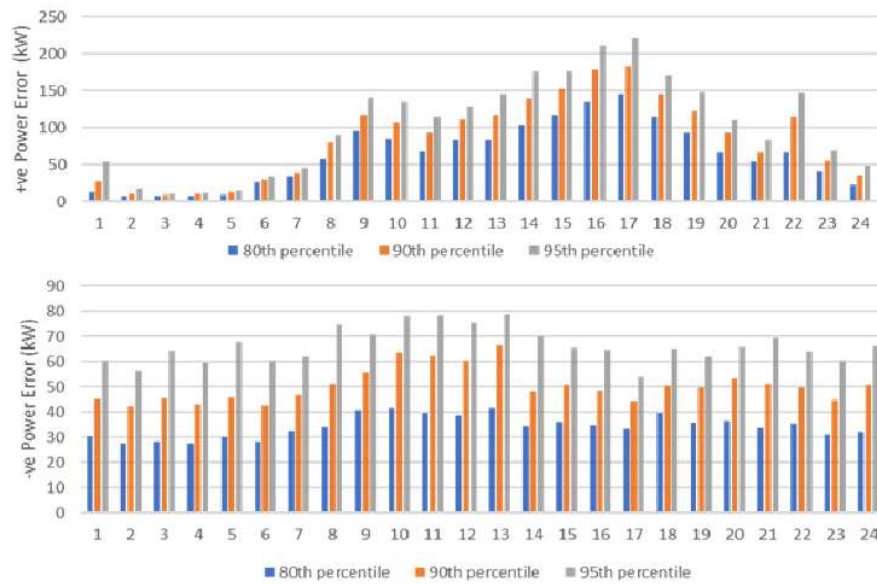
to permit prediction of the charging power requirements and exploration of the potential flexibility. The flexibility is obtained by curtailing the demands using the individual EVSE offered current limits which are passed to the EVCS management system. The initial observation is that Thursdays offer most energy flexibility potential with more certainty than other days. However, even on these days, there is a 10% chance of very little flexibility available. Therefore, the reliability of the use of EVCS as a means for providing flexibility requires deeper understanding and compensation for this uncertainty, by combining with other flexible assets such as BESS or HVAC. Alternatively, another possibility for flexibility service provision is the exploitation of the potential of bidirectional charging capabilities of some EVCS.

c) Machine Learning Model for EVCS loading prediction

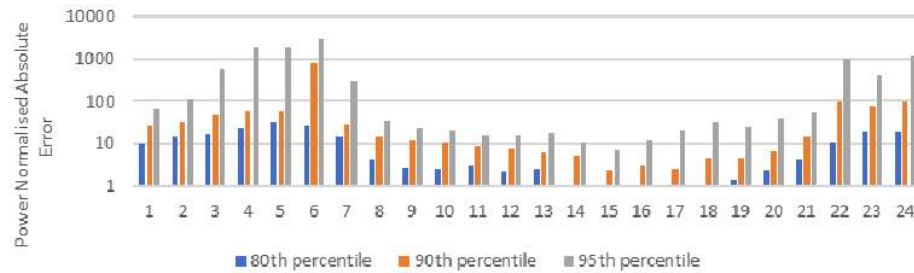
A Machine Learning (ML) based digital twin model has been created from the data using PowerBI™ to predict the EVCS loading in advance, such as a day ahead. The model uses the AutoML features to select the most appropriate model for prediction based on the data provided. AutoML uses feature extraction, such as time of day and day of week and selects the best fitting models over training and test data sets, which for larger data sets (2 months) is the extra tree model. Offered current is the maximum current permitted for the EV charging stations, which is used to curtail or limit the capacity. In this manner it is possible to determine that there is high variability in the error with 95th percentile errors as high as 200kW between 15:00 and 16:00 in the afternoon with average error of 60kW, which is due to significant variability in the fleet vehicle arrivals at this time. Hence, curtailment of current EVCS sessions (which takes 3 mins to activate) combining with BESS or other assets is needed to minimise peak power with high certainty when there is highly variable demand and generation.

The offered current is used to curtail the charging, but the response of the vehicles depends on the charge cycle and behaviour and capabilities of the vehicle charge management, which can take up to 5 minutes, and also the underlying load balancing that is already performed in the EVCS Management System. Therefore, the aggregate offered current and active power data was converted to timeseries sets in order to determine how accurately the aggregate power can be predicted given the overall offered current, which permits session curtailment to be more selective (such as curtailing sessions that have highest SoC first). The KQL query used for retrieving the timeseries active power data from the digital twins is as follows:

```
AzureDataExplorer.KqlDatabase("https://dthistory.ukwest.kusto.windows.net", "dthistorydb",  
"[AdtPropertyEvents] | where TimeStamp > ago(60d) | where Key=='powerActiveImport' or Key=='timestamp' |  
where Id contains 'it-tle' | where Id notcontains '-sim' | join kind=inner (AdtPropertyEvents) on TimeStamp |  
where Key=='timestamp' and (Key1=='powerActiveImport') | make-series total = sum(todouble(Value1))  
default=0 on todatetime(Value) step 5m ", [MaxRows = null, MaxSize = null, NoTruncate = null,  
AdditionalSetStatements = null])
```



(a)



(b)

Figure 54: Power Prediction Error versus Hour of the Day (a) absolute error (b) normalised absolute error (non-zero demand)

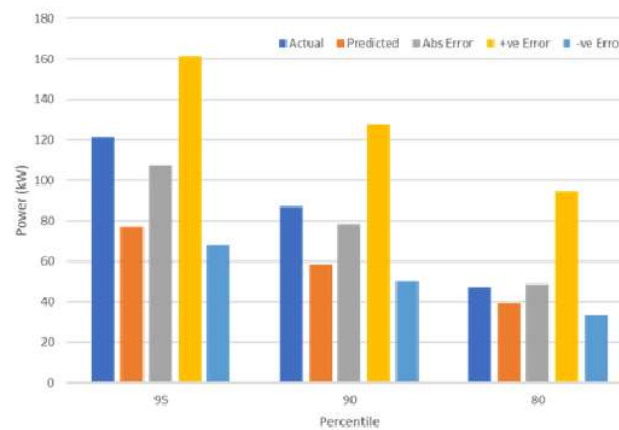


Figure 55: Overall ML Prediction of Total Charging Power and Associated Error

The average prediction error of the ML model over the complete period is 18kW with an average absolute error of 37kW. Hence, the ML model significantly outperforms the simple probabilistic model. Improvement was obtained by reducing the interval t_i used for training to 5mins and using an extra tree regression model when the training data set is relatively large (i.e. 2 months +) otherwise xBoost provides the best solution for limited training data (less than a month). The interesting observation from the summary (see Figure 55) is that the +ve power is the most significant component of absolute error. Hence the ML models tend to under estimate more than over estimate, with 80th percentile -ve error being <40kW, which can be compensated for by using BESS or other storage assets. This is obtained using the queries of the following format:

```
select distinct DATEPART(weekday, dbo.EVCSDData7Model3InferenceTest.Value), DATEPART(hour,
dbo.EVCSDData7Model3InferenceTest.Value), PERCENTILE_CONT(0.95) within group (order by
(abs(dbo.EVCSDData7Model3InferenceTest.Custom - dbo.EVCSDData7Model3InferenceTest.PowerPrediction)))
over (PARTITION by DATEPART(weekday, dbo.EVCSDData7Model3InferenceTest.Value), DATEPART(hour,
dbo.EVCSDData7Model3InferenceTest.Value)) as percentile from dbo.EVCSDData7Model3InferenceTest where
dbo.EVCSDData7Model3InferenceTest.Custom - dbo.EVCSDData7Model3InferenceTest.PowerPrediction > 0
```

As a consequence, the flexibility power reduction is ~17kW on average and up to 120kW for the 95th percentile of cases (see Figure 56). This significant variability requires consideration of both time of day and day of the week and is conservative based on the under estimation tendency of the ML model in the peak times. **This permits a strategy for energy flexibility that can exploit the probability of curtailment of EV charging in combination with BESS and other flexible assets to provide higher certainty of delivery, which is necessary, given the variability in EVCS charging.**

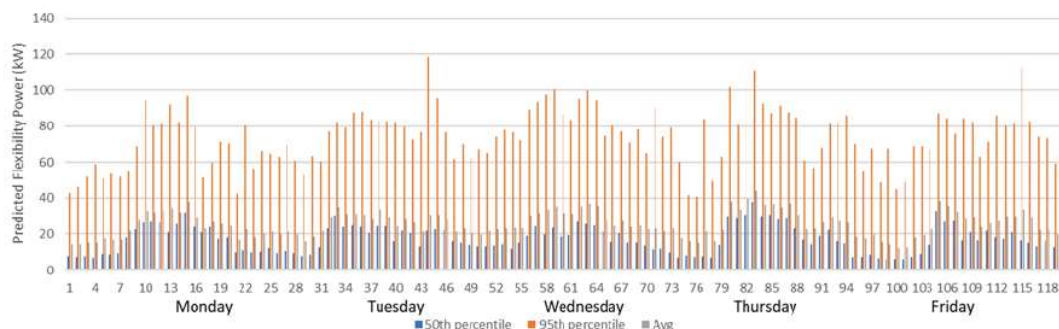


Figure 56: Predicted EVSE flexibility power for weekdays

d) Combined EVCS and BESS control

In order to minimise the impact to the EV charging sessions while meeting the combined peak power goals, the ML model day-ahead profile is used to estimate the peak power requirement when combined with predicted PV generation. As there is considerable uncertainty, this is when the maximum requirement for combined use of the BESS to permit flexibility targets to be met.

To compare the benefit of coordinated control strategy of BESS and EVCS curtailment, the analysis considered the baseline case of curtailing the EVCS according to the predicted offered current limit that satisfies the peak power target or flexibility goal. The coordinated strategy is able to reduce uncertainty in reducing peak power due to the fact that the BESS can be discharged when the peak power is likely to exceed the peak power constraint in the intraday adapted schedule.

When looking at the possible flexibility options, the BESS discharge states have the highest control priority and predictability, followed by EV charging curtailment to 11 kW and finally the 0 kW curtailment or suspension state (using two Corsa and Zoe vehicles as proof of concept and subsequently extended to the simulated EVCS digital twins for scaling). The four defined energy control or constraint state levels are prioritised as follows:

- 0 – BESS charge
- 1 – BESS discharge
- 2 – EVCS curtail
- 3 – EVCS suspend charge (offered current < min threshold)

The states 1, 2, 3 can be selectively activated in each period, when available, in prioritised order to meet the operational target defined by the optimisation tool for that period, which combines the peak-shaving setpoint and the load-shifting setpoint derived from the day-ahead schedule. Conversely, during preceding time intervals, the 0 state—representing BESS force charging—is activated to charge the BESS. The opportunity for PV self-consumption arises from the excess PV generation compared to EVCS and building cooling demand (HVAC systems), which permits zero energy costs, or can be charged when the energy tariff is lower than the peak tariffs, when the BESS is subsequently discharged. This was evaluated with the deployed BESS over a period of 2 months as summarised in Table 4.

