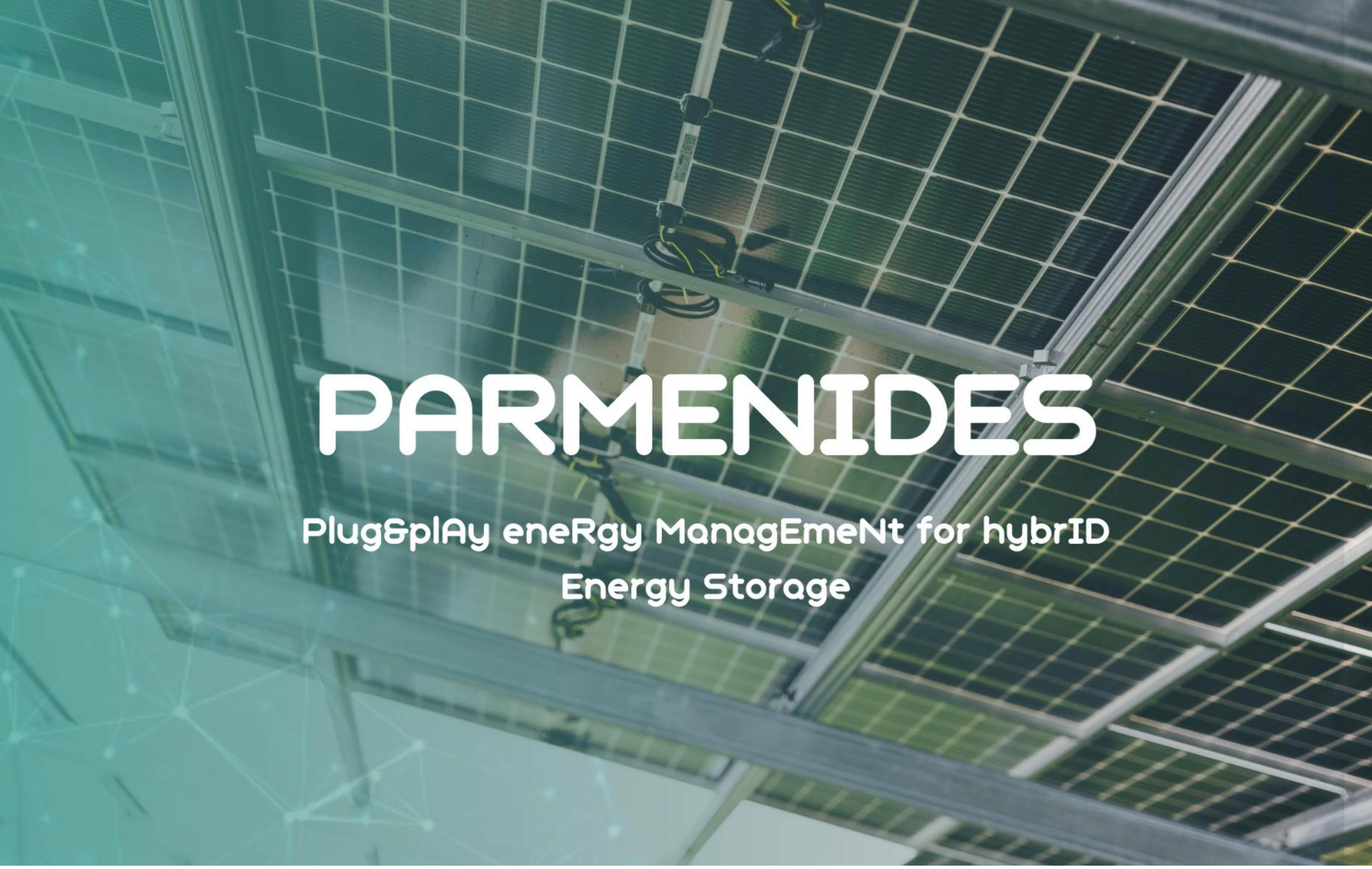

PARMENIDES

Plug&plAy eneRgy ManagEmeNt for hybrID Energy Storage

Deliverable D7.4

Best practice report

Work Package 7

Funded by the European Union's Horizon Europe programme under Grant Agreement nº 101096453

Grant agreement	101096453
Type of action	HORIZON-IA HORIZON Innovation Actions
Topic	HORIZON-CL5-2022-D3-01-10 Interoperable solutions for flexibility services using distributed energy storage
Starting date of project	01.01.2023
Project duration	36 months

Work package	WP7 – Exploitation and sustainability business models through BRIDGE
Related task	T7.4 – Best Practice and road-mapping through BRIDGE collaboration (M12-M36)
Deliverable due date	M36 (31.12.2025)
Actual delivery date	M37 (15.01.2025)
Dissemination level	PU - Public
Deliverable responsible	Trialog

Document Information

Document Version: 1.0

Revision / Status: Submission

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Document History

Revision	Content/changes	Resp. partner	Date
0.1	Structure of the report	Léo Cornec (TRI)	21/11/2024
0.2	Update of the structure and contribution to deliverable content	Léo Cornec (TRI)	23/06/2025
0.3	Section 2.2 completion	Tareq Chy (TRI) Dune Sebilleau (TRI) Léo Cornec (TRI)	07/07/2025
0.4	Section 2.2 completion	Tommaso Francese (TRI)	09/07/2025
0.5	Section 2.3 completion	Tareq Chy (TRI) Léo Cornec (TRI)	22/08/2025
0.6	Section 3 completion	Léo Cornec (TRI)	16/10/2025
0.7	First complete draft version	Léo Cornec (TRI)	20/11/2025
0.8	Deliverable review	Dune Sebilleau (TRI)	28/11/2025
0.9	Refinement	Léo Cornec (TRI)	06/11/2026
0.10	Deliverable review	Malek Anouti (EXP)	14/01/2026
1.0	First version	Léo Cornec (TRI)	15/01/2026

Document Approval

Final approval	Name	Resp. partner	Date
1.0	Mark Stefan	AIT	15/01/2026

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Executive Summary

The ongoing transition of the energy system is accompanied by digitalisation activities, enabling new applications. This results in a fragmentation of existing platforms, protocols, and standards. Therefore, interoperability among various platforms as well as cross-domain interoperability must be ensured. The PARMENIDES project was conceived and designed to cover this fundamental problem. In this project, the notion of Energy Community (EnC) is central. Among the project results, the following three were selected as Key Exploitable Results (KERs):

- KER#1: PARMENIDES Energy Management System EMS4HESS (developed by MAPS);
- KER#2: PARMENIDES flexibility and load management strategy (developed by KTH);
- KER#3: Grid Capacity Management Tool (developed by AIT).

This document serves as a strategic resource for stakeholders, guiding future research and innovation on the EnC, EMS and energy storage topics.

More specifically, its objective is to support the market introduction of project results by studying relevant European projects and summary reports. These sources of information will enable the identification of risks and challenges, best practices, and roadmaps. The document is organised to offer clarity and actionable insights for stakeholders, including policymakers, researchers, and industry experts.

It begins with a comprehensive literature review of EU-funded projects (e.g., MERLON, InterConnect) and key studies done by initiatives like the EU Commission, ETIP SNET[1] and European Association for Storage of Energy (EASE)[2]. The European best practices section examines technical, regulatory, and market challenges, synthesising lessons learned and recommendations. The report concludes with a roadmap for innovation, emphasising collaboration and research priorities.

Table 1 presents the categories identified for the risks, challenges and best practices.

Table 1: Risks, challenges, and best practices categories identified within the study

Aspect	Risks/Challenges/Best practices categories
Technical	• Interoperability and integration risks • Cybersecurity and data protection risks • Grid stability and energy management risks • Data and infrastructure limitations • Cost and economic viability risks • Scalability and deployment challenges • Maintenance and operational complexity • Technical control and aggregation risks • Supply chain and external dependencies • Societal and market risks

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[1] https://smart-networks-energy-transition.ec.europa.eu/

[2] https://energystorageeurope.eu/

Regulatory	• Lack of legal and regulatory framework risks • Cross-border and compliance risks • Grid connection and interconnection risks • Approval and licensing risks • Market and revenue uncertainty risks • Data governance and cybersecurity risks • Market mechanism and flexibility risks • Role and responsibility uncertainty • Safety and technical risks • User engagement and social risks • Business model and investment risks

This analysis offers valuable insights into technical, regulatory, and policy risks, as well as the most effective strategies identified across Europe. It highlights development and deployment roadmaps for EnCs. The findings emphasise, for example, the need for standardised and interoperability frameworks, complete regulatory frameworks, policy support, modular and scalable design, economic viability, cross-sector collaboration, and adaptive policies to accelerate the transition toward a sustainable and resilient energy system.

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Abbreviations

Acronym	Description
A-CAES	Adiabatic Compressed Air Energy Storage
aFRR	automatic Frequency Restoration Reserve
AI	Artificial Intelligence
AIT	Austrian Institute of Technology - Partner of the project
ANM	Active Network Management
ATP	Automatic Trading Platform
BESS	Battery Energy Storage Systems
BMS	Building Management System
BRP	Balance Responsible Party
BtM	Behind-the-Meter
CAES	Compressed Air Energy Storage
CAPEX	Capital Expenditure
CDEMS	Charging-Discharging Energy Management System
CEC	Citizen Energy Communities - Directive (EU) 2019/944
CEMS	Charging Energy Management System
CEMS	Community Energy Management System
CEP	Clean Energy Package
CHP	Combined Heat and Power
CIM	Common Information Model
CRA	Cyber Resilience Act
CSP	Concentrated Solar Power
DER	Distributed Energy Resources
DGA	Data Governance Act
DMP	Data Management Plan
DPIA	Data Privacy Impact Assessment
DPO	Data Protection Officer
DPP	Digital Product Passport
DR	Demand Response
DSA	Digital Service Act
DSO	Distribution System Operator
DTC	Distribution Transformer Controller
EASE	European Association for Storage of Energy
EEM	Elastic Energy Management
EES	Electrical Energy Storage Systems
EMS	Energy Management System
EMS4HESS	Energy Management System for Hybrid Energy Storage System
EnC	Energy Community

ENS	Energienetze Steiermark - Partner of the project
ESCO	Energy Service COmpanies
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
EV	Electric Vehicle
EWHs	Electric Water Heaters
EXP	Experientia - Partner of the project
FEMS	Factory Energy Management System
GDPR	General Data Protection Regulation
H2	Hydrogen
HEMS	Home Energy Management System
HESS	Hybrid Energy Storage System
HLUC	High-Level Use Case
HVAC	Heating, Ventilation, and Air Conditioning
I-CAES	Isothermal Compressed Air Energy Storage
ICT	Information and Communication Technologies
ILESEM	Integrated Local Energy System Energy Management & Optimisation
IML	Information Management Layer
IoT	Internet Of Things
JRC CoC ESA	Joint Research Centre Code of Conduct Energy Smart Appliances
KER	Key Exploitable Result
KTH	Swedish: "Kungliga Tekniska högskolan"; English: "KTH Royal Institute of Technology" - Partner of the project
LCA	Life Cycle Assessment
LEM	Local Energy Market
LFM	Local Flexibility Market
LV	Low Voltage
MAPS	MAPS Group - Partner of the project
mFRR	Frequency Restoration Reserve with manual activation
MV	Medium Voltage
NC DR	Network Code on Demand Response
NIS	Network and Information Security
NIST	National Institute of Standards and Technology
NRA	National Regulatory Authority
OPEX	Operational Expenditure
P2P	Peer-to-peer
PARMENIDES	Plug&plAy eneRgy ManagEmeNt for hybrID Energy Storage
PCC	Point of Common Coupling
PECO	PARMENIDES Energy Community Ontology

PIA	Privacy Impact Assessment
PII	Personal Identifiable Information
PKI	Public Key Infrastructure
PMS	Power Management System
PMV	Performance Measurement & Verification
PPC	Priority Project Concept
PQ	Power Quality
PSH	Pumped Storage hydro-power
PV	Photovoltaic
RBAC	Role-based Access Control
REC	Renewable Energy Community
RED II	Renewable Energy Directive (RED II) - Directive (EU) 2018/2001
RES	Renewable Energy Sources
SAREF	Smart Applications REFerence ontology
SBM	Stationary Battery Manager
SCADA	Supervisory Control and Data Acquisition
SCEMS	Smart Community Energy Management System
SGAM	Smart Grid Architecture Model
SITP	Smart IT platform
SMES	Superconducting Magnetic Energy Storage
SoA	Service-Oriented Architecture
TES	Thermal Energy Storage
TSO	Transmission network operator
VPP	Virtual Power Plant
VRFB	Vanadium redox flow battery
VTES	Virtual Thermal Energy Storage

1 Introduction

1.1 PARMENIDES project introduction and summary

The ongoing transition of the energy system is accompanied by digitalisation activities, enabling new applications. This results in a fragmentation of existing platforms, protocols, and standards. Therefore, interoperability among various platforms as well as cross-domain interoperability must be ensured.

The usage of ontologies provides an opportunity to address cross-platform and cross-domain interoperability. PARMENIDES aims to develop a new ontology by extending existing ontologies to provide a knowledge base, with a focus on the electricity and heating domain for buildings, customers, and energy communities (EnCs). It will support different use cases, focusing on the utilisation of Hybrid Energy Storage Systems (HESS). Besides the representation of storage technologies, information about EnC customers, their behaviours, and components, including their relations, will be part of the ontology, providing a standardised vocabulary of the domain of EnCs. This further includes technical, economic, regulatory, behavioural, and social constraints to be considered in operation.

To support use cases, a new generation of innovative Energy Management Systems (EMS) will be developed. These systems will be capable of using ontologies as a knowledge base. This will enable a very generic software design and ensure the scalability and replicability of the solution.

As a framework for the integration of the EMS, PARMENIDES have defined an information and communication architecture, enabling an interoperable, reliable, and secure exchange of data and instructions. The developed EMS was demonstrated in diverse pilots in Austria and Sweden. The Austrian pilot addressed two project EnCs with different storage technologies; the Swedish pilot focused on flexibility from a very short time scale through innovative heat pump control and electrical and thermal energy storage.

1.2 Context

Europe aims to spearhead the global shift to clean energy by rapidly scaling up the development, production, and integration of cutting-edge battery technologies. The Net-Zero Industry Act[3] sets a target for the EU to achieve a battery manufacturing capacity of at least 550 GWh by 2030. This ambition underscores the region's commitment to accelerating its green energy transition.

1.2.1 European energy storage target and status

According to the *Report from the Commission on the progress on competitiveness of clean energy technologies* [1] published in February 2025, at the start of 2024, the EU appeared to be in line with its 2030 battery goals. However, the Northvolt's bankruptcy in November 2024 and the cancellation or delay of 616 GWh of planned capacity now threaten those targets. In 2024, the EU accounted for just 7% of global battery production—less than initially expected. However, with global output poised to grow nearly five

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[3] https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

times over the next five years, reaching the EU's targeted 10% share by 2030 would be enough to meet all of Europe's anticipated demand.

European energy storage status

The European Commission *Real-time Energy Storage Dashboard* [4] [2] describes the real-time energy storage power in Europe. Figure 2, Figure 3, Figure 4 and Figure 1 describe the situation in Europe in December 2025. At this stage in Europe, 74GW are already operational, 123GW are expected, and 4GW are inactive. Most of the operational storage systems are mechanical, and most of the expected ones are electrochemical.

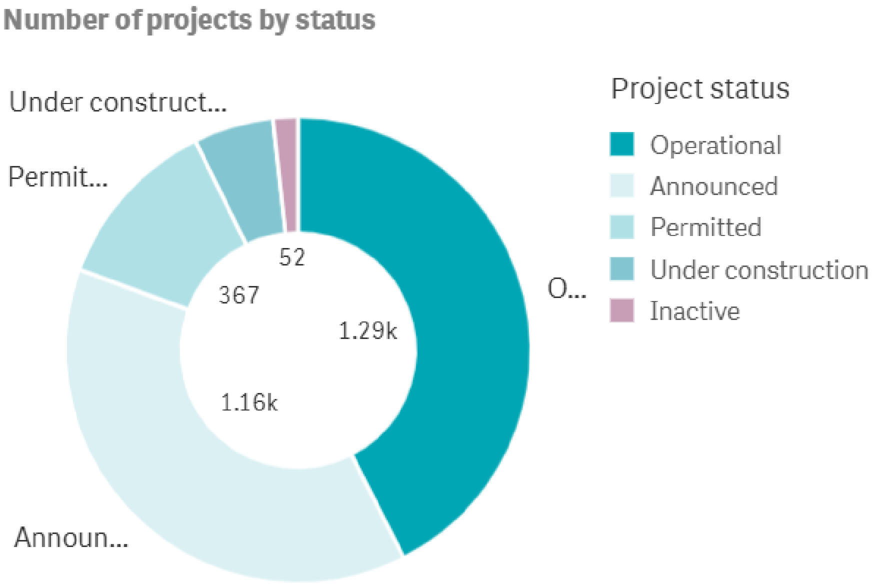

Figure 1: Number of energy storage projects (December 2025)

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[4] https://ses.jrc.ec.europa.eu/storage-inventory

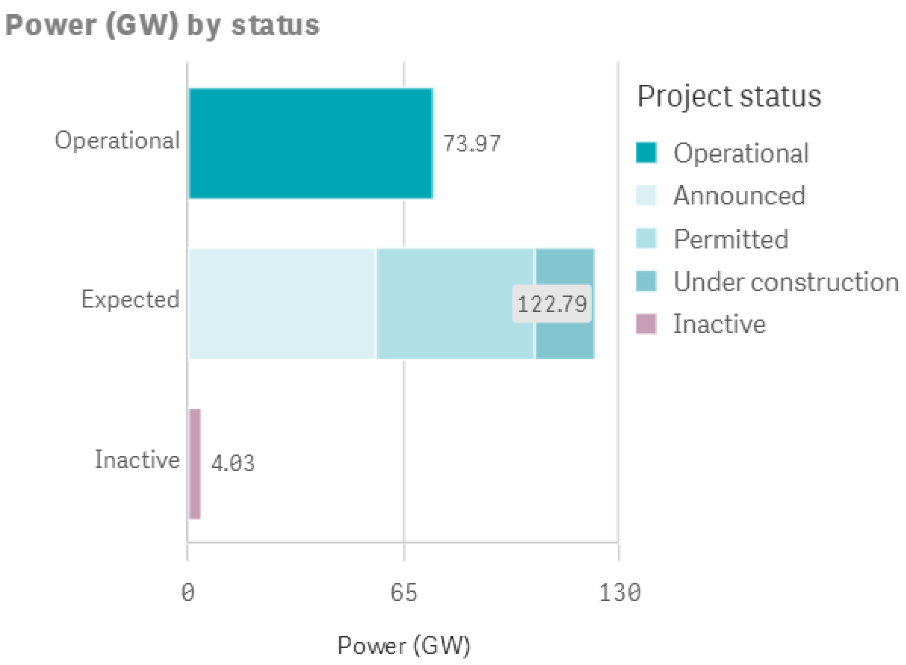

Figure 2: Energy storage capacity status (December 2025)