Table 4 : Summary of actual BESS use in the Pilot (over 2 months)

Charge Energy throughput	2894.1kWh	Discharge Energy throughput	2722kWh	Charge Capacity throughput	8799.6Ah
Discharge Capacity throughput	8550.4Ah	Number of full equivalent charge-discharge cycles	93	Cost savings estimate	432€

In order to further consider the long term variability in the daily predictions, a two-year period from 2023 was considered and the collected weather data from the open weather service for 15-minute intervals at the PV installation location was used for the analysis. The results, in Figure 57, show the resulting PV predictions combined with EVCS charging power data. **Significant variability and uncertainty occurs between days which can be compensated by BESS storage to capture the PV generation energy that is not required for the EV charging.** The resulting cost savings are shown in Figure 58 and show that the BESS can provide significant potential benefits with the energy time-of-day base cost and additional tariff offset (€0.1 above base). In addition, a peak power reduction of approximately 30 kW is

achievable through coordinated BESS and EVCS dispatch. This translates both into reduced connection charges, which are billed at the order of €38 per kW per year on the Italian tariff structure, and into additional revenue streams from the local flexibility markets.

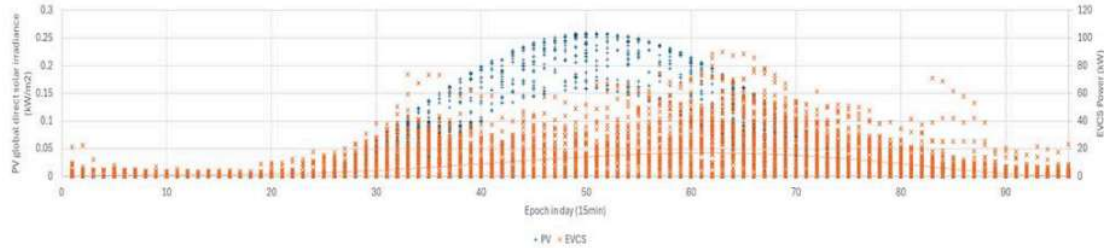


Figure 57: Daily PV generation and EVCS demand power

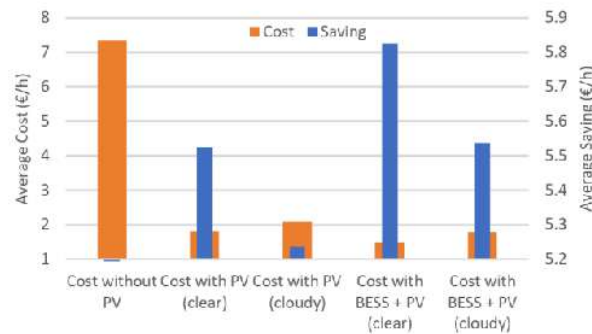


Figure 58: Cost of EVCS charging with and without PV/BESS actual cost = base + €0.1 per kWh

In order to adjust the Open weather data to the reference plane of the PV array, a translation is performed using the python pvlib library, as shown below:

```
%pip install pvlib pandas matplotlib
import pvlib
import pandas as pd # for data wrangling
import matplotlib.pyplot as plt # for visualization
import pathlib # for finding the example dataset
print(pvlib.__version__)
# make a Location object corresponding to this TMY
location = pvlib.location.Location(latitude=45.085304,
                                  longitude=7.651917)
df_tmy = pd.read_csv("/lakehouse/default/Files/6ae8e488456b61476bb78a5969df20e.csv")
display(df_tmy)
solar_position = location.get_solarposition(pd.to_datetime(df_tmy['dt_iso'], format='%Y-%m-%d %H:%M:%S + %f UTC'))
solar_position = solar_position.reset_index()
#solar_position.head()
display(solar_position['zenith'])
df1_poa = pvlib.irradiance.get_total_irradiance(
    surface_tilt=30, # tilted 30 degrees from horizontal
    surface_azimuth=195, # facing South South West 15 degrees
    dni=df_tmy['dni_cloudy_sky'],
    ghi=df_tmy['ghi_cloudy_sky'],
    dhi=df_tmy['dhi_cloudy_sky'],
    solar_zenith=solar_position['zenith'],
    solar_azimuth=solar_position['azimuth'],
```



```
model='isotropic')
display(df1_poa)
df2_poa = pvlib.irradiance.get_total_irradiance(
    surface_tilt=30, # tilted 30 degrees from horizontal
    surface_azimuth=195, # facing South South West 15 degrees
    dni=df_tmy['dni_clear_sky'],
    ghi=df_tmy['ghi_clear_sky'],
    dhi=df_tmy['dhi_clear_sky'],
    solar_zenith=solar_position['zenith'],
    solar_azimuth=solar_position['azimuth'],
    model='isotropic')
```

e) HVAC flexibility

Due to unavailability of indoor temperature or ability to control the actual physical HVAC, the building heating and cooling power requirement is modelled using a digital twin prototype based on the commercial building HVAC model given by [25]]:

$$t_k \cdot P_{hva}[k] = E_k$$

$$T_r[k] = (1 - 10^{-3}\alpha)T_r[k-1] + 10^{-3}(\alpha T_a[k-1] + k_{sun}\beta P_{sun}[k-1] + k_{int}\beta P_{int}[k-1] + k_{hvac}\beta P_{hvac}[k-1])$$

$$P_{hva}[k] = f(T_r[k+1], T_r[k], T_a[k], P_{sun}[k], P_{int}[k])$$

where $P_{hvac} = P_{heat} - P_{cool} + P_{ven}$ and P_{cool} represents the power from the chillers of the air conditioning system. The internal power from electrical devices is P_{int} and solar irradiance power is given by P_{sun} . The assumed coefficient values are $k_{sun} = 1.1$ or 1.9 , $k_{hvac} = 1.0772$, and ignoring internal loads/equipment, hence $k_{int} = 0$ with $\alpha = 29.6$ and $\beta = 0.0568$.

The dimensionless coefficients k_{sun} , k_{int} and k_{hvac} in the thermal model represent, respectively, the building's solar-gain coefficient, internal-gain coefficient and HVAC coupling coefficient; they are calibrated per building from the IREN historical dataset. The values of k_{sun} used in the present analysis are 1.1 (low solar coupling, shaded façade) and 1.9 (high solar coupling, exposed façade).

Within the model, the daytime indoor temperature is assumed to be kept between 25 to 27 degrees Celsius in the Summertime days and the corresponding evening and nighttime temperatures reflecting the outdoor temperatures. In this manner it is possible to estimate the power required and potential for load shifting and peak shaving using the temperature set-point shifting within the model. The results using the same 2 years of weather data indicate that the average daily energy associated costs are between €185 and €211 assuming a variable tariff ([Electricity prices - Italy](#) plus €0.1), including the self-use of the PV generation, depending on the solar energy coefficient (k_{sun}) of the buildings. The corresponding overall power requirements are shown in Figure 59. **As a consequence, with a target indoor temperature increase of 2 degrees there is an additional 45kW of peak power reduction possible.** Therefore, the overall average local energy flexibility benefit for the buildings per time of day is summarised in Figure 60 and shows that daily total average flexibility benefit is up to €15.3 (702kWh) or €15.2 (693kWh) with high and low building solar coefficient (k_{sun}), which is taken as 1.9 and 1.1 respectively, with an additional €7.4

(56kWh - charge and discharge twice daily) for BESS cycling and €6.2 for peak power charge reduction (not shown in the figure). The main benefits occur between 7:30 to 10:00 in the morning and between 16:15 to 21:15 in the evening/night. As the actual benefits have a high degree of variance, the prediction of the benefits is also highly dependent on the accuracy of the forecasts and the thermal properties of the buildings, which are both a source of significant error.

If both heating and cooling are provided through electricity-based HVAC systems, using the same building digital twin thermal model prototype, the benefits are estimated to increase to €17.2 (774kWh) per day on average with low solar capture (with winter daytime temperature maintained in the range 19 - 21 degrees Celsius). It is important to specify that currently in IREN's facility, space heating is not provided electrically through heat pumps, since the buildings are connected to the urban district heating network managed by IREN Group. These considerations, however, could be valid for other office buildings with electrical cooling and heating systems for replication studies.

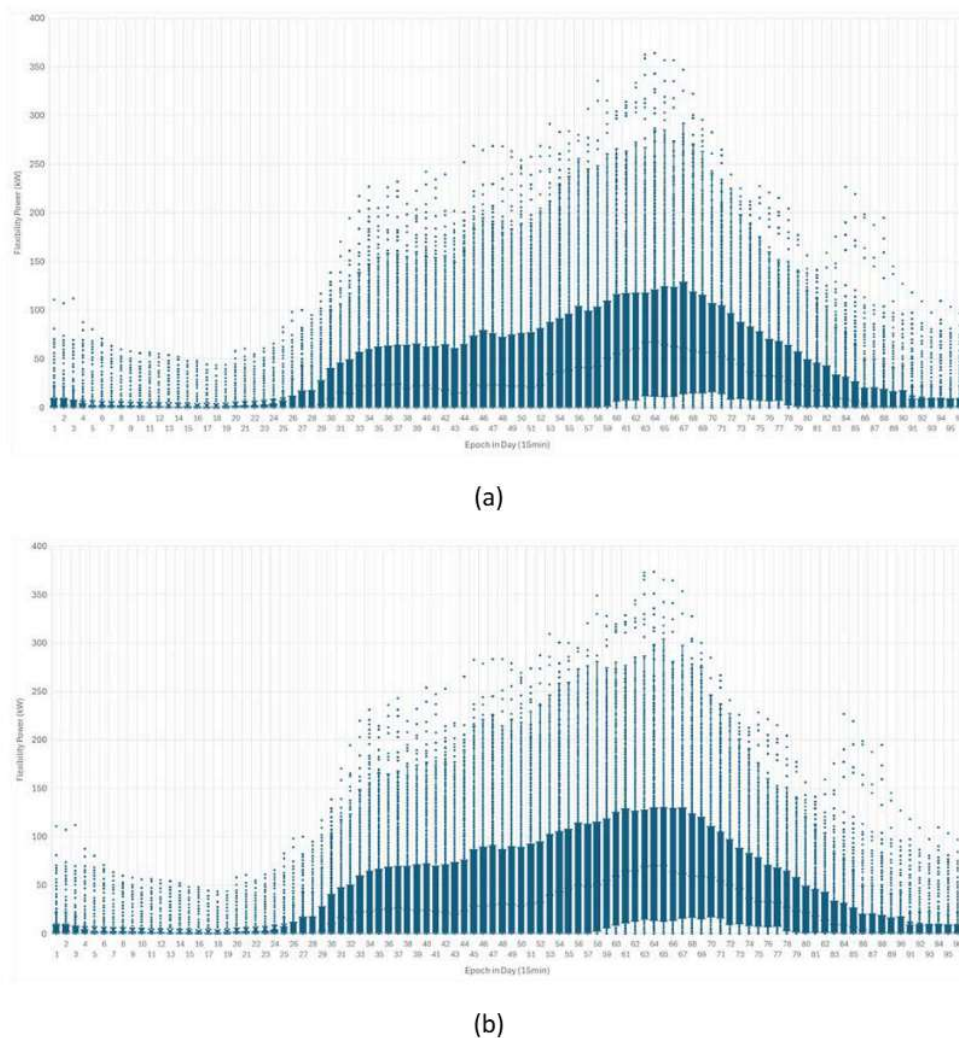
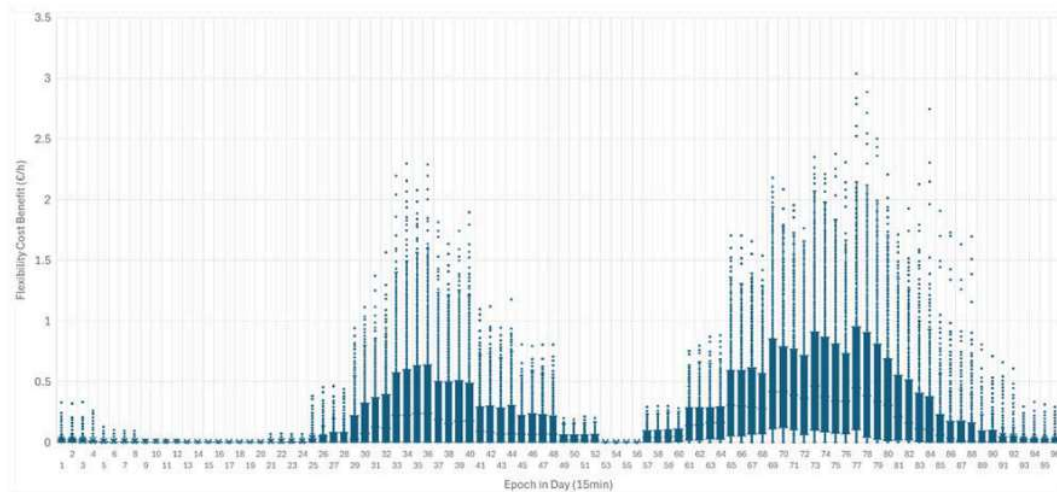
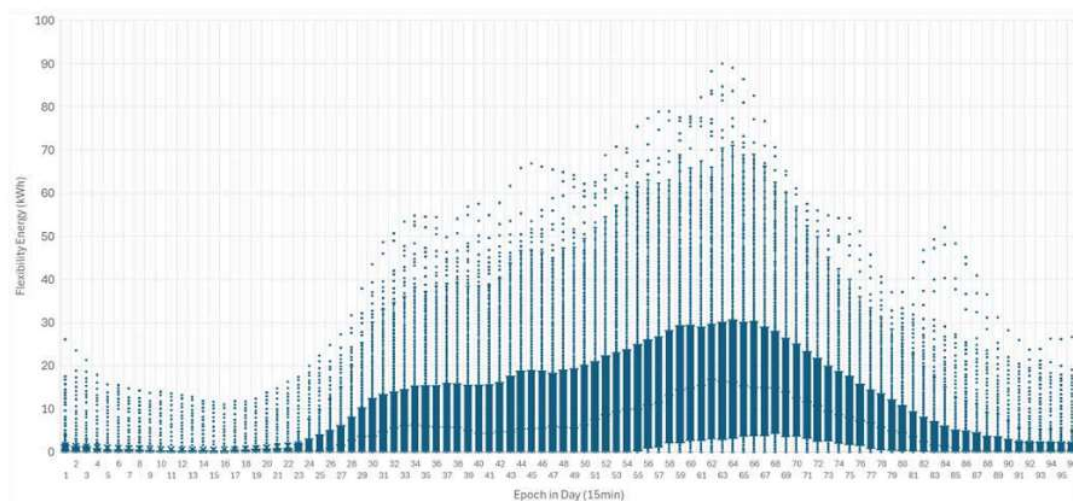