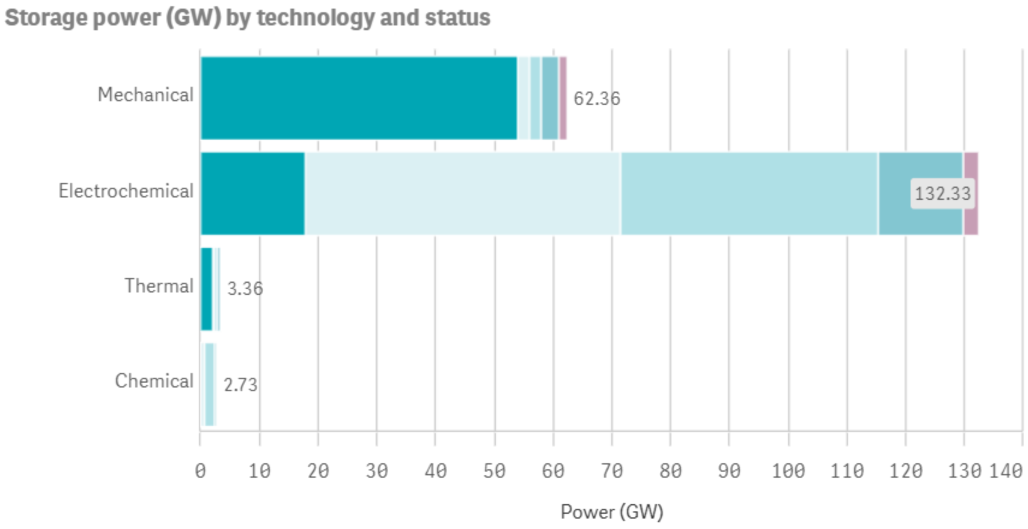

Figure 3: Storage power by technology and status (December 2025)

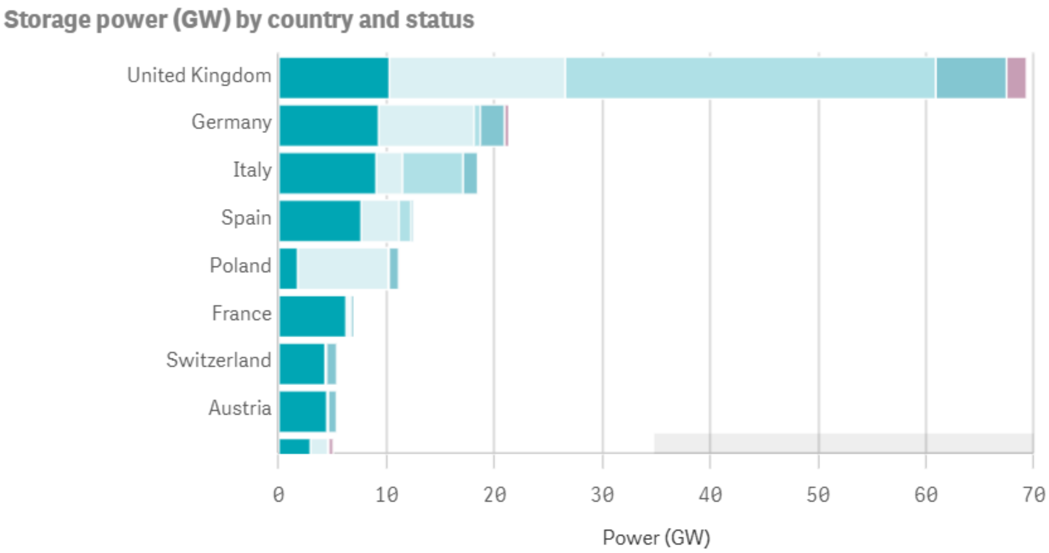

Figure 4: Storage power by country and status (December 2025)

The following figures describe the specific situation for energy storage in the countries of the PARMENIDES consortium.

Austria

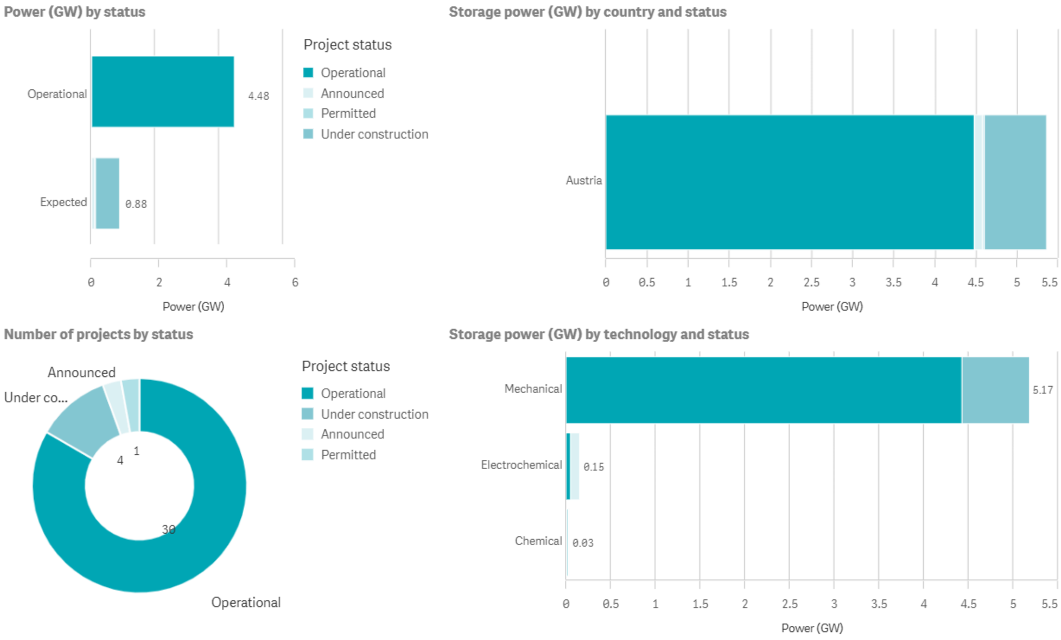

Figure 5: Energy storage status in Austria (December 2026)

Sweden

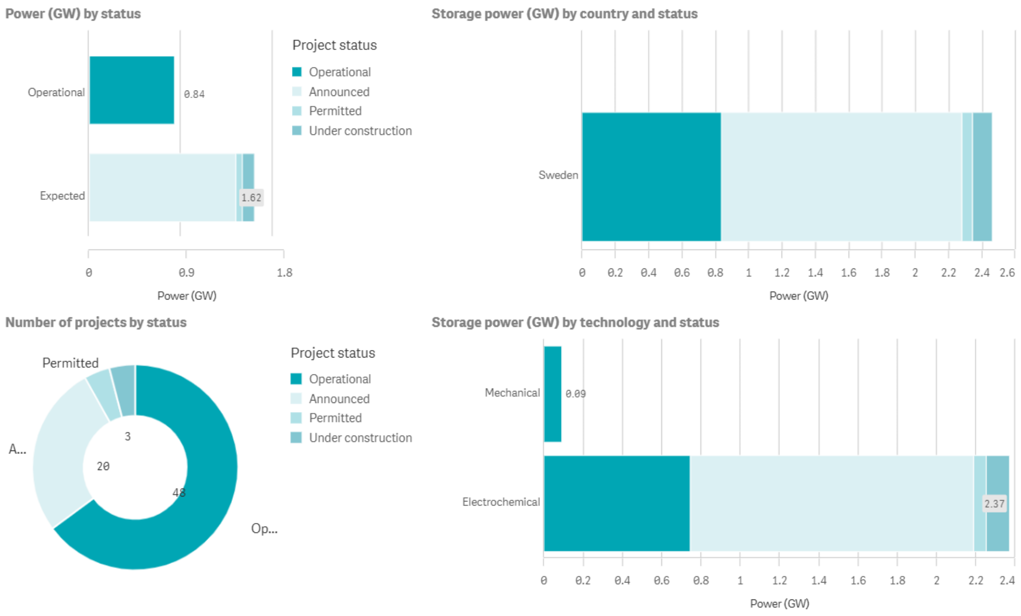

Figure 6: Energy storage status in Sweden (December 2026)

France

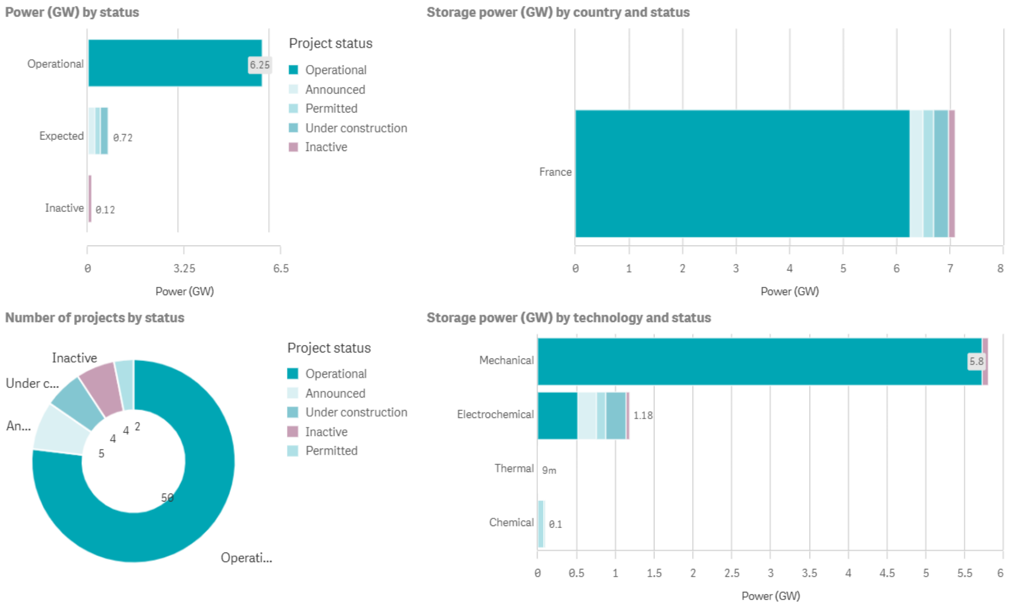

Figure 7: Energy storage status in France (December 2026)

Italy

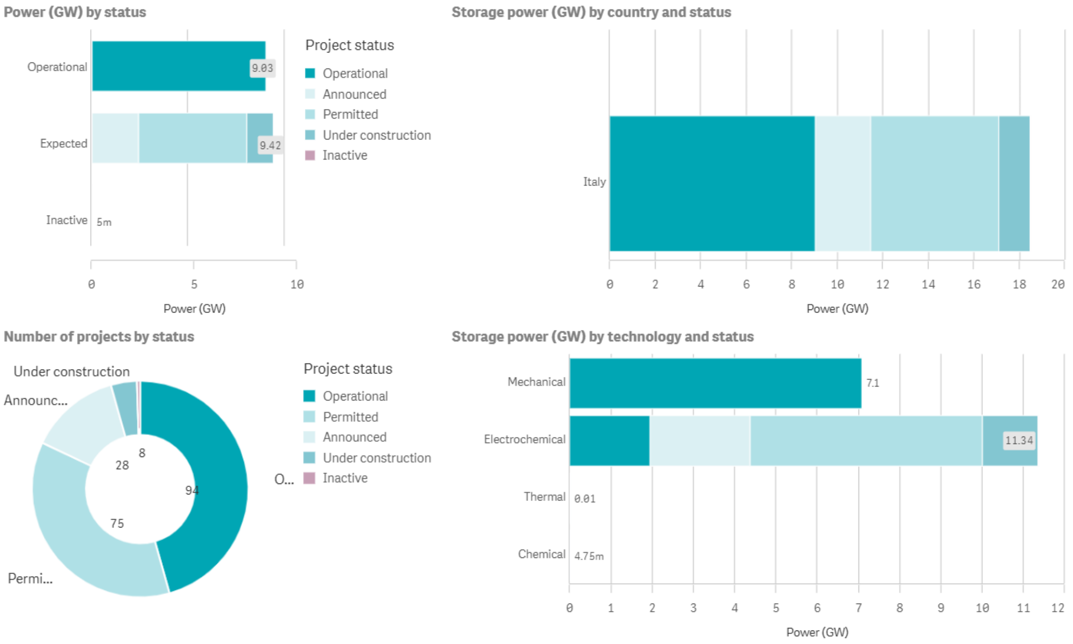

Figure 8: Energy storage status in Italy (December 2026)

Switzerland

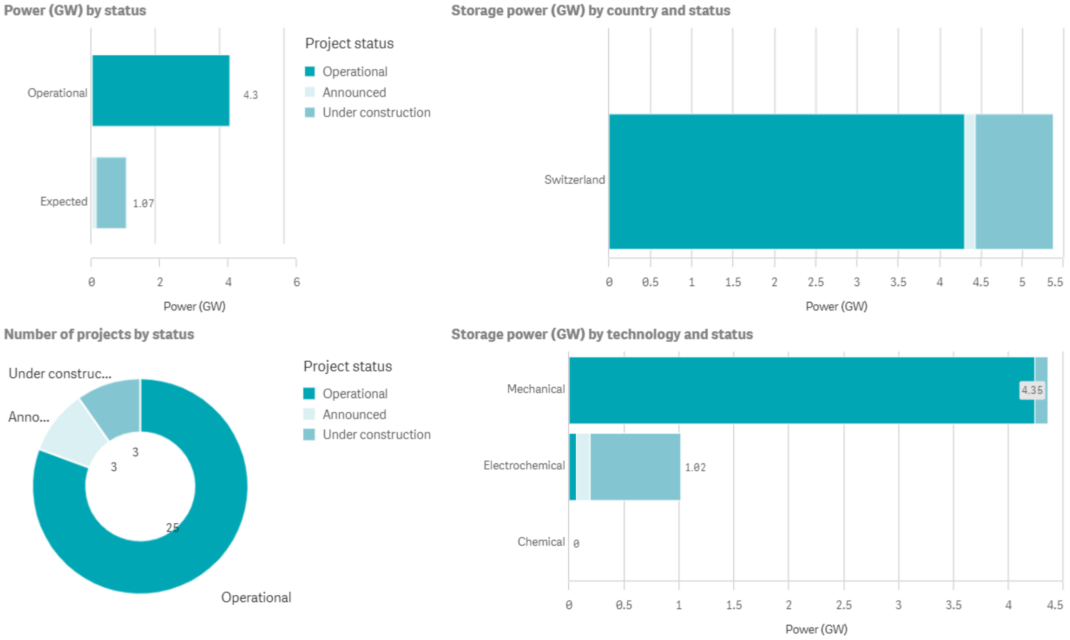

Figure 9: Energy storage status in Switzerland (December 2026)

Germany

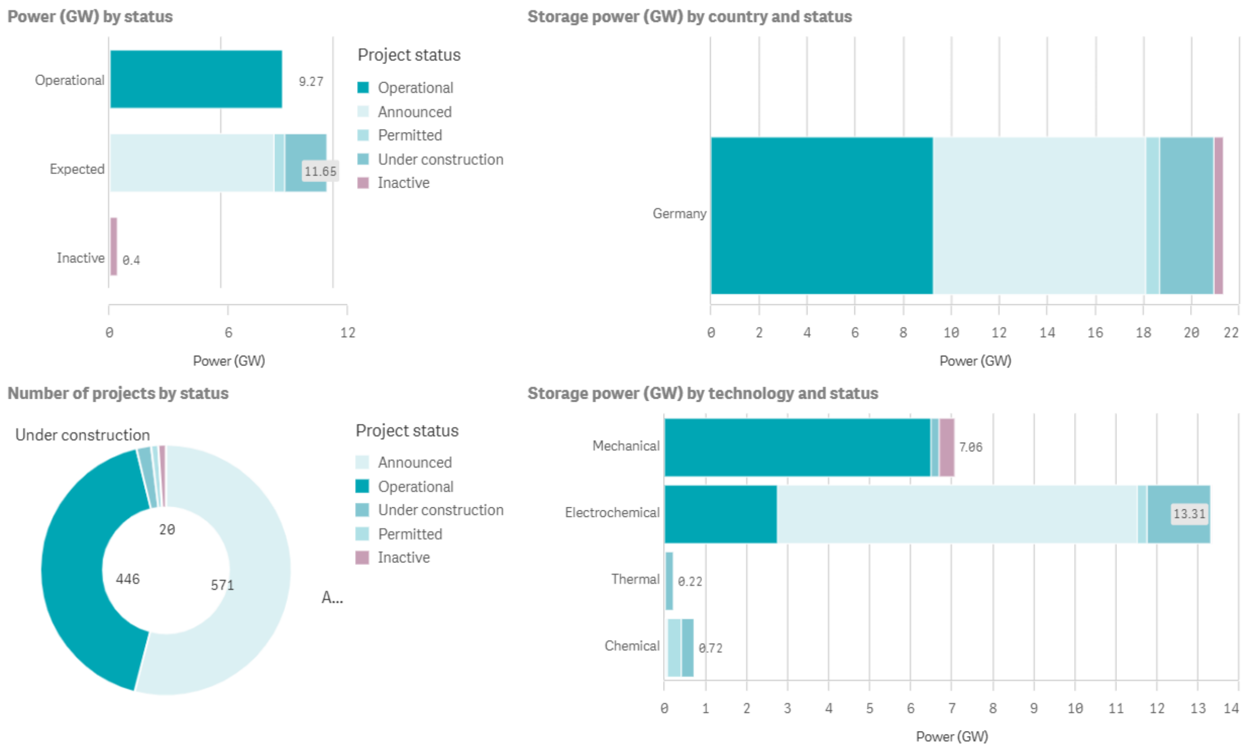

Figure 10: Energy storage status in Germany (December 2026)

1.2.2 Regulatory context

The regulatory scheme of the PARMENIDES project was identified and studied in *PARMENIDES Deliverable 6.3 - Standards and legislation for the market introduction of the PARMENIDES results* [3]. An overview can be found in Table 2.

Table 2: PARMENIDES regulatory framework

Category	Regulation/initiative
Energy	Clean Energy Package (EU) – 2019 [4]
	Renewable Energy Directive (RED II) - Directive (EU) 2018/2001 [5]
	Citizen Energy Communities (CEC) - Directive (EU) 2019/944 [6]
	Regulation (EU) 2019/943 on the internal market for electricity (recast) [7]
	Regulation on demand response (based on Network code on demand response) [8]
	Smart Readiness Indicator (SRI) [9]
	JRC CoC energy smart appliance (ESA) and energy management system (EMS) [10]
	Cyber Resilience Act (CRA) – 2024 [11]

Data, Data privacy, cybersecurity, AI and trustworthiness	Artificial Intelligence (AI) Act – 2024 [12]
	Ecodesign for Sustainable Products Regulation (ESPR) - 2024
	Data Act – 2024 [13]
	Data Governance Act – 2023 [14]
	Network and Information Security 2 (NIS 2) - 2022 [15]
	Digital Service Act (DSA) - 2023
	General Data Protection Regulation (GDPR) – 2018 [16]

1.2.3 Energy storage technologies

Table 3 presents an overview of the different energy storage technologies as a support for this document.

Table 3: Overview of energy storage and conversion technologies [17]

Type of storage	Type of technology	Description
Electrochemical storage	Battery	Electricity can be converted from chemical energy into electrical energy on demand
Chemical	P2-Gas-2P	Electricity can be converted into gases to be later used as feedstock for power generation plants (e.g., gas turbines, fuel cells, etc)
	P2-Liquids-2P	Electricity can be converted into liquid fuels (e.g., methanol) to be later used as feedstock for power generation plants
	P2-Gas-2Industry (as gas, to heat)	Electricity can be converted into gases to be later used into industrial facilities as heat sources or process gases
	P2-Liquid-2Industry (as liquid, to heat)	Electricity can be converted into liquid chemicals to be later used into industrial facilities as heat sources or process fluids
	P2-Gas-2Mobility	Electricity can be converted into gases to be later used into light or heavy-duty vehicles as fuel
	P2-Liquid-2Mobility	Electricity can be converted into liquid fuels (e.g., methanol) to be later used into light or heavy-duty vehicles as fuel
	P2-Heat-2P	Electricity can be converted into heat to be later used as feedstock for power generation plants

Thermal	P2-Heat	Electricity can be converted into heat to be used directly as heat sources (e.g. heat pump)
	CSP (Concentrated Solar Power)	Heat generated through concentration of solar light to be used as feedstock for power generation plants or heat source
Mechanical	Flywheels	A kinetic energy storage system composed by a rotating mass, typically axisymmetric, which stores rotary kinetic energy, driven by an electrical machine able to work as a motor or a generator
	Pumped storage hydropower (PSH)	Pumped storage hydropower is based on transfer of water potential energy between two reservoirs.
	Compressed air (CAES)	The CAES technology stores electrical energy in the form of high-pressure air and then generates back electricity through an expansion process when needed.