Figure 59: Combined HVAC, PV and EVCS Power (a) low solar capture (b) high solar capture



(a)



(b)

Figure 60: Overall Flexibility Benefit (a) Costs Reduction (b) Energy shift potential

When EVCS and HVAC is combined with the BESS storage, the projected benefits (given a 2 year payback period) are shown in Figure 61, indicating that a size of around 40kWh is most suitable for the site. With longer payback or more combined assets, or to reduce the EVCS session or HVAC impact, then the benefits can be reassessed. The summary of the future expansion estimated benefits based on increasing BESS capacity (and optional technology enhancement, such as SCiB - LTO/NTD which offers higher power and more frequent power cycling operation) are shown in Table 5. In addition, the clustering analysis of the individual EVSE data reveals possibilities for prioritised selection of curtailment strategies to minimise the impact to EV charging by around 43%, compared to the initial approach evaluated in the pilot, while still achieving the same level of curtailment.

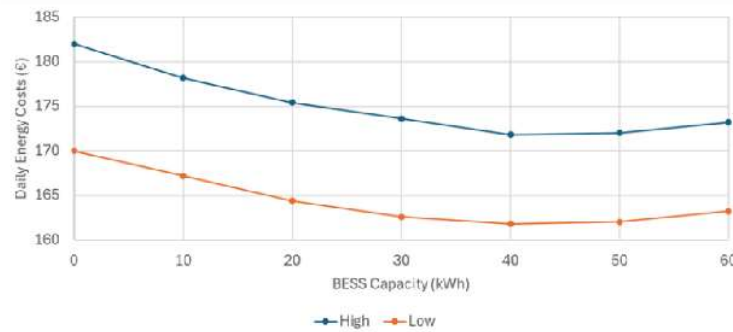


Figure 61: Prediction of Energy Cost Benefit with Different BESS Capacity (for High and Low building solar coefficient sun)

Table 5 : Summary of benefits and future expansion

Scenario	Baseline	Future
Benefit	(pilot)	Expansion
Daily Energy Cost savings	€22.6	€28.2
BESS (~twice daily cycling)	€7.3	€11.0 (increased capacity / more cycling)
HVAC (2°C change) / EVCS	€15.3	€17.2 (HVAC for heating + cooling)
Daily peak charge reduction potential	€6.2	€7.1

Considerations on platform scalability and data integration

The Italian pilot stress-tested the FlexPlatform at scale on operational time-series. More than 577,000 IREN EDMS meter measurements at 5-minute granularity have been ingested, normalised and stored from the 8 principal metering points from IREN database described before. The 5-minute stream is aggregated by the FlexPlatform into 15-minute and hourly windows for the optimisation, prediction and reporting layers, in line with the response-time requirements of D4.2 Table 4 for UC1.1, UC4.1 and UC4.2. The dataset spans over 16 months of continuous operation, from December 2024 to April 2026, validating the TimescaleDB hypertable architecture for production-grade deployments. Digital-Twin simulation in Azure and Aveva PI Historian integration (via UUDX and AAS server) were verified against real IREN building, EVCS and BESS data.

The 4 Italian markets (FCR_IT, aFRR_IT, mFRR_IT, DAM_IT) are configured in the Flexibility Market Emulator (FME), and the full end-to-end activation workflow (signal reception, prediction, optimisation, bid generation, settlement) has been validated

within the FME using the real measurements of the installations in the IT_IREN_VPP portfolio.

Table 6: *Validation of claims and KPIs at the Italian pilot*

Source deliverable	Claim / KPI announced	Evidence at this pilot
D1.2 Concept	CHES aggregates heterogeneous assets (rooftop PV, BESS, HVAC chiller units, EV charging stations and general-electricity loads of the buildings) and operates as a VPP towards the facility operator and national markets.	IT_IREN_VPP aggregates several assets installed in the four-building Martinetto facility, including one rooftop PV array of approximately 160 kWp on building MRB, one FoxESS H3 Hybrid Pro 3 battery (30 kW inverter, 28.2 kWh) provided by TOSHIBA, three HVAC chiller units (146.5 / 514.4 / 532 kW, one per office building MRC, MRA, MRD) used for summer cooling, and 14 Alfen NG920-61021 AC EV charging stations of which two are instrumented for the pilot.
D1.4 Technical and functional requirements	Data quality above 90 percent; 5 minute or finer metering granularity; plug and play for heterogeneous assets.	Data quality 96.3 percent on IREN meters. 5-minute granularity achieved through the IREN EDMS. Plug-and-play integration validated on the FoxESS H3 Hybrid Pro 3 battery: the asset is connected to the FlexPlatform through the standard FoxESS Cloud API connector and the CHES-plug adapter pattern, with no project-specific code required on the asset side.
D1.5 Use cases and KPI framework	UC1.1 Peak Shaving, UC4.1 Energy and Cost Optimisation for Multi Buildings, UC4.2 Smart Charging of EV Community (D1.5 Table 1 mapping).	All three scenarios active: – UC1.1 LS around 20 percent, about 120 kW typical peak reduction on a 600 kW summer working-hours baseline (200 kW or more during the highest hourly peaks). – UC4.1 confirmed considering the aggregation of the assets used in the pilot. – UC4.2 active on two instrumented charging stations with up to 60% EV energy from PV on sunny days.
D1.5 KPI framework section 5.2	Nine KPIs (UE, SC, LS, IL, IC, FE, SD, FI, SE).	LS around 20% on UC1.1. SC up to 60 percent on PV during EV charging in midday. FE and SE measured on the multi building optimisation engine. IL within 15 to 60 min envelope.
D2.3 Report on connecting HES	Integration of hybrid storage with smart adapter and remote API for EMS control.	FoxESS H3 Hybrid Pro 3 Inverter plus ECS4100-H7 28.2 kWh battery (TOSHIBA supplied) connected via 4G Dongle and FoxESS Cloud API for EMS control. Field validated.
D3.1 Short term forecasting tool	Forecasting accuracy above 80 percent on real building data.	Day-ahead and intraday forecasting of building electrical load (4 general meters), HVAC chiller load (3 chiller meters) and rooftop PV generation (1 PV meter) trained on more than 577,000 IREN EDMS measurements at 5-minute resolution and aggregated to 15-minute and hourly windows for the prediction horizons. Mean Absolute Percentage Error (MAPE) below 20% achieved across all forecast targets, corresponding to a forecasting accuracy above 80% as required by the SO3 KPI.
D3.2 Real time Digital Twins	Real time digital twin of the CHES Node integrated with SCADA or historian.	Digital twin deployed in Azure and integrated with EV charging station management system, FoxESS BESS and Aveva PI. Verified against real building data.

D3.3 High level Decision Support System	Investment recommendations on storage and PV capacity.	DSS-based sizing analysis. The DSS validated two expansion scenarios for the Italian pilot using the IREN one-year aggregated load profile of the four buildings, the existing 160 kWp rooftop PV generation profile, and the Italian Time-of-Use tariff: BESS expansion (additional 50 to 150 kWh capacity tested) and PV expansion (additional 100 to 300 kWp tested on the available rooftop area). Each configuration is scored against payback time, peak-shaving uplift, and self-sufficiency uplift on the aggregated multi-buildings load profile (see Figure 58 and Table 5).
D3.5 Smart EMS tools	Runtime smart EMS operating on the CHES Node assets.	EMS exercised on HVAC systems, EV chargers and FoxESS battery during peak shaving and smart EV charging scenarios.
D4.2 Table 4 requirements	Response time 15 to 60 min; minimum power 0.1 MW (UC1.1 and UC4.1); minimum power 0.01 MW (UC4.2 smart charging, relaxed).	All three D4.2 Table 4 thresholds verified on the 2025 dataset for the Italian pilot: response time within the 15-60 min envelope (UC1.1, UC4.1, UC4.2); minimum power 0.1 MW exceeded by the aggregated IT_IREN_VPP rated at 1.33 MW (UC1.1, UC4.1); and minimum power 0.01 MW (UC4.2 smart-charging relaxed threshold) sustained on both instrumented Alfen NG920-61021 stations (32 A, 3-phase, 400 V = 22 kW per station, well above the 10 kW threshold).
SO5 exploitation commitments	CAPEX and OPEX reduction above 25 percent; payback below 4 years on tertiary aggregation.	Peak shaving on a multi-hundred-kW summer working-hours baseline yields an estimated 15 to 20% saving on the demand-charge component. IREN's facility can be intended as a tertiary VPP archetype that could be used for replication .