1.3 Document objectives and structure

Its objective is to support the market introduction of project results by studying relevant European projects and summary reports. These sources of information will enable the identification of risks and challenges, best practices, and roadmaps. The document is organised to offer clarity and actionable insights for stakeholders, including policymakers, researchers, and industry experts.

It begins with a comprehensive literature review of EU-funded projects (e.g., MERLON, InterConnect) and key studies done by initiatives like the EU Commission, ETIP SNET[5] and European Association for Storage of Energy (EASE)[6]. The European best practices section examines technical, regulatory, and market challenges, synthesising lessons learned and recommendations. The report concludes with a roadmap for innovation, emphasising collaboration and research priorities.

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[5] https://smart-networks-energy-transition.ec.europa.eu/

[6] https://energystorageeurope.eu/

2 Literature review

2.1 Introduction

This section presents the summary of the literature review performed in the context of T7.4, intending to review European projects supporting BRIDGE [7]and other sources, focusing on EnC, EMS, and storage/hybrid-storage to extract best practices and support the PARMENIDES market introduction.

Two main types of sources were studied:

- European projects supporting BRIDGE initiatives were selected based on their scope (see Table 4)
- Other sources and, more precisely, reports focusing specifically on the topics of the study (see Table 5)

European projects were selected among a list of 174 projects linked to BRIDGE activities. The project list was defined based on BRIDGE annual brochures from 2019, 2021, 2023, 2024 and filtered by topics. The following topics were targeted: EMS, storage, hybrid-storage and EnC. All the project's relevant deliverables were reviewed, and the findings were summarised in a template table for all the projects.

Table 4 presents the list of the selected EU projects for the literature review.

Table 4: List of EU projects relevant for the study

BRIDGE/EU Project	Status
MERLON **[18]**	Finished
InterConnect **[19]**	Finished
ISLANDER **[20]**	Finished
AnyPLACE **[21]**	Finished
GIFT **[22]**	Finished
GOFLEX **[23]**	Finished
NETfficient **[24]**	Finished
PARITY **[25]**	Finished
SENSIBLE **[26]**	Finished
TILOS **[27]**	Finished
BD4OPEM **[28]**	Finished
ebalance-plus **[29]**	Finished
2LIPP **[30]**	Ongoing
MAESHA **[31]**	Finished
ROBINSON **[32]**	Finished
SERENE **[33]**	Finished

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[7] https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/

Table 5 presents the list of other sources and reports selected for the literature review.

Table 5: Other sources

Source	Organisation
Recommendations on energy storage **[34]**	EU Commission
Energy storage systems **[17]**	ETIP SNET
R&I roadmap 2022-2031 **[35]**	ETIP SNET
Energy communities impact on grids **[36]**	ETIP SNET
Energy storage targets 2030 and 2050 **[37]**	EASE
Local Flexibility at DSO level and multi-service business case **[38]**	EASE
Business case taxonomy of behind-the-meter battery energy storage systems in Europe **[39]**	EASE
European Market Monitor on Energy storage (EMMES) 9.0 **[40]**	EASE
Study on energy storage **[41]**	ENTEC

2.2 EU projects review

2.2.1 MERLON

Project name	Integrated Modular Energy Systems and Local Flexibility Trading for Neural Energy Islands
Scope	It delivers and demonstrates an integrated modular local energy management framework for holistic optimisation of local energy systems with high shares of distributed Renewable Energy Sources (RES). It coordinates local generation, demand and storage flexibility, including Electric Vehicles (EVs), residential buildings, grid-scale batteries and Combined Heat and Power (CHP) plants, and enables local flexibility markets for EnCs and DSOs ("aggregator of aggregators") to improve grid stability and reduce curtailment. Use-case types: residential/building, transport (EVs), and utility/industrial (CHP, grid-scale storage).
Duration	2019-2022
Pilot countries	Austria and Spain
Energy Management System	• Defines its EMS as the Integrated Local Energy System Energy Management & Optimisation (ILESEM) used for managing and optimising local energy systems. • Includes an operation forecasting module that provides short-to-medium-term forecasts to establish the baseline loading at the Point of Common Coupling (PCC) for system optimisation. • Provides a scheduling module that defines the schedule for each controllable device within the integrated local energy system.

	• Incorporates a Virtual Power Plant (VPP) configurator & control dispatch module that analyses demand/storage flexibility and DSO signals to configure dynamic VPPs that deliver required flexibility to the grid. • Offers a flexibility forecasting, segmentation & aggregation module with an aggregator visual-analytics platform for forecasting, segmentation, clustering, and portfolio analysis of demand flexibility. • EMS is delivered together with an integrated ILESEM platform and end-user interfaces for all actors involved in its operation. • Relies on an Interoperability & Data Management Framework that specifies sub-modules, interfaces, and data flows supporting EMS functions. • Uses a Common Information Model that defines semantic concepts, events, relations, and data models underpinning ILESEM data exchange. • Integrates with a Blockchain-enabled Local Flexibility Marketplace to enable prosumer participation in local market transactions with contract templates.
Data management structure (e.g., use of ontology, data space)	• Relies on its CIM-like information model and the Interoperability & Data Management Framework for data governance/exchange. • Defines a Common Information Model for MERLON that captures semantic concepts, events, relations and the associated data models underpinning the ILES platform. • A dedicated Interoperability & Data Management Framework specifies sub-modules, APIs, interfaces and end-to-end data flows for ingestion and exchange across all components. • The framework architecture lays down functional, technical and communication specifications, including internal/external interfaces and interoperability aspects for system integration. • A comprehensive review of EU interoperability standards and data models guides harmonisation choices and profiles to ensure cross-stakeholder data exchange. • A formal Data Management Plan (DMP) describes how project data are collected/processed, standards applied, sharing/open-access policies, and long-term curation/preservation. • The aggregator analytics platform ingests historical flexibility data from pilot sites to enable forecasting, segmentation and clustering—evidence of organised storage and reuse of operational datasets.
Storage system(s)	• **Austrian pilot BESS (installed asset):** 250 kW / 250 kWh lithium-ion battery energy storage system deployed for the Austrian MERLON pilot; operated under the MERLON smart management to provide local flexibility within the integrated local energy system. • **Spanish pilot BESS (local EnC):** Battery storage installed to support local PV utilisation in the Crevillent EnC; the BESS directly enabled ~7% energy-cost reduction for LV consumers (with a further ~15% via explicit demand response using domestic water heaters).

	- **Virtual Thermal Energy Storage (VTES):** Software-defined **virtual thermal storage** component that configures and manages building-level thermal flexibility (applicable across different building sizes/uses), used alongside electrical storage in MERLON pilots. - **Planning & sizing with battery behaviour:** The simulation-based planning/sizing module explicitly studies "battery system behaviour" (transient analysis, power quality, etc.) to right-size storage for pilot needs. - **Pilot network models including storage assets:** Detailed Matlab/Simulink models of the Spain and Austria pilot networks include their storage assets and scenarios for asset evolution. - **DER flexibility modelling including storage:** Formal device models for DERs were configured to define control/response capabilities to reach target flexibility levels. This includes storage units used in MERLON pilots.
Risks related to technological weakness and lack of legislation	<u>Technological</u>: - Standardisation and harmonisation gaps across interoperability standards and data models, requiring a dedicated "standardisation punch-list" before wide rollout. - Interoperability risks between systems/devices and data exchange layers, addressed by a dedicated Interoperability & Data-Management framework and a project Common Information Model. - Grid-integration constraints (device/grid code conformance, interfaces, operational practices) prompting specific integration recommendations before field deployment. - Functional reliability risks before deployment, evidenced by the need for pre-trial validation to ensure problem-free operation of the integrated platform. - Power-quality (PQ)/transient-behaviour and battery-system-behaviour uncertainties that must be studied in planning/sizing, to avoid PQ events and mis-sizing. - Forecasting dependency at the local level (short- to medium-term demand/generation baselining needed for safe operation and scheduling), implying operational risk if forecasting is poor. <u>Regulation</u>: - Prevailing national/EU frameworks in pilot countries include constraints and restrictions that hinder the smooth introduction of innovative local energy technologies and business models. - Need for policy and market reforms (identified and formulated) indicates that current market design/tariff rules are not yet aligned with local flexibility business cases. - Network-related charges materially affect the viability of local energy systems and have to be evaluated alongside business models. - Business models for local flexibility must fit (or adapt) to current market/regulatory frameworks; otherwise, they require novel arrangements anticipated only under broader uptake.

Best practices and key take away	• **Validate in the lab before field roll-out:** run pre-trial testing/FAT of the ILESEM platform in a controlled environment to de-risk pilot deployment. • **Define PMV early:** establish a Performance Measurement & Verification (PMV) methodology and baselines up front to monitor post-intervention impact consistently. • **Plan pilots with ex-ante audits:** perform site audits and detailed deployment plans per location to smooth installation and validation. • **Iterate the system architecture:** publish an initial framework architecture and update it after integration and field feedback to capture real-world constraints. • **Maintain a standardisation punch-list:** derive grid-integration and standardisation recommendations after each roll-out phase to align with evolving codes and practice. • **Use a Living-Lab approach for user adoption:** plan, run, and evaluate Living-Lab activities and dedicated community recruitment to onboard prosumers and refine services. • **Standardise data & semantics early:** define a Common Information Model and evolve an Interoperability & Data-Management Framework to ensure component/actor interoperability. • **Prototype market mechanisms before scale-up:** implement a blockchain-enabled flexibility marketplace with contract templates, then iterate post-deployment. • **Evaluate holistically and feed back into design:** run impact assessment and cost–benefit analysis (incl. user-experience) after each roll-out phase to prioritise what works. • **Link tech with business/regulation:** define business models early, reassess them with pilot evidence and network-charge impacts, and issue policy/market reform recommendations.
Roadmap	• **Scaling-up & Replication roadmap defined:** At project end, MERLON states that a “Scaling-up & Replication roadmap” was defined to guide post-project roll-out. (CORDIS Periodic Reporting for period 2) • **Business innovation plan for market uptake:** A Business innovation plan was finalised alongside the roadmap to support exploitation and commercialisation after the project. (CORDIS Periodic Reporting for period 2)

2.2.2 InterConnect

Project name	Interoperable solutions connecting smart homes, buildings and grids
Scope	The solutions developed within the scope of InterConnect will allow a digitalisation of homes, buildings and electric grids based on an Internet of Things (IoT) architecture. The main goal is to bring efficient energy management within reach of the end-users.

	It includes use cases on residential, industrial and commercial areas as well as EnC.
Duration	2019-2024
Pilot countries	Belgium, Netherlands, Italy, Portugal, Greece, France, Germany
Energy Management System	• HEMS - Home Energy Management System; • BMS - Building Management System; • SCEMS -- Smart Community Energy Management System
Data management structure (e.g., use of ontology, data space)	• Use of the SAREF ontology • Semantic interoperability framework, including an interoperability layer for data management
Storage system(s)	• Netherlands: batteries • Italy: Storage units • Germany: thermal storages
Risks related to technological weakness and lack of legislation	Technological: • Unavailability of components • Operational issues related to the interoperability layer, like stability, performance, and security • Technical difficulties in the aggregated control of devices • The charging stations and battery in the charge lounge may not have the appropriate protocols to control their flexibility Regulation: • Developments in Belgian regulation are not suitable for local EnCs business cases • Privacy legislation requires that only the end user has access to the login and password of a service. When this changes, data flow and automatic steering stop
Best practices and key take away	• Pre-testing of service interaction without performing real command actions should discover potential operational interoperability layer flaws before the pilot site goes operational with real end-users. Partial tests can be started in case not all SSAs are on time. Create a step-by-step integration process of the services and complexity. • Look for potential rewarding schemes to compensate for additional electricity consumption due to control steering
Roadmap	• No roadmap available

2.2.3 ISLANDER

Project name	ISLANDER
scope	ISLANDER is an EU-funded project completed in 2025. It aims at accelerating the decarbonisation of European islands through the deployment of innovative and sustainable energy solutions. Industrial and residential flexibilities in the context of geographical islands
Duration	2020 - 2025
Pilot countries	Germany, Scotland, Croatia and Greece
Energy Management System	Smart IT platform (SITP) for energy management of the island. • design to monitor and control devices with smart interfaces. • AI systems are implemented to automatically decide how to operate and maintain aggregated green energy assets. • This platform will allow aggregations to participate as a Virtual Power Plant in different energy markets, providing advanced services. • Demand response mechanisms to optimise electricity costs and reduce grid load • Open-source
Data management structure (e.g., use of ontology, data space)	Data management supported by the Smart IT platform.
Storage system(s)	• Hydrogen technologies for long-term energy storage • Ultracapacitors for grid stabilisation • Battery storage systems (Households, buildings, large-scale) for balancing renewable energy and short-term energy storage • A seawater district heating network including a heat storage tank • EV storage and smart charging infrastructure
Risks related to technological weakness and lack of legislation	Technological: • Hydrogen storage: ○ Lack of maturity and reliability of technologies and devices. ○ Lack of maturity and responsiveness of the supply chain, e.g., when upgrading infrastructures, as the hydrogen sector is only in its emerging phase. ○ Reliant on a limited pool of suppliers which are at an early development phase and under-resourced. ○ Complex carriage of hydrogen on roads and passenger ferries (production point to end use point) due to multiple regulatory frameworks.

	○ Lack of skills and training during and after the project/implementation, e.g., use, security, storage, maintenance and transport. • Grid capacity and integration of renewable limitations • Complex material selection of components and consideration of operational environment and infrastructure in a maritime context Regulation: Island energy systems are complex and diverse, involving interaction with multiple regulatory frameworks (European, national and regional) and boundaries at once. Complex regulations and permissions eventually result in significant obstacles in the installation of project technologies, the export of local excess production, and real-time communication of equipment. Navigating through these regulatory landscapes and ensuring compliance also constitutes a hurdle to replication efforts.
Best practices and key take away	• Use of an island energy management system is needed to ensure a centralised and efficient monitoring and control of the energy. • Use of diverse storage technology • The project has developed a method to assess and replicate their model, including, for example, the digitalisation of the energy system, integration of renewables and hybrid-storage systems development. • The project encourages the involvement of local communities and stakeholders in the transition process, including awareness campaigns and initiatives to promote public acceptance and behavioral changes • Ensure a regulatory watch to detect in order to identify when certain regulatory constraints will be overcome
Roadmap	No roadmap

2.2.4 AnyPLACE

Project name	Adaptable Platform for Active Services Exchange
Scope	Developed a low-cost, modular, adaptable smart energy platform for residential use only.
Duration	2015-2018
Pilot countries	Portugal, Germany, Austria, Belgium
Energy Management System	• Based on a **modular Service-Oriented Architecture (SoA)** on a **Raspberry Pi**. • Built on **openHAB** with a proprietary control/security layer. • Key components:

	- **Energy Services**: Dynamic pricing, demand response, energy optimisation. - **End-User GUI**: Developed with PhoneGap and Qt for intuitive interaction. - **ICT & Device Management**: Secure local device control and remote access. - **Optimisation Engine**: MILP-based scheduling of household loads (shiftable and thermal). - Controlled shiftable loads (e.g., dishwashers) and thermal storage (e.g., water heaters) intelligently.
Data management structure (e.g., use of ontology, data space)	- Used **SoA** for integration across heterogeneous environments. - Emphasised **interoperability** over defining a new data ontology. - Two communication domains: - **Internal**: Wi-Fi, ZigBee, Bluetooth managed via openHAB. - **External**: Secure communication with DSOs/aggregators using PKI and encryption. - Data stored locally in **PostgreSQL**, optimised for low-resource environments. - Security-by-design approach: - Principle of least privilege. - User-defined data access policies. - Secure, encrypted remote communication.
Storage system(s)	- Focused on **software-based optimisation of thermal storage** rather than installing batteries. - **Electric Water Heaters (EWHs)** used as thermal batteries with predictive scheduling. - Managed other thermal appliances (heat pumps, space heaters) similarly. - Treated shiftable loads as "virtual storage" by delaying their operation.
Risks related to technological weakness and lack of legislation	Technological: - **Interoperability issues** due to fragmented smart metering protocols. - Integration risks with open-source **openHAB** (e.g., unstable bindings). - Limited appliance control due to legacy device constraints. - Security risks from **heterogeneous IoT environments** with weak device protections. Regulation: - Regulatory **fragmentation across the EU** complicates market entry. - **GDPR** introduced a high compliance burden for managing personal consumption data. - Lack of **residential-scale demand response markets** limits monetisation of flexibility.

Best practices and key take away	**Best Practices** • Use of **modular, service-oriented architecture** for adaptability. • Strategic, selective use of **open-source middleware** with added security. • **User-friendly, non-intrusive** dashboard design. • Prioritise **cost-effective use of existing appliances** (thermal flexibility). • Implement **security and privacy by design** from the start. **Key Takeaway** • Residential DR is a **complex socio-technical challenge**, not just technical. • **Standardisation gaps** remain the core barrier to scalable deployment. • Future lies in **hybrid systems** combining open-source connectivity with secure, proprietary control. • **Policy evolution** is critical to unlock the economic value of residential flexibility.
Roadmap	• Industrial partners (e.g., Bosch, Efacec) to integrate EMS features into products (e.g., smart heat pumps, EV chargers). • Communication tech companies (e.g., Power Plus) to apply insights in smart metering solutions. • Key exploitable results: ○ Modular EMS software. ○ MILP optimisation algorithms. • Expertise in **multi-standard smart metering integration**. • Continued influence on **European standardisation** and commercial adoption. • Future research to focus on: • **Machine learning** for user behaviour prediction. • **Emerging standards** (e.g., Matter) for improved interoperability. • **New business models** for aggregating residential flexibility.