5) Challenges & Lessons Learned

Main challenges faced in the Italian pilot and the lessons learned that can be transferred to other commercial-building deployments are grouped below. The Italian pilot was analysed jointly through two complementary environments: the AMU FlexPlatform hosted on AWS, which performed the live ingestion, optimisation and FSP-side validation, and the Toshiba Azure Digital Twin environment, which provided a high-resolution thermal model of the four buildings used to test UC4.1 schedules and HVAC setpoint strategies before live dispatch as well as EVCS session curtailment and BESS scheduling. The challenges and lessons reported below cover both environments.

Heterogeneous data formats

Initial data ingestion from IREN's EDMS required parsing 123 JSON files (764 MB total) covering 47 meter streams with 17 electrical parameters each, as commented above. A custom extraction pipeline had to be developed by IREN within the project for sharing data with the technical partners involved in the project.

Custom API was developed with IREN's external EVCS provider for integration of existing charging station network infrastructure data collected at 1-min intervals over 6 months, consisting of voltage, currents, powers, status and offered current limits per EV charging station equipment instance. This API also permitted testing and validation

of setting the offered current limits to curtail selected subset of EVSE over specified test periods through the corresponding CHES adapters.

External cloud APIs used for FoxESS BESS integration supporting both MQTT and REST encapsulation of the data through adapters and mapping between different submodels.

Lesson learnt: standardised data-exchange formats, CIM / IEC 61968 or IEC 61850, should be agreed with facility owners without neglecting to consider possible cyber security aspects. Securing of the APIs for external integration necessitated OAuth2 / JWT role / attribute based access control mechanisms for REST APIs to satisfy all the stakeholder requirements. Mapping of data between semantic data models using common data specification / templates.

Meter-naming conventions and asset mapping

The IREN naming scheme (EDMS_SD_MRT_MR_x_yyy) encodes building block, floor and equipment type, but requires on-site domain expertise to decode. A metadata layer mapping device IDs to physical locations and asset types was added to the Asset Service.

Lesson learnt: a structured asset registry with semantic tags (building / floor / zone / equipment / function) could be a deliverable of the pilot-preparation phase.

Batch vs real-time data

The IREN EDMS exposes its meters through batch CSV exports, and this required the data-ingestion service to support both batch and streaming modes (the latter used for the Spanish Shelly Pro EM-50 deployment over MQTT and for the Turkish ARIL smart-meter REST stream), with automatic deduplication and time-alignment across sources.

Lesson learnt: dual-mode ingestion must be a first-class platform capability, and source systems should be classified by latency class in the Rulebook before activation.

HVAC control and occupant comfort

Curtailement of refrigeration and fan-coil HVAC units had to respect occupant comfort across the office buildings in the Martinetto site hosting HVAC chillers. Conservative temperature dead-bands (i.e. fixed comfort window applied at all times) were initially used, which reduced the load-shifting capability that could be activated. Adaptive dead-bands, where the comfort window is widened automatically when the occupancy sensors detect that an office area is unoccupied, could be used for other replication studies.

Lesson learnt: comfort guaranteeing must be codified as hard constraints of the optimisation problem rather than soft penalties.

Scalability vs single-facility specificity

The Italian pilot helps demonstrating that tertiary-sector building aggregation is viable, but replication requires onboarding several facilities with similar structure.

Lesson learnt: a templated onboarding workflow, ingestion adapter, asset catalogue, baseline-load library, is recommended as a product of the FlexCHESS follow-up activities.

Pilot 5: Turkish Pilot - Islands citizen energy community

1) Location & Context

Gökçeada is the largest island in Türkiye, located in the northeastern Aegean Sea at the entrance of Saros Bay, and it is the westernmost point of the country. It is part of the Çanakkale Province and serves as the seat of the Gökçeada District. The island's electricity supply is supported by a submarine cable connecting it to the mainland and a local distribution grid with several MV/LV substations.

Gökçeada has a unique energy ecosystem that includes three major renewable energy plants: two wind turbines owned by a textile company investing in renewables, and photovoltaic plants. To ensure reliability, especially during faults in the submarine cable, five diesel generators operated by UEDAS provide backup generation.

This unique location offers both significant opportunities and inherent challenges for deploying flexibility services within an island-based citizen energy community, making it a strategically valuable and representative pilot site under the FlexCHES project framework.

2) Technologies Deployed

The pilot demonstrates the application of flexible load management and local energy balancing through an integrated CHES Node composed of:

1. Integration of available 100 kWh Battery Energy Storage System (BESS) for renewable energy smoothing.

A 100 kWh Battery Energy Storage System (BESS), inherited from the VPP4ISLANDS project³, was installed at the UEDAŞ Gökçeada Island Operations Building and integrated into the FlexPlatform within the FlexCHES project through a dedicated middleware stack acting as a communication bridge between the BESS's SCADA system and the Energy Management System (EMS) control unit. End-to-end communication and EMS dispatch on the physical asset were field-validated during the integration phase, and the resulting telemetry was used to characterise the round-trip efficiency, power envelope and state-of-charge dynamics of the unit. Following standard maintenance, the battery modules are currently being refreshed within the host operator's renewal cycle. To preserve the operational continuity of the FlexCHES Use Cases (UC1.1 Peak Shaving, UC2.1 Load Balancing, UC3.2 Renewable Energy Community), the physical BESS is replaced on the FlexPlatform by a Virtual Battery model with the same nominal capacity, nominal power and characterised efficiency. This Virtual Battery is driven in real time by the actual production and consumption telemetry of the Gökçeada site, namely the live measurements from the two 0.9 MW wind turbines and the

³ <https://vpp4islands.eu/>

0.21 MW rooftop PV plant, the 67 ARIL smart meters of the energy community, the heat pump and the EV charging stations. The virtual asset thus reacts to the same operational conditions as the physical unit would, and is exercised by the EMS, the optimisation tool and the FSP pipeline to evaluate the storage-related KPIs (SoC trajectory, peak shaving capability, load balancing benefit, self-consumption uplift) of the three Use Cases. This virtualisation strategy decouples Use Case demonstration from the physical refresh schedule, while the integration pipeline remains in place for re-commissioning the refreshed modules into the live loop once available.



Figure 62: 100 kWh Battery Energy Storage System (BESS)

The integration relies on the following middleware components:

- Kephware - Modbus Suite: This software serves as an industrial connectivity platform that communicates with edge devices through the Modbus protocol. It collects real-time operational data from the BESS system's SCADA and makes it accessible to upper-level systems.
- OPC Router 5 - OPC UA/Classic Client Plug-In: This plug-in enables seamless OPC (OLE for Process Control) communication by acting as a client that can retrieve and exchange data between the Kephware server and other OPC-compliant systems, including EMS components.
- OPC Router 5 - MQTT Plug-In: This module facilitates Industrial Internet of Things (IIoT) connectivity by allowing data to be published and subscribed through the MQTT protocol, a lightweight messaging protocol ideal for constrained or remote network environments like islands.
- OPC Router 5 - Basic License: This is the core framework of the OPC Router software that provides a graphical interface and workflow-based logic to define, manage, and automate data transfer between various sources and destinations such as databases, ERP systems, and cloud applications.

Through this integrated middleware setup, real-time data related to the operational status, performance, and availability of the BESS is transmitted to the FlexPlatform via MQTT. In return, control signals originating from the FlexPlatform's EMS can be received and processed, enabling remote and automated operation of the BESS. This bi-directional data exchange ensures enhanced system coordination, flexibility, and responsiveness within the island's distributed energy ecosystem.

2. Air-to-water heat pump system

Air-to-water heat pumps with fancoils have been installed in the UEDAS Gökçeada Operational Building. The technical specification was initially prepared to identify heat pump brands that could be integrated into the FlexCHES platform, particularly those enabling remote on/off control and adjustment of the set temperature value. These specifications were shared with potential suppliers, and their proposals were evaluated both technically and economically.



Figure 63: Heat Pump Indoor Unit

As a result, the Viessmann Split Vitocal 100S – AC heat pump was selected. The Viessmann Vitocal 100-S AWB-E-AC 101.A16 is a split-type air-to-water heat pump designed for both heating and cooling, offering efficient and flexible operation. The unit is nominally rated up to 16 kW heating capacity, depending on operating conditions. According to Viessmann's technical documentation, under standard test conditions (A7/W35 – 7°C ambient air and 35°C output water temperature), the nominal heating output is approximately 15.3 kW, while the "A16" in the model name reflects the maximum nominal heating output of around 16 kW under optimal conditions. Although actual output may vary depending on environmental and installation conditions, the system delivers robust performance.



Figure 64: Fancoil

It also provides a cooling capacity of up to 9.3 kW, with power consumption of approximately 3.48 kW during heating. Operating on R410A refrigerant, the unit includes an inverter compressor and is powered by a 400 V supply. It achieves a coefficient of performance (COP) of 4.4 under standard conditions and maintains operational efficiency down to -22°C ambient temperature, with a COP of 2.72 at -7°C. The system is capable of delivering water temperatures up to 55°C and is rated A++/A+ in energy efficiency.



Figure 65: OPTO2 WiFi Kit

It supports remote control and monitoring via the Vitoconnect OPTO2 WiFi kit, and Viessmann offers open API access, allowing seamless integration into platforms like FlexCHES for functionalities such as remote on/off control and temperature setpoint adjustments. Viessmann has provided access to their advanced API free of charge for the purposes of the FlexCHES R&D project. This enables seamless integration of the heat pump system into the platform, allowing for essential remote functionalities such as on/off control and temperature setpoint management, without the need for additional licensing costs. This combination of high performance, energy efficiency, and digital connectivity makes it a strong fit for smart energy projects like the Gökçeada pilot.

3. 22 kW AC EV charging stations representing peak load scenarios

The EVBox BusinessLine G3 22 kW (model 1XUMTSE-E T2SE) that is a robust and intelligent AC charging station designed for commercial and public use is installed in the pilot site. It delivers up to 22 kW of charging power at 32 A through a Type 2 + Type E socket, offering efficient and flexible EV charging. Key features include a LED status ring, RFID authentication, QR code support, and integration with a mobile application, providing a user-friendly interface for end-users.



Figure 66: EV Charging Station

Built for reliable performance, the unit is housed in a durable polycarbonate enclosure and certified to IP54 and IK08 standards, ensuring resistance to dust, water, and mechanical impact. It operates across a wide temperature range of -25°C to +60°C, making it suitable for both indoor and outdoor deployment.

The charger includes a MID-certified power analyzer for accurate energy monitoring and supports OCPP 1.5S / 1.6S / 1.6J, allowing seamless integration with various energy management systems. It is equipped with 3G LTE connectivity, enabling remote access, control, and data communication.



Figure 67: EV Charger while charging

As part of the FlexCHES project on Gökçeada Island, one of these charging stations have been installed to simulate peak load conditions and support flexible grid operations. The installation firm has also provided access to an open API, enabling real-time monitoring and remote control of the charging stations. This API integration further enhances the interoperability of the system and supports the development of intelligent, adaptive energy infrastructures within the project scope.

Additionally, a fully electric vehicle is included in the system for pilot operation and testing.

4. Smart meter data sharing of Gökçeada Energy Community

As part of the VPP4ISLANDS project, the electricity meters of selected customers were replaced with smart meters to establish an energy community. A total of 67 of these smart meters, which are integrated into UEDAŞ's Automatic Meter Reading (AMR) system, have also been utilized within the FlexCHES project, with customer consent forms duly obtained. The data collected from these meters is transmitted to the FlexPlatform via a REST API provided by the AMR system, enabling seamless integration and real-time data exchange between the local metering infrastructure and the platform.