2.2.5 GIFT

Project name	Geographical Islands FlexibiliTy
Scope	GIFT is an innovative project that aims at decarbonising the energy mix of European islands through holistic energy management, trading and innovative storage solutions. Industrial flexibilities in the context of geographical islands
Duration	2019-2023

Pilot countries	Italy, Norway
Energy Management System	- Industrial prosumer EMS - EV EMS - Hybrid storage EMS
Data management structure (e.g., use of ontology, data space)	- Part of the data management supported by the Enterprise Service Bus - Use of the FlexOffer communication protocol to support flexibility trading
Storage system(s)	- Smart energy hub: Hydrogen storage and batteries combination - Hydrogen–bromine (HBr) flow battery system - Virtual power plant including industrial prosumers and storage
Risks related to technological weakness and lack of legislation	Technological: - Costs of installations for storage solutions is higher than expected - Insufficient communication capabilities for scale-up - Large footprint of the installation (HBr storage) Regulation: - DSOs are not allowed to own a battery for commercial purposes in some countries - Many areas, such as cultural heritage sites, can't be considered for construction due to urban planning - Safety regulations are very strict regarding H2 - The innovative storage solutions developed in GIFT are difficult to fit into a regulatory category - Few buildings satisfy the technical requirements
Best practices and key takeaways	- Virtual storage systems with technology-neutral flexibility offers - Thorough planning, including legislative aspects for any on-site deployments, in particular when involving H2
Roadmap	No roadmap

2.2.6 GOFLEX

Project name	Generalized Operational FLEXibility for Integrating Renewables in the Distribution Grid

Scope	It is an innovative H2020 project that enables cost-effective use of distributed energy flexibility in local distribution grids to enhance adaptability and support higher renewable integration. It uses advanced demand response and automated flexibility trading based on existing smart-grid systems. Tested with 400+ prosumers in Cyprus, Germany, and Switzerland, it demonstrated flexibility from factories, buildings, and electric vehicles, covering industrial, residential/building, and transport use cases.
Duration	2016-2020
Pilot countries	Cyprus, Switzerland and Germany
Energy Management System	• EMS types include: HEMS (Home EMS), FEMS (Factory EMS), CEMS (Charging EMS), and CDEMS (Charging-Discharging EMS). • Each EMS unit contains a local controller with capabilities for sensing, control, and user interaction. • The EMS performs local data acquisition (e.g., readings, process variables, user inputs). • Provides a web-based GUI (xEMS configurator) for users to monitor and configure the system. • Enables local optimisation of energy consumption, respecting user comfort and process constraints. • Responsible for generating FlexOffers based on available flexibility and sending them to the FlexOffer Agent (FOA). • Adjusts device schedules dynamically based on trading outcomes and control commands from higher-level systems. • Communicates with other components via standard interfaces and follows a modular architecture for integration.
Data management structure (e.g., use of ontology, data space)	• Cloud service platform offers four main services: IoT data ingestion, weather ingestion, energy forecasting, and a unified data store with the GOFLEX data model, deployed per site instance. • A range of APIs (metering, weather, forecasting, network topology, energy price, key/value) is available for core data access. • Data is secured and anonymised, transferred over MQTT, REST, OPC UA, or AMQP, using JSON/XML formats with encryption, authentication tokens, and role-based access. • The platform enables data exchange among xEMS, FOA/FMAN/FM AR, DOMS, and external sources like weather and price data, with aggregation of anonymised information. • DOMS relies on the platform to fetch metadata (like GIS/topology), sensor readings, and forecast data to support its observability functions. • Trading modules (FOA, FMAN, FMAR) both retrieve external weather, meter, and price forecasts and export anonymised prosumer data via the same service platform.

Storage system(s)	- Uses two types of storage: explicit storage (e.g., batteries) and virtual storage (flexibility by shifting consumption within processes). - Both storage types are managed by FEMS, HEMS, CEMS, and CDEMS, which optimise operation locally and provide flexibility to the FlexOffer Agent for trading. - Industrial storage includes thermal reservoirs and material storage (virtual) as well as backup generation units (explicit). - Residential/building storage uses devices like electric water heaters as thermal buffers, optimised for cost, operational constraints, and comfort (virtual). - Transport storage treats EV batteries as virtual reservoirs, with CDEMS enabling bidirectional charging/discharging using LiFePO4 units ranging from 3–54 kWh and up to 10 kW output (explicit and virtual). - The Cyprus campus microgrid pilot demonstrates explicit storage integration alongside renewable generation and demand-side management.
Risks related to technological weakness and lack of legislation	Technological: - Integrating many heterogeneous devices and subsystems over multiple protocols/APIs (MQTT, REST/HTTP(S), OPC UA, AMQP; JSON/XML) increases interoperability and integration risk. - Sensitive data must be anonymised before sending and exchanged over secure connections, adding security/configuration risk. - Each demo site must build and operate ingestion clients to extract/anonymise/publish metering data to the cloud platform, creating operational/ICT risk. - If certified smart-meter data cannot be accessed, sub-metering is a last-resort option using non-certified data, which poses data-quality risk. - The system relies on internet transport and sufficient bandwidth to the cloud platform for data acquisition and services, introducing connectivity/performance risk. Regulation: - Flexibility markets exist for TSOs but not at the local/regional level, so GOFLEX demonstrates local trading in a regulatory gap. - Future market roles, functions and processes are not yet clear for decentralised flexibility, creating implementation uncertainty. - DSOs are not permitted to be remunerated for avoided costs through flexibility, limiting DSO-centric business models. - Local use of flexibility is often not regulated, making investment payback uncertain for actors driving deployment.
Best practices and key takeaways	- **Industry–Academia Partnership:** A 12-partner consortium blended solution providers, research organisations, DSOs and consultancies to accelerate R&D-to-trial transfer.

	• **Real-world Validation:** Multi-country deployment in operational grids (Cyprus, Germany, Switzerland) controlled loads of 500+ prosumers and offered ~800 MWh of flexibility. • **Unified Flexibility Model:** The FlexOffer format standardised the description, aggregation, optimisation, and trading of flexibility across heterogeneous prosumers. • **Interoperable & Secure Data Exchange:** A defined set of GOFLEX APIs and standard protocols with anonymisation at DSO/FOA level enabled secure, privacy-preserving data flows. • **EMS–Market Coupling:** xEMS (HEMS/FEMS/CEMS/CDEMS) generated FlexOffers for FOA/FM modules and the ATP, enabling local flexibility market operation for DSOs. • **Stakeholder & Pricing Guidance:** Best-practice guidance compiled communication strategies to stakeholders and pricing models, including a SWOT-based implementation guide. • **Replicability & Scalability Planning:** Impact indicators and demo architectures were documented to support scaling and replication across sites.
Roadmap	• **Complete integration:** Finish the **TOTALFLEX–KIBERnet** merge to deliver **fully integrated FMAN and FMAR** subsystems. • **Broaden EMS coverage: Extend FOA** to handle **additional xEMS** beyond those used in GOFLEX. • **Commercialise the platform: Start commercialisation** of the Automatic Trading Platform (ATP). • **Exploitation/market follow-up:** Use the final conference as the entry point into the exploitation phase and continue GOFLEX Community actions (e.g., roles "3 years after GOFLEX").

2.2.7 NETfficient

Project name	Energy and economic efficiency for today's smart communities through integrated multi-storage technologies
Scope	The project aimed to **deploy and demonstrate local storage technologies (TRL 5-6) in a real electrical grid environment** while developing ICT tools to exploit synergies between storage systems, smart grids, and citizens
Duration	2015-2018
Pilot countries	Germany
Energy Management System	• **Local Control**: Direct storage system management and optimisation • **Use Case Activation**: Peak shaving, primary reserve, instantaneous reserve, self-consumption optimisation

	• **Modular Design**: Eight 125 kW inverter racks with independent disconnection capability • **Advanced Control**: Predictive algorithms for power distribution between storage components
Data management structure (e.g., use of ontology, data space)	• **CAN Bus**: Low-level device communication for real-time data exchange • **Web Services**: RESTful APIs for EMS-EMP communication and remote monitoring • **Standardised Interfaces**: Common communication protocols across different storage technologies • **Hierarchical Structure**: Local EMS reporting to higher-level EMP for coordinated control • **Distributed Storage**: Decentralised data collection with centralized optimization • **Interface Standardisation**: Common data formats and communication protocols
Storage system(s)	**Medium Voltage HESS (MV-HESS):** • **Power Output**: 1 MW total system capacity • **Li-ion Battery**: 500 kWh capacity for long-term energy storage • **Ultracapacitor Technology**: Short-term storage via DC/DC converter for power peak coverage and battery life extension • **Form Factor**: 19-inch rack format with 200mm height (**2-4x smaller than commercial alternatives**)
Risks related to technological weakness and lack of legislation	<u>Technological</u>: • **Battery Degradation**: Concerns with frequent cycling reducing battery lifespan and performance • **Integration Complexity**: Challenges in coordinating multiple storage technologies with the existing grid infrastructure • **System Reliability**: Need for advanced control systems to manage hybrid storage configurations • **Scalability Issues**: Technical challenges in scaling solutions from pilot to wider deployment • **Development Stage**: Some technologies at TRL 5-6 require further development for commercial readiness • **Performance Variability**: Inconsistent performance across different storage technologies and operating conditions • **Maintenance Requirements**: Complex systems requiring specialised technical expertise for operation and maintenance • **Cost Competitiveness**: High initial costs compared to conventional grid solutions <u>Regulation</u>: • **Regulatory Framework**: Lack of clear regulatory framework for distributed energy storage deployment

	- **Market Recognition**: Insufficient recognition and monetisation of full value of storage services - **Grid Connection**: Complex and inconsistent grid connection procedures across EU member states - **Approval Processes**: Lengthy and unclear approval processes for distributed storage deployment - **Revenue Uncertainty**: Unclear revenue streams from grid services and energy markets - **Policy Support**: Limited policy support for EnCs and cooperative models - **Standards**: Absence of standardised technical and safety requirements for distributed storage - **Legal Framework**: Insufficient legal framework for EnCs and citizen participation - **Barrier Identification**: Project produced a comprehensive "Regulation analysis and barriers identification report" - **Policy Recommendations**: Proposed changes to regulations in social and economic areas to reduce deployment barriers - **Cross-border Issues**: Regulatory complexity across different EU member states creates deployment challenges
Best practices and key take away	- **Industry-Academia Partnership**: Strong collaboration between research institutions and industry partners is essential - **Real-world Validation**: Actual deployment in the operational grid provides crucial validation data - **Stakeholder Engagement**: Continuous engagement with local community, utilities, and regulators throughout project lifecycle - **Flexible Approach**: Adaptability to address emerging technical and regulatory challenges - **Documentation**: Comprehensive project deliverables and technical reports enable knowledge transfer - **Demonstration Events**: Study visits and knowledge-sharing events facilitate technology adoption - **Follow-up Projects**: Successful securing of follow-up funding demonstrates technology viability
Roadmap	**Short-term Development 2025-2027** - **Expanded Deployment**: Extension to 4 additional islands (Orkney UK, Cres Croatia, Skopelos and Lefkada Greece) - **Technology Scaling**: Validation of NETfficient solutions' scalability across different island contexts - **Enhanced Technologies**: Integration of hydrogen-based storage systems and seawater district heating networks - **Advanced IT Platform**: Machine learning-based forecasting and mathematical optimisation for energy aggregation