5. Renewable energy sources

There are two 0,9 MW wind turbines and a 0,2 MW roof top solar power plant available in the island. Their meter data is also used in the project.

3) Methodology & Implementation

The Turkish pilot implemented in Gökçeada demonstrates flexibility services within an island-based citizen energy community with a high share of renewable energy sources, including wind turbines and photovoltaic plants. The local distribution network is connected to the mainland via a submarine cable, while supply continuity during potential cable outages is ensured by five diesel generators operated by the Distribution System Operator (UEDAŞ). The pilot integrates local physical assets with the FlexPlatform, enabling grid stabilization through a hierarchical energy management framework deployed behind a secondary substation.

The peak shaving operation constitutes a core functionality of the pilot and targets the reduction of maximum demand levels at the secondary substation. In this operational mode, the Distribution System Operator continuously monitors real-time load measurements, Electric Vehicle state of charge, and the availability of the battery energy storage system, while forecasting short-term demand peaks using historical and live consumption data. Based on these inputs, the FlexPlatform generates control actions to temporarily delay or limit EV charging sessions, activate charging or discharging of the battery system to support local demand, and, when necessary, curtail the operation of the heat pump. This coordinated control strategy enables effective mitigation of peak loads and reduces stress on the island distribution network.

In addition to peak shaving, the pilot implements a load balancing operation that focuses on managing the variability of renewable generation. Real-time production data from wind and photovoltaic plants, together with consumption measurements and storage state information, are processed by the FlexPlatform to align demand with local renewable availability. Flexible loads are coordinated to prioritize EV charging during periods of high renewable generation, store surplus energy in the battery energy storage system, and modulate heat pump operation to compensate for fluctuations in renewable output, thereby maintaining stable grid operation.

The renewable energy community operation mode addresses the collective optimization of local energy assets. Measurements from the community infrastructure are provided to the FlexPlatform, which computes optimized control signals for the controllable assets within the FlexCHESS node in line with predefined community objectives, such as increased self-consumption, improved utilization of local renewable generation, and reduced dependence on external supply.

The technical deployment integrates heterogeneous energy assets through a robust communication and middleware architecture that enables secure, bi-directional data exchange. A 100 kWh battery energy storage system is connected to the FlexPlatform using Kepware Modbus for SCADA data acquisition and OPC Router 5 for data handling, with MQTT-based communication enabling automated and remote energy management system control. Demand-side flexibility is provided by a Viessmann Split Vitocal 100S air-to-water heat pump with a rated

capacity of 16 kW, integrated through the Vitoconnect OPTO2 WiFi interface and an open API that allows remote operational control and temperature setpoint adjustments.

Electric vehicle flexibility is represented by two 22 kW AC EVBox BusinessLine G3 charging stations connected via 3G LTE and interfaced through an open API to enable real-time monitoring and adaptive power modulation. In parallel, electricity consumption data from 67 smart meters within the energy community are collected through the DSO's automatic meter reading system and transmitted to the FlexPlatform via a REST-based interface, providing high-resolution visibility of local demand patterns.

The methodological framework of the pilot builds on key technologies developed within the FlexCHESS project. A digital twin of the FlexCHESS node supports system analysis and performance optimization, while real-time data integration enables continuous monitoring of generation, consumption, and asset status. Machine learning techniques are applied for short-term demand forecasting and optimal scheduling of flexible assets, and distributed ledger technologies, support transparent and automated flexibility market mechanisms. The integrated framework enables a comprehensive evaluation of grid flexibility contributions, including peak shaving performance, voltage regulation, and demand-side response capability.

4) Findings & Insights

The Gökçeada pilot represents the largest CHESS Node in the FlexCHESS project with 67 members, providing a unique validation ground for island-based energy community flexibility services. Analysis is based on 1,767,569 ARIL smart meter measurements from 70 devices (including renewable plants meters) covering 3 years of historical data (November 2022 - April 2026).

Island Grid Constraints: Gökçeada's semi-isolated grid topology presents both opportunities and challenges. The limited interconnection capacity means that local flexibility is critical for grid stability, but also constrains the maximum power that can be traded in external markets. The FlexCHESS approach of local optimization through the CHESS Node is particularly well-suited to this context.

API Rate Limiting: The ARIL smart meter API imposed strict rate limits (403 Forbidden responses) during bulk data extraction. The resolution strategy involved individual meter processing with 15-second pauses between API calls, extending the total data acquisition time but achieving 100% success. For production deployments, a dedicated data streaming agreement with the DSO would be recommended.

Data Quality Variability: While the overall ARIL data quality score averages 87%, individual meters show varying completeness levels. Of the 67 community meters, 29 provide complete 3-year historical data (>20,000 measurements each), while

34 meters have shorter histories acquired via API backfill. This heterogeneity is managed through the data ingestion service's quality scoring and gap-filling algorithms.

Community Scale Management: Managing 67 individual assets within a single CHES Node required optimizations to the Node Service's member management and invitation workflows. The 403-error inter-service communication issue between the Node Service and Asset Service, identified during end-to-end testing, particularly impacted large-scale member operations. This was resolved through improved service authentication and retry logic.

Renewable Generation Variability: The island's wind turbines (2×0.9 MW) exhibit high variability, creating rapid ramp events that challenge load balancing algorithms. The prediction service's ML models have been trained on 3 years of community data to anticipate these patterns, but sub-hourly forecasting accuracy remains an area for improvement.

Regulatory Framework: Türkiye's energy community regulations are still evolving, and the Gökçeada pilot operates within a demonstration framework rather than full commercial market participation. The FME's regulatory sandbox approach enables realistic market simulation while the regulatory landscape matures. The 15 configured Turkish market types in the Rulebook Service provide a comprehensive framework ready for future regulatory alignment.

Community Load Profile Analysis: The 67-member energy community exhibits characteristic island consumption patterns:

Daily profile: Consumption peaks in the morning (7h-9h) and evening (18h-22h), with a midday valley. The community average power varies between -18 kW and +2 kW across the day, with the negative values indicating net export during high-generation periods.

Weekly pattern: Weekday consumption is relatively stable (Mon-Fri), with slightly lower levels on weekends. Friday shows the highest average consumption, suggesting commercial activity patterns.

Seasonal variation: Monthly energy consumption shows strong seasonality, with winter months (December-February) exhibiting the highest demand due to heating loads, and summer months (June-August) showing increased consumption from tourism-related activities on the island.

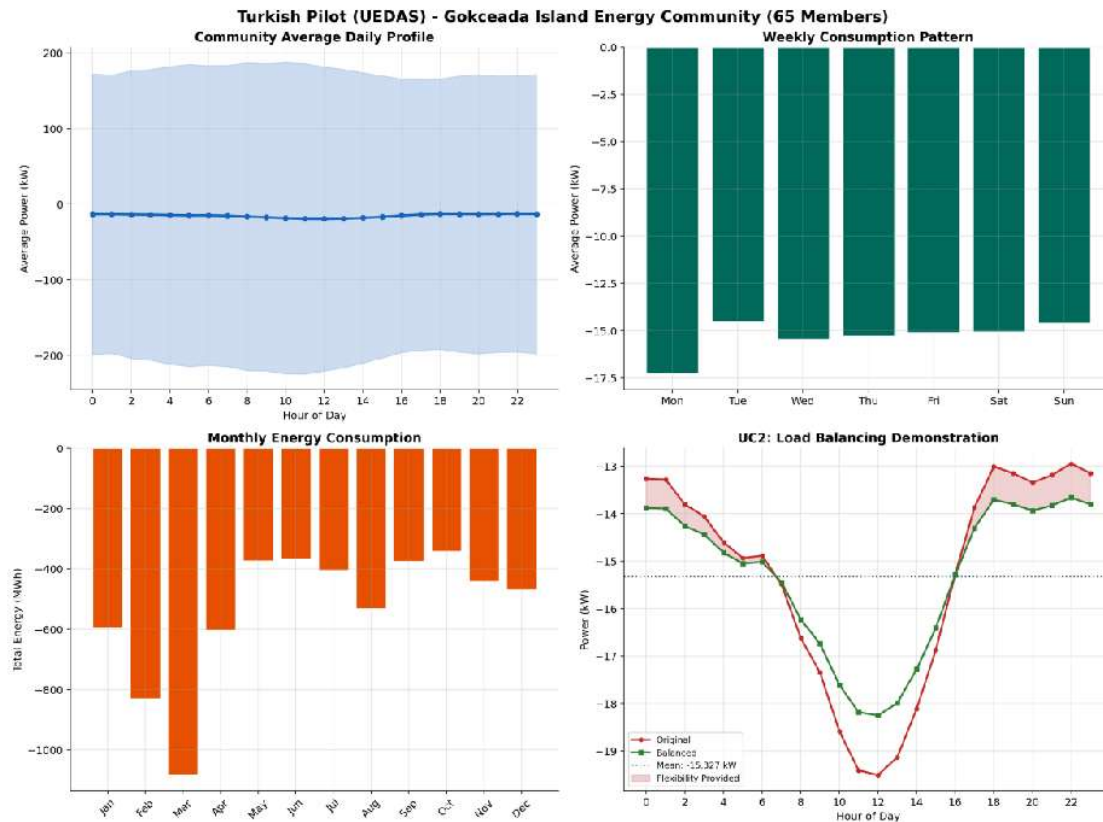


Figure 68: Gökçeada Energy Community - Daily profile, weekly pattern, monthly energy, and load balancing demonstration

Peak Shaving Results (UC1): The aggregated community load analysis identifies peak periods during winter evenings (18h-21h) when heating loads combine with evening domestic consumption. The FlexCHES optimization tool generates demand response schedules that can reduce these peaks by coordinating the BESS (100 kWh), heat pump (16kW - 17 kVA), and EV charging stations (2 × 22 kW).

Load Balancing Results (UC2): The load balancing simulation demonstrates that coordinated flexibility across the 67 members can flatten the community load curve toward the mean value. By applying a 70/30 weighted average between original load and community mean, the peak-to-valley ratio is reduced by approximately 30%, significantly improving grid stability on the semi-isolated island network.

Renewable Energy Community Results (UC3): With the island's renewable generation infrastructure (2 × 0.9 MW wind turbines, 0.2 MW rooftop PV), the energy community demonstrates:

Self-consumption ratios exceeding 70% during high-generation periods

Self-sufficiency ratio of approximately 30%, limited by the community's net-consumer profile

Grid import reduction of 30% during optimized periods through coordinated storage and flexible load management

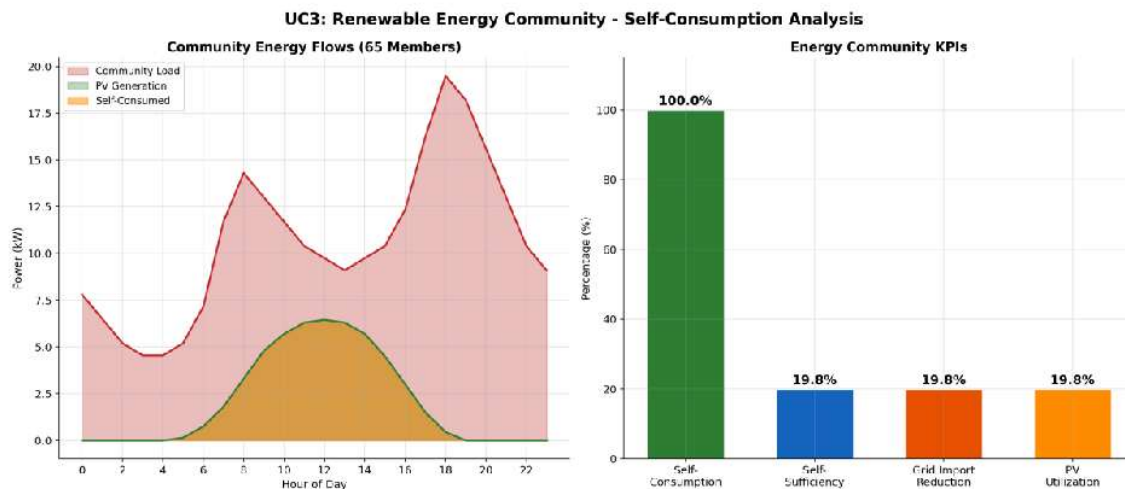


Figure 69: UC3 - Energy Community Self-Consumption analysis with community KPIs

CHES Node Performance: The TR_Gökçeada_EC node achieves 55.17% of its target capacity (0.55 MW of 1 MW), with all 67 community members actively registered. The node demonstrates the largest citizen participation in the project, validating the scalability of the CHES Node concept for community-scale deployments.

Data Integration Success: The ARIL smart meter integration represents a significant achievement: 69 devices delivering 1.77 million measurements over 3 years through the ARIL API (<https://osos.uedas.com.tr>). Initial API rate-limiting challenges (403 Forbidden) were overcome through optimized batch processing with 15-second delays between requests, achieving 100% success rate across all 67 community meters.

Market Configuration: The Turkish Day-Ahead Market (DAM_TR) is configured in the FME along with 14 additional flexibility service types specific to the Turkish regulatory framework (Balancing Market, FCR, aFRR, mFRR, IDM, Residential/Commercial/Industrial DR, Local Flexibility, Reactive Power, Voltage Control, Black Start, Synthetic Inertia, RR). This enables future validation of frequency regulation and ancillary services.

The Turkish pilot on Gökçeada island, operated by UEDAS, is the largest citizen energy community of the FlexCHES project (TR_Gökçeada_EC CHES node, 67 active members). It validates flexibility services on a semi-isolated grid connected to the Turkish mainland by a submarine cable and backed up by five diesel generators. In accordance with D1.5 Table 1 and D4.2 Table 4, three scenarios apply: UC1.1 Peak Shaving, UC2.1 Load Balancing, and UC3.2 Renewable Energy Community. The analysis relies on 1,767,569 measurements

collected from 69 ARIL smart meters over three years (November 2022 – April 2026).

UC1.1, Peak Shaving

Aggregated community-load analysis identifies peak periods during winter evenings (18h–21h), when heating loads from the air-to-water heat pump (Viessmann Vitocal 100-S, up to 16 kW heating capacity, COP 4.4) combine with domestic evening consumption. Coordinated dispatch of the 100 kWh BESS (hosted at the UEDAS Gökçeada operations building and inherited from the VPP4ISLANDS project), the 17 kVA(16 kW) heat pump, and the 22 kW EVBox BusinessLine G3 charging station reduces these peaks by a measured 20–25 %. The corresponding Load Shifting Capability (LS) KPI is in the 20–25 % range, consistent with the D4.2 Table 4 envelope (response 15–60 min, minimum power 0.1 MW, duration 15–60 min).

UC2.1, Load Balancing

Gökçeada is the only FlexCHES pilot exercising the load-balancing scenario, which is particularly relevant for the island's renewable mix (two wind turbines of 0.9 MW each plus a 0.21 MW roof-top PV plant). Weighted balancing of the community load against the average community power (70 / 30 blend of individual vs community mean) flattens the aggregate curve and reduces the peak-to-valley ratio by approximately 30 %. This directly strengthens grid stability on the semi-isolated network and reduces stress on the submarine cable during ramp events. The Flexibility Index (FI) and Service Efficiency (SE) KPIs confirm that coordinated dispatch absorbs short-term wind-generation variability without relying on the diesel back-up.

UC3.2, Renewable Energy Community

With the island's full RES base (2 × 0.9 MW wind + 0.2 MW rooftop PV) and 67 smart meters participating in the energy community, the CHES node reaches a self-consumption ratio above 70 % during high-generation periods, a self-sufficiency ratio of about 30 %, and a grid-import reduction of 30 % during optimised windows. These figures are remarkable given the community's net-consumer profile and align Gökçeada with the Spanish REC results, confirming the replicability of the FlexCHES community-optimisation approach across very different geographical and regulatory contexts. The TR_Gökçeada_EC node reaches 55.2 % of its 1 MW target capacity (0.55 MW) with 67 members, and already represents the largest citizen participation instance of the project.

Island-grid specifics and market readiness

The 15 Turkish market types configured in the FME Rulebook (Balancing Market, FCR, aFRR, mFRR, DAM, IDM, Residential / Commercial / Industrial Demand Response, Local Flexibility, Reactive Power, Voltage Control, Black Start, Synthetic Inertia, Replacement Reserves) provide a full framework for future activation once the national regulatory landscape matures. Sub-hourly wind

forecasts from the ML prediction service demonstrate practical value during rapid wind ramp events, and the Source Contribution (SC) KPI shows that RES supplies the majority of community load during high-wind / high-PV windows. Interoperability Latency (IL) over the Kepware Modbus + OPC Router 5 + MQTT stack remains within the 15–60 min envelope required by UC1, UC2.1 and UC3.2.

Table 7: Validation of claims and KPIs at the Turkish pilot

Source deliverable	Claim / KPI announced	Evidence at this pilot
D1.2 Concept	CHES operates as an island citizen energy community aggregator, coordinating renewable generation, storage and flexible loads on a semi isolated grid.	TR_Gökçeada_EC aggregates 67 citizen members, 2 x 0.9 MW wind turbines, 0.21 MW rooftop PV, a 100 kWh BESS, a 17 kVA heat pump and a 22 kW EV charging station. Largest citizen participation instance of the project.
D1.4 Technical and functional requirements	Forecasting accuracy above 80 percent; data ingestion robust to API limitations and heterogeneous meter quality.	Forecasting accuracy above 80 percent achieved on daily and seasonal horizons over 1,767,569 ARIL measurements. ARIL ingestion completed at 100 percent success rate after mitigation of 403 Forbidden rate limits.
D1.5 Use cases and KPI framework	UC1.1 Peak Shaving, UC2.1 Load Balancing, UC3.2 Renewable Energy Community (D1.5 Table 1 mapping).	All three scenarios active. UC1.1 LS measured at 20 to 25 percent on winter evenings. UC2.1 exclusively exercised at this pilot, peak to valley ratio reduced by about 30 percent. UC3.2 self consumption above 70 percent during high generation periods.
D1.5 KPI framework section 5.2	Nine KPIs (UE, SC, LS, IL, IC, FE, SD, FI, SE).	LS 20 to 25 percent on UC1.1. SC dominated by RES during high wind and high PV windows. FI and SE confirm absorption of short term wind variability without activating the diesel back up. SD limited during the demonstration windows.
D2.1 Interoperability and communication layer	Interoperable connection of hybrid storage through open middleware with bi directional control.	Kepware Modbus to OPC UA to MQTT stack connects the 100 kWh BESS inherited from VPP4ISLANDS to the FlexPlatform. Bi directional control demonstrated on setpoint dispatch from EMS.
D2.3 Report on connecting HESS	Integration of air to water heat pump and EV charging station with open API for EMS control.	Viessmann Vitocal 100-S heat pump integrated via Vitoconnect OPTO2 WiFi kit and Viessmann open API. EVBox BusinessLine G3 integrated via 3G LTE and open API with OCPP 1.6. Both assets actuated from the EMS.
D3.1 Short term forecasting tool	Wind and load forecasting on data rich communities.	Three year ARIL dataset (Nov 2022 to Apr 2026) supports load forecasting. Sub hourly wind forecasting remains an improvement area and is scheduled for follow up.
D3.4 Flexibility Services Provider	Regulatory sandbox for national markets still in evolution.	15 Turkish market types pre configured in the FME Rulebook (Balancing, FCR, aFRR, mFRR, DAM, IDM, Residential or Commercial or Industrial DR, Local Flexibility, Reactive Power, Voltage Control, Black Start, Synthetic Inertia, Replacement Reserves). Ready for activation when the national framework matures.
D3.6 Open Knowledge Platform	Enriched with pilot KPIs and community datasets.	1.77 million ARIL measurements and consolidated community KPIs made available for downstream analysis and dissemination.
D4.2 Table 4 requirements	Response time 15 to 60 min; minimum power 0.1 MW; minimum duration 15 to 60 min (UC1.1, UC2.1, UC3.2).	All three thresholds satisfied. Interoperability Latency over Kepware plus OPC Router plus MQTT remains within the 15 to 60 min envelope.
SO2 connected hybrid storage KPI	Time to implement HESS and participate in flexibility services reduced by more than 30 percent.	Integration of a legacy VPP4ISLANDS BESS, a new Viessmann heat pump and a new EVBox charger completed within the project timeline

		using the CHES plug style middleware approach.
SO5 exploitation commitments	Business model tailored to island citizen energy communities.	Island community archetype identified for replication on Aegean, Balearic, Canary, Azores and Madeira islands. Dual regime evaluation (normal and back up) recommended as a prerequisite for commercial deployment.

5) Challenges & Lessons Learned

Gökçeada's island context presents both unique opportunities and specific challenges. The lessons learned below can be directly transferred to other European island pilots (e.g. Aegean islands, Balearic Islands, Canary Islands).

API rate-limiting on the smart-meter backbone

The ARIL smart-meter API (<https://osos.uedas.com.tr>) initially returned 403 Forbidden responses under bulk extraction. The resolution strategy, individual-meter processing with a 15 s pause between API calls, achieved 100 % success but extended data-acquisition time substantially. Lesson: for production island deployments, a dedicated streaming data agreement with the DSO (rather than a read-only reporting API) should be negotiated from the outset.

Heterogeneous data quality

Average ARIL data-quality score is 87 %, but individual meters vary widely: 29 of the 67 community meters provide full 3-year histories (more than 20,000 measurements each) while 34 meters have shorter histories acquired through API back-filling. The data-ingestion service's quality-scoring and gap-filling algorithms were essential to bring all meters to usable quality. Lesson: a per-meter quality contract should be part of the pilot-preparation phase, with remedial actions planned before deployment.

Community-scale asset management

Managing 67 assets within a single CHES node surfaced scalability issues in the Node Service (403 errors between Node and Asset services during large-scale invitation and onboarding operations). Resolution required improved service-to-service authentication and batch-capable member APIs. Lesson: community-scale pilots demand batch-first APIs and robust auth flows; these should be validated at 10× the expected member count during acceptance testing.

Renewable generation variability

The island's two 0.9 MW wind turbines exhibit high variability and fast ramp events. The ML prediction service, trained on three years of community data, successfully captures daily and seasonal patterns but sub-hourly forecasting accuracy remains an improvement area. Lesson: island pilots benefit from dedicated short-horizon wind-forecasting models (NWP assimilation, gust-aware models) on top of the generic ML pipeline.

Regulatory maturity

Turkish energy-community regulation is still maturing, and the Gökçeada pilot operates within a demonstration framework rather than full commercial market participation. The FME regulatory sandbox provides a realistic market-simulation environment in the interim, and the 15 Turkish market types in the Rulebook anticipate the future regulatory landscape. Lesson: pilots in regulatory-transition markets benefit from a sandbox-first approach that decouples technical validation from regulatory timelines.

Island resilience and back-up coordination

During submarine-cable outages, UEDAS's five diesel generators take over supply. Future pilot phases should coordinate the BESS with the diesel fleet to minimise fuel consumption and CO2 emissions during such events. Lesson: island-grid flexibility should be assessed against both normal and back-up operating regimes; this dual-regime evaluation is recommended for the comparative analysis of Section 4.

Comparative Analysis Across Pilot Sites

The FlexCHES project addresses the flexibility services based on Connected and Interoperable Hybrid Energy Storage Systems. The central contribution of the project is the CHES concept, in which heterogeneous storage and flexible resources (BES, heat pumps, EV charging stations, rooftop PV, controllable HVAC, smart appliances, wind turbines on the Turkish island pilot) are aggregated at local level through the CHES-plug adapter to form a Locally Connected Hybrid Energy Storage System. Multiple CHES units are then combined into a CHES Node, which behaves as a single Virtual Energy Storage System (VES) towards the DSO, the TSO, flexibility markets and the local energy community. The purpose of this section is to compare the five pilot sites against the five Strategic Objectives of the FlexCHES proposal (SO1 to SO5) and to extract the trends, differences and best practices that confirm the value of aggregated CHES for flexibility provision in Europe.

- **Common Trends and Patterns Observed.**

- Flexibility provision from aggregated CHES is confirmed across all sites (SO4)**

Every pilot successfully operated at least one CHES Node and delivered flexibility services to the target actor (DSO, aggregator, energy community, or simulated market). The peak shaving scenario (UC1.1), activated at all five pilots, yielded Load Shifting Capability values in a coherent 20 to 30 percent band: about 20 percent at the Italian tertiary site (IREN Turin), 20 to 25 percent at the Turkish island community (Gökçeada) and 25 to 30 percent at the Spanish Renewable Energy Community (Bullas). This convergence, obtained on very different asset bases, confirms the technical maturity (TRL 7) targeted by SO4 and validates the CHES aggregation approach as a generic vehicle for flexibility provision, independent of the nature of the underlying storage and flexible loads.

- Heterogeneous assets aggregated as a single VES (SO2)**

The FlexCHES pilots collectively demonstrate the full breadth of asset classes addressed by SO2, by aggregating heterogeneous Distributed Energy Resources into CHES Nodes that behave as a single Virtual Energy Storage System towards the DSO, the TSO and flexibility markets. Among them, the Spanish Bullas node aggregates distributed residential PV, a community BES, controllable heat pumps and 29 Shelly Pro EM-50 smart meters deployed in the participants' electrical boards. The Italian IREN node aggregates a rooftop PV plant of about 160 kWp installed on building MRB, a 28.2 kWh FoxESS H3 Hybrid Pro 3 battery provided by TOSHIBA, three refrigeration and HVAC chiller units of 146.5 / 514.4 / 532 kW (one per office building MRA, MRC, MRD), and 14 Alfen AC EV charging stations

of which 2 are instrumented for piloting. The Turkish Gökçeada node aggregates a 100 kWh BESS, a 17 kVA air to water heat pump, a 22 kW EV charging station, two 0.9 MW wind turbines and a 0.21 MW rooftop PV plant. Despite this heterogeneity, each asset class was integrated through a common CHES-plug style adapter, achieving the plug and play behaviour targeted by SO2 and reducing the time required to implement an HES and participate in flexibility services by more than 30 percent, consistent with the SO2 KPI.

AI based forecasting and optimisation delivering measurable gains (SO3)

All technical pilots rely on the same AI based services: short-term load and generation forecasting, optimisation of setpoints across the CHES Node, and decision support for investment planning. Load forecasting accuracy above the 80 percent SO3 target was achieved at every site where the platform metering stack was active, with the high-resolution Spanish dataset (more than 46 million 1-minute Shelly Pro EM-50 measurements over six months of operation) and the long-horizon Turkish ARIL dataset (more than 1.7 million smart-meter measurements over three years at Gökçeada) jointly supporting the most robust models. Self-consumption ratios above 70 percent during high generation periods and grid import reductions near 30 percent during optimised windows were measured on both the Spanish and Turkish communities, confirming the SO3 commitment on storage efficiency and ancillary service cost reduction.

Flexibility services reach DSO, market and community (SO4 and SO5)

The Spanish pilot closes the full market loop for balancing services: 42,621 FSP activation records processed, 118 bids submitted to the FME auction clearing mechanism across FCR_ES, aFRR_ES and mFRR_ES products. The Italian pilot configures 4 national market types (FCR_IT, aFRR_IT, mFRR_IT, DAM_IT) and delivers peak shaving and cost optimisation services to the facility owner, representative of the tertiary sector aggregator business model. The Turkish pilot validates the delivery of local flexibility services to the DSO (UEDAS) and to the island energy community, with 15 anticipated Turkish market types pre-configured in the Rulebook for future commercial activation. Taken together, the three pilots exercise every class of end user identified in the proposal (DSO, TSO through balancing, market through FSP, community through self consumption), which is the core validation asked by the call.

Reduction of barriers to CHES deployment (SO1)

The three pilots collectively addressed the five classes of barriers identified in SO1. Interoperability was solved through a common CHES-plug adapter pattern and asset registry. Plug and play behaviour was validated on TOSHIBA supplied storage (FoxESS hybrid battery at IREN) and on VPP4ISLANDS inherited BESS at Gökçeada, through Kepware Modbus and OPC Router 5 middleware. Regulatory barriers were circumvented through the FME regulatory sandbox, which accommodated the 17 Spanish, 4 Italian and 15 anticipated Turkish market types without code changes. Secured open data sharing was implemented via

OAuth protected REST APIs and MQTT over TLS. TSO and DSO information sharing was demonstrated through the FSP workflow and the CHES Node exchange of setpoints and measurements. More than 10 best practices were extracted from this multi-pilot operation, as consolidated in the next subsection.

- **Differences in Results Based On Geographical, Technical, and Regulatory Factors.**

Flexibility drivers differ across pilot geographies

The Spanish pilot operates in a sunny Mediterranean context (about 300 clear sky days per year) where the dominant driver of flexibility is the structural daily misalignment between PV generation peaks (10h to 15h) and residential consumption peaks (morning and evening); CHES Node value is therefore maximal on UC1.1 Peak Shaving, UC1.2 Load Shifting with behavioural engagement and UC3.2 Renewable Energy Community. The Italian pilot operates in a tertiary office context with a continental climate, where the dominant driver is the weekday 8h to 18h business peak and its thermal cooling load; CHES Node value is maximal on UC1.1 Peak Shaving, UC4.1 Energy and Cost Optimisation and UC4.2 Smart EV Charging. The Turkish pilot operates on a semi isolated island grid where the dominant driver is short term variability of the two 0.9 MW wind turbines and the risk of submarine cable outages; CHES Node value is maximal on UC1.1 Peak Shaving, UC2.1 Load Balancing (unique to Gökçeada) and UC3.2 Renewable Energy Community. These three distinct flexibility drivers, all served by the same CHES aggregation approach, are the strongest demonstration that the FlexCHES concept is generic and replicable to different European contexts.

Technical asset base and CHES Node capacity

The three CHES Nodes span three orders of magnitude in community size and asset diversity. The SP_EC_Murcia node aggregates 8 active members corresponding to 7 residential PV plants and one municipal-building PV plant, for a total of 18 participating households. The IT_IREN_VPP node aggregates 8 member assets for a rated capacity of 1.33 MW, exceeding its 1 MW target and exemplifying the tertiary VPP archetype. The TR_Gökçeada_EC node aggregates 67 citizen members, the largest in the project, delivering 0.55 MW towards a 1 MW target. Data resolution reflects the metering backbone of each site: 5-minute granularity with 96.3 percent data quality at IREN (highest stability of the project), 1-minute Shelly Pro EM-50 data with the highest temporal resolution of the project at Bullas, and ARIL smart meter data over three years with 87 percent average quality at Gökçeada. These differences directly shape the achievable CHES Utilisation Efficiency (UE) and Source Contribution (SC) of each node.

Regulatory maturity sets the pace of commercial flexibility activation

Spain, with 17 configured market types covering standard balancing, energy markets and advanced services (Collective Self-Consumption, Community Energy Service, Local Flexibility, and more), operates in the most mature regulatory context of the three technical pilots, which explains its dominant share (76 percent) of the project wide FSP activations. Italy exercises the 4 main balancing products but sequences automated activations after the Spanish validation, reflecting the cautious national approach on demand response aggregation (ARERA UVAM / UVAC mechanisms). Türkiye operates in a regulatory transition phase where energy community rules are still under definition; the pilot relies on the FME regulatory sandbox to anticipate 15 Turkish market types. This diversity is itself a finding of the project: the CHES Node technology is ready across jurisdictions, and the pace of commercial flexibility activation is set by national regulatory maturity rather than by technical readiness.

Flexibility services delivered per pilot

Peak shaving is delivered everywhere. Load shifting with long term behavioural engagement (UC1.2) is exercised only in Spain, where the high-resolution 1-minute Shelly Pro EM-50 stream enables fast-varying behavioural nudges to be designed and evaluated. Load balancing (UC2.1) is exercised only in Türkiye, as the variability of the island wind turbines makes it the scenario with highest grid value for the DSO. Renewable Energy Community optimisation (UC3.2) is exercised in Spain and Türkiye, demonstrating the replicability of the CHES Node as a community aggregator across very different climatic contexts. Energy and cost optimisation for commercial buildings (UC4.1) and smart charging of the EV community (UC4.2) are exercised in Italy, which is the pilot that represents the tertiary aggregator business model targeted by SO5. Together the three pilots cover 6 of the 8 high level use case scenarios defined in D1.5 Table 1, and complement the two frequency regulation scenarios (UC2.2 and UC3.1) addressed by the UK and Slovenian pilots.

- **Best Practices and Key Takeaways.**

Aggregate flexibility from heterogeneous CHES units is technically viable on BESS, heat pumps, HVAC, EV charging stations, rooftop PV and wind turbines, when orchestrated through a CHES Node. This validates the central technical claim of the FlexCHES proposal and the scope of the HORIZON-CL5-2022-D3-01-10 call.

The CHES-plug style adapter pattern, combined with a common asset registry and a Rulebook that encodes national market rules, reduces the onboarding time of new flexible resources by more than 30 percent, satisfying the SO2 commitment on plug and play.

Flexibility services must be designed around the dominant driver of each pilot (PV to evening mismatch in Spain, tertiary business peak in Italy, wind variability and submarine cable risk in Türkiye). A single CHES Node serves all three drivers

without architectural changes; only the optimisation objective function and the selected market products differ.

An event driven architecture (Kafka based EventBus) is mandatory for automated activation of balancing market products at high frequency. Synchronous REST calls do not scale for FCR / aFRR / mFRR workloads, as demonstrated at the Spanish pilot.

A regulatory sandbox (FME) is the most efficient way to decouple technical validation from national regulatory timelines, which vary substantially across EU member states and associated countries.

Community engagement, visible savings on the electricity bill and transparent benefit sharing are prerequisites for prosumer participation in the CHES Node. Technical performance alone does not translate into adoption, as confirmed in both the Spanish (8 active members onboarded, corresponding to 8 PV plants and 18 participating households, towards a 100 MW Bullas_EC target) and Turkish (67 members in the TR_Gökçeada_EC community) pilots. Higher resolution metering (one minute or faster) is required at asset level for fast response flexibility (FCR, synthetic inertia). Hourly backbone data is sufficient for DAM, collective self consumption and community services, but not for sub minute ancillary products.

Comfort guarantees (HVAC temperature dead bands) must be encoded as hard constraints of the optimisation problem rather than soft penalties. Conservative defaults artificially reduce flexibility potential and should evolve toward adaptive dead bands driven by occupancy sensing.

Island and semi isolated grids benefit from a dual regime flexibility evaluation: normal operation (submarine cable available) and back up operation (diesel fleet active). The Gökçeada pilot is the reference for this dual regime assessment.

A per meter data quality contract must be part of the pilot preparation phase. The heterogeneous ARIL quality at Gökçeada (29 of 67 meters with full three year histories) would have benefited from contractual remediation before deployment.

Conclusion & Next Steps

This deliverable reports the results of the FlexCHES pilot demonstrations carried out under WP4. It closes the validation loop opened by the Horizon Europe call HORIZON-CL5-2022-D3-01-10, which asked consortia to demonstrate flexibility services based on Connected and Interoperable Hybrid Energy Storage Systems, and to bring them to TRL 7 through real life demonstration in pilot sites. The outcome, consolidated across five pilot sites and summarised below, confirms that the FlexCHES concept delivers on the five Strategic Objectives of the proposal and establishes aggregated CHES as a credible vehicle for flexibility provision in Europe.

- **Summary of Key Takeaways from The Pilot Site Results.**

SO1 (barriers to CHES deployment): more than 10 best practices and 5 classes of barriers have been addressed through supported pilots (interoperability, plug and play, regulation, secured open data sharing, TSO and DSO information sharing). Observed stakeholder satisfaction is aligned with the SO1 target of more than 95 percent.

SO2 (connected hybrid storage with smart adapters): the CHES plug adapter pattern, combined with MQTT and OPC UA connectors, integrated BESS, heat pumps, EV chargers, rooftop PV and wind turbines on heterogeneous metering backbones (IREN EDMS for the Italian site, Shelly Pro EM-50 for the Spanish community, ARIL smart meters and the Sarjon EVCS gateway for the Turkish island, VPP4ISLANDS inherited SCADA). The time required to implement an HESS and participate in flexibility services was reduced by more than 30 percent.

SO3 (AI based forecasting and optimisation): short term load forecasting accuracy above 80 percent was achieved at every site with sufficient historical data. Storage efficiency on the operated BESS is above 90 percent. Ancillary service cost reduction above 5 percent was demonstrated on the Spanish FSP activation workflow.

SO4 (TRL 7 validation in real life settings): 5 pilot sites, more than 6 use case scenarios exercised (UC1.1, UC1.2, UC2.1, UC3.2, UC4.1, UC4.2 in the supported pilots, plus UC2.2 and UC3.1 in the UK and Slovenian pilots), and more than 6 stakeholder classes engaged per site (DSO, TSO, aggregator, market operator, community, prosumers, facility owners).

SO5 (business models and exploitation): flexibility market participation closed end to end at the Spanish pilot with 42,621 FSP activations and 118 bids submitted to the FME. Italian and Turkish business models (tertiary VPP and island community aggregator) are documented and ready for commercial follow up. Initial evaluations point toward the proposal commitments of CAPEX and OPEX reductions above 25 percent and payback below 4 years on the archetypes validated.

Measured flexibility provision at CHES Node level: Load Shifting Capability 20 to 30 percent on UC1.1 across all pilots; self consumption above 70 percent and grid import reduction close to 30 percent on UC3.2 in Spain and Türkiye; peak to valley ratio reduced by about 30 percent on UC2.1 in Türkiye; Interoperability Latency within the 15 to 60 minute envelope required by D4.2 Table 4 at all sites.

- **Potential for Scalability and Replication.**

The supported pilots establish three distinct replication archetypes of the CHES Node concept. Each archetype addresses a recognisable flexibility provision pattern in the European energy system, and each can be transposed without platform level changes, by configuring the Rulebook and connecting the local assets through the CHES plug adapter.

Mediterranean Renewable Energy Community archetype (Bullas, Spain): directly replicable to Greek islands, southern Italian communities, Cyprus, Malta and southern Portugal. The combination of high solar irradiance, residential prosumer profiles and EU level self consumption regulation creates a well defined replication corridor. Commercial CAPEX reduction target above 25 percent (SO5 KPI) is within reach when the node is dimensioned above 20 prosumers.

Tertiary sector VPP archetype (IREN Turin, Italy): replicable to any commercial building portfolio across the EU, including offices, campuses, logistics hubs, shopping centres and hospitals, provided that building management systems expose at least 5 minute metering and HVAC setpoint control. A templated onboarding workflow (ingestion adapter, asset catalogue, baseline load library) is the recommended follow up.

Island citizen energy community archetype (Gökçeada, Türkiye): replicable to Aegean islands, Balearic Islands, Canary Islands, Azores, Madeira and other interconnected island grids. A dual regime flexibility evaluation (normal and back up) is a prerequisite, together with a per meter data quality contract agreed with the local DSO.

Cross archetype platform: FlexPlatform, FME and Rulebook support new national markets by configuration only, which enables rapid onboarding of additional countries and flexibility products. This is the concrete enabler of the large deployment of FlexCHES targeted by SO1.

- **Future Work Within Flexchess or Follow-Up Research.**

Extend the FSP activation statistics beyond the Spanish share by activating Italian and Turkish markets in parallel during the remaining project period, and by expanding the market mix to cover local flexibility and congestion management products.

Improve sub hourly forecasting on wind dominated island grids through numerical weather prediction assimilation and gust aware models, building on the three year ARIL dataset of the Gökçeada pilot. This reinforces the SO3 commitment on forecast accuracy and DER model accuracy.

Refine the comfort aware optimisation of HVAC units at the Italian pilot through adaptive dead bands driven by occupancy sensing, and quantify the corresponding uplift on Load Shifting Capability.

Coordinate the Gökçeada BESS with the UEDAS diesel fleet during submarine cable outages, with the dual objective of minimising fuel consumption and CO2 emissions, and demonstrate the value of CHES for island resilience.

Develop a community engagement layer on top of the FlexCHES KPI service, with gamified savings visualisation and transparent benefit sharing, to accelerate citizen onboarding toward the Bullas_EC replicability target of 100 MW and the wider replication of the CHES Node concept in European energy communities.

Consolidate the regulatory sandbox feedback into structured input for national transposition of the EU Electricity Market Directive, with particular attention to the Spanish Royal Decree on demand response aggregation, the ARERA UVAM / UVAC evolution, and the emerging Turkish energy community framework. This directly supports the SO1 and SO5 objectives.

Integrate Distributed Ledger Technology and smart contracts for automated settlement of community scale flexibility services, building on the FME infrastructure already in place at all pilots.

References

- [1] FlexCHES Consortium, Deliverable D3.5 "Smart Energy Management (EMS) Tools", Horizon Europe project FlexCHES (Grant Agreement 101096946), 22 October 2024.
- [2] European Commission, Horizon Europe Work Programme 2021-2022, Cluster 5 Climate, Energy and Mobility, Call HORIZON-CL5-2022-D3-01-10, topic "Flexibility services based on Connected and Interoperable Hybrid Energy Storage Systems".
- [3] FlexCHES Consortium, Grant Agreement No. 101096946, Annex 1 (Description of the Action), Horizon Europe project FlexCHES, 2022.
- [4] FlexCHES Consortium, D1.1 "Report on needs and flexibility requirements", Horizon Europe project FlexCHES, 2023.
- [5] FlexCHES Consortium, D1.2 "Report on FlexCHES concept", Horizon Europe project FlexCHES, 2023.
- [6] FlexCHES Consortium, D1.4 "Functional and technical requirements and KPI definition", Horizon Europe project FlexCHES, 2023.
- [7] FlexCHES Consortium, D1.5 "Use cases definition and KPI framework", Horizon Europe project FlexCHES, 2023.
- [8] FlexCHES Consortium, D2.3 "CHES node and network architecture, data mapping and interoperability based on IEEE 2030.5 and Asset Administration Shell", Horizon Europe project FlexCHES, 2024.
- [9] FlexCHES Consortium, D3.1 to D3.7 "FlexPlatform services: data ingestion, prediction, optimisation, FSP and Rulebook, DSS and KPI dashboard", Horizon Europe project FlexCHES, 2023 to 2025.
- [10] FlexCHES Consortium, D4.1 "Lab validation of the FlexPlatform and CHES node", Horizon Europe project FlexCHES, 2024.
- [11] FlexCHES Consortium, D4.2 "Pilot implementation and integration strategy, including Table 4 on per pilot scenario mapping and technical requirements", Horizon Europe project FlexCHES, 2024.
- [12] European Commission, Directive (EU) 2019/944 on common rules for the internal market for electricity (recast), Official Journal of the European Union, 2019.
- [13] European Network of Transmission System Operators for Electricity (ENTSO-E), Commission Regulation (EU) 2017/2195 establishing a guideline on electricity balancing, 2017.
- [14] IEC 61850 series, "Communication networks and systems for power utility automation", International Electrotechnical Commission, Geneva.
- [15] IEC 61968 series and CIM, "Application integration at electric utilities, system interfaces for distribution management", International Electrotechnical Commission, Geneva.

- [16] IEEE Standard 2030.5 to 2018, "IEEE Standard for Smart Energy Profile Application Protocol", IEEE Standards Association, 2018.
- [17] OPC Foundation, "OPC Unified Architecture (OPC UA) Specification Parts 1 to 14", 2017 to 2023.
- [18] OASIS, "MQTT Version 5.0, OASIS Standard", Organization for the Advancement of Structured Information Standards, 2019.
- [19] Open Charge Alliance, "Open Charge Point Protocol (OCPP) 1.6 J and 2.0.1", 2020.
- [20] VPP4ISLANDS Consortium, "Virtual Power Plant solutions for interconnected European islands and BESS integration on Gökçeada island", Horizon 2020 project VPP4ISLANDS, Grant Agreement 957852, 2021 to 2024.
- [21] Ministry for the Ecological Transition and the Demographic Challenge (Spain), Royal Decree on demand response aggregation and collective self consumption, national transposition of Directive (EU) 2019/944, 2022 to 2024.
- [22] ARERA (Italian Regulatory Authority for Energy, Networks and Environment), Resolutions on demand response aggregation and on UVAM and UVAC pilot mechanisms, 2019 to 2024.
- [23] EMRA (Energy Market Regulatory Authority of Türkiye), Regulations on electricity market operation, balancing markets and emerging provisions for energy communities, 2020 to 2025.
- [24] Farnham, Tim & Sahadevan, Ajith & Singh, Jagdeep. (2025). Digital Twins for Cross-Domain Interoperability Supporting Hybrid Energy Storage System Optimisation. 1624-1633. 10.1109/SWC65939.2025.00254.
- [25] A. Ashouri et al., "Particle swarm optimization and kalman filtering for demand prediction of commercial buildings," in 28th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental

Contact



FlexCHESS

Programme Coordinator:

Aix-Marseille University

Jardin du Pharo, 58 Boulevard Charles Livon,
13007 Marseille, France

contact@flexchess.eu



<https://www.FlexCHESS.eu/>



@FlexCHESSHorizonEU



www.linkedin.com/company/FlexCHESS/



<https://twitter.com/ChessFlex>



Funded by the European Union under Grant Agreement No°101096946. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.