2.2.8 PARITY

Project name	Pro-sumer AwaRe, Transactive Markets for Valorization of Distributed Flexibility enabled by Smart Energy Contracts
Scope	It demonstrates a three-pillar flexibility framework: (1) grid services from electricity storage (including batteries and V2G), power-to-X (notably power-to-heat), demand response, and variable generation to support decarbonisation; (2) smart-grid observability, automation, and control of grids and distributed resources to enhance resilience and security, including under extreme climate events; and (3) market mechanisms such as dynamic network tariffs and non-frequency ancillary services coordinated with TSOs to integrate wholesale and retail markets and mitigate short and long-term congestion.
Duration	2019-2023
Pilot countries	Spain, Greece, Switzerland, Sweden
Energy Management System	• EMS consists of the PV manager and the stationary battery manager. • The PV manager monitors and controls the PV installation at the site and produces PV generation forecasts using historical PV production and weather data, exchanging data with the LEM/LFM Repository and the Aggregator Toolset's DER Dispatch module. • The stationary battery manager takes inputs from the LEM/LFM Repository and on-site meters to optimise operation, implement local peak shaving, and interact with the aggregator toolset for flexibility services through three engines (peak shaving forecasting, peak shaving real-Time, and flexibility response real-time). • At the pilot sites, the EMS (PV manager plus stationary battery manager) was installed, and pre-runs were performed, with battery issues identified for the supplier to fix before final system checks. • The Information Management Layer (IML) cloud gathers real-time building data, securely handles and cleanses it, and facilitates communication between the IoT infrastructure and EMS-related components such as the LEM/LFM repository, the building-as-a-battery application, and the prosumer flexibility manager. • Prosumer and market applications use the LEM/LFM Repository's API to retrieve stored data, authenticate users, and store new entities or user preferences, supporting EMS configuration and monitoring.
Data management structure (e.g., use of ontology, data space)	• This project implements a four-layer data architecture: field/IML cloud, market (Blockchain Agents, Oracle, LEM/LFM Repository, off-chain services), services (optimisation/forecasting), and applications (UIs) with the LEM/LFM Repository as the central store for collected and pre-processed IoT data. • A common data/information model underpins entity and event storage, with ongoing "refinement and corrections of the common data model" noted during integration.

	• The LEM/LFM repository stores measurements, user info, and off-chain data and exposes web services, while the Oracle anonymises measurements/forecasts before sending them to the blockchain to activate smart contracts. • IML cloud gathers real-time building/asset data via IoT gateways and couples it to the LEM/LFM Repository, enabling downstream EMS and market components to consume cleansed data. • Standardised interfaces use HTTP/JSON (and HTTP/OCPP for EV chargers), with components retrieving/storing data through the Repository's APIs and receiving dispatch signals from the Aggregator. • Security and privacy are enforced with role-based access control, authentication/authorisation, secure protocols, encryption, and data anonymisation/pseudonymisation at the IoT and LFM levels. • The Data Management Plan defines principles for handling, sharing, protection, collection, storage, retention and destruction, and FAIR/open-data practices, and establishes a PARITY community on Zenodo for public datasets. • System tests confirm repository JSON exchanges, token-based access control, and stable component integration (Repository, off-chain, Oracle, Marketplace UI), including specific checks for authentication/authorisation.
Storage system(s)	• **Stationary Battery Manager (SBM):** Takes inputs from the LEM/LFM Repository and on-site meters to optimise operation and implement peak shaving locally, and interacts with the Aggregator Toolset for flexibility services via three engines: Peak Shaving Forecasting, Peak Shaving Real-Time, and Flexibility Response Real-Time (commands sent to the BMS for charge/discharge). • **PV + Storage system composition at pilots:** The PV + Storage (Battery Management) System comprises PV installation, solar inverter, stationary battery, BMS, power converter (hybrid inverter/rectifier), DC/AC fuse boxes, plus the PV Manager (monitors/forecasts PV) and the Stationary Battery Manager (monitoring, forecasting, peak shaving, and real-time battery control for flexibility). • **EV battery flexibility (storage via smart charging):** The EV Profiling & Smart Charging component supports V1G and V2G schemes, stores EV charging events in the LEM/LFM Repository, forecasts usage/load/flexibility, and sends control commands to EV charging stations; the Aggregator can activate flexibility by modifying schedules or discharging EV batteries. • **Interfaces & data flow for storage control:** SBM and PV Manager use HTTP/JSON APIs to exchange data with the LEM/LFM Repository and DER Dispatch Module; real-time operations data and dispatch instructions are passed to the BMS to charge/discharge the BESS. • **Pilot deployment & commissioning notes (storage):** Pilot activities include EMS device installation, network setup of battery system (BMS, EMS), and specialist commissioning; a noted issue was problems with Nilar NiMH battery cells during commissioning (supplier to fix before final checks).

	- **Battery EMS dataset for analysis:** PARITY defines the dataset "DS-13-Stationary battery status data" (sampled every 1–15 minutes) from a Battery Energy Management System, used for testing energy management applications.
Risks related to technological weakness and lack of legislation	Technological: - Limited transparency/possible bias in automated trading & smart-contract logic; difficulty explaining decisions to stakeholders. - Reliability & resilience concerns in distributed LFM/LEM operation (algorithm errors, failures, unstable outcomes under stress). - Cyber-security & privacy exposure across IoT + blockchain stack; need for RBAC, encryption, secure protocols, breach response, DPIA. - Smart-contract constraints (immutability/upgradability issues) and scalability/throughput limits; dependence on off-chain components/oracles. - Interoperability/standardisation gaps between devices, protocols, and platforms; vendor heterogeneity complicates integration. - Data quality/forecasting & distribution-level technical constraints that can degrade tool performance and customer outcomes. - Aging/heterogeneous infrastructure (varied maturity, end-of-life assets); uncertainty on how best to exploit new tech in planning. - EV flexibility & smart-charging, human-centric profiling, and P2H integration identified as technology areas with notable gaps. - Large-scale IoT deployments operate over untrusted/closed networks; device mix (very small → very large) increases attack surface. Regulation: - DSO procurement of flexibility is not allowed in most EU countries; cooperation agreements and new grid regulation for LFM are required. - BRPs' full balance responsibility prevents real P2P trading; current frameworks don't enable direct prosumer-to-prosumer transactions. - No DSO-level ancillary services market in many jurisdictions; prequalification thresholds keep small DER/flexibility out. - DSOs must act as neutral market facilitators without end-consumer contact; National Regulatory Authorities (NRAs) need to update rules to support DSOs' roles in LFMs. - Access, usage, and sharing of metering/prosumer data are tightly governed (GDPR, national laws); contractual data-access arrangements are needed. - Market-abuse/consumer-protection concerns (hoarding, monopoly power, non-neutrality) require explicit safeguards and oversight. - Blockchain legal uncertainty (e.g., GDPR compatibility, right to erasure vs immutability) is evolving; needs continuous legal monitoring. - Role definitions, operator responsibilities (LEMO/LFMO), and rights to impose locational grid prices in implicit LFM need regulatory clarity.

Best practices and key takeaways	• Plan extra time for on-site commissioning in large offices and prefer a single “general comfort” setup over per-person tweaks; COVID-era delays showed the value of longer installation windows. • Anticipate permits and space constraints for street-level equipment (e.g., D-STATCOM); start municipal approvals early. • Train residential users for plug-and-play installs and schedule around working hours; provide extra assistance for older participants. • Validate connectivity where assets live (often basements): survey Wi-Fi, and be ready with independent backhaul (e.g., 4G); communicate transparently about new wireless tech in homes. • For stationary batteries, budget more time/money for DC-side works, secure fire-safety approvals with local fire departments, and vet suppliers’ technical/financial robustness before commercialisation. • Ensure contracts and automations respect GDPR and keep a human-in-the-loop for automated decisions affecting data subjects. • Do lab pre-validation & end-to-end integration tests before field rollout; maintain a standard “bring-along” toolkit and a detailed deployment plan for installers. • Clarify project roles & responsibilities across pilot partners (installers, integrators, training leads) to speed decisions and remove blockers during deployment.
Roadmap	• **Market adoption roadmap (6 phases):** Education & awareness → Business needs & use-case definition → Energy sources & technical requirements → Tool/service selection → Adoption (IoT + blockchain LFM in place) → Validation (KPIs, ROI). • **Replication & scale-up:** Dedicated “Report on PARITY results replication roadmap” outlining how to scale the solution beyond pilots and actions in D10.5.

2.2.9 SENSIBLE

Project name	Storage-Enabled Sustainable Energy for Buildings and Communities
Scope	It demonstrated the integration of electro-chemical, electro-mechanical and thermal storage with micro-generation (CHP, heat pumps) and PV into distribution grids, homes and buildings, to create value for grid operation and behind-the-meter applications covering residential, community/building and commercial/industrial use cases across the three pilots.
Duration	2015-2018
Pilot countries	Portugal, United Kingdom, Germany

Energy Management System	• **HEMS in Évora & Nottingham**: residential controller that handles local storage and flexible assets in an integrated way, used to bridge citizens to energy markets; in Évora it was integrated with the retailer's infrastructure to enable new energy services; in Nottingham it supported a local EnC. • **BEMS in Nuremberg:** building-level controller able to operate with zero import/export at the PCC, manage electrical/thermal storages and other components, and participate in Day-Ahead and Balancing Power Markets; cost-saving potential up to 31% reported. • **Measured impact of HEMS (Évora):** households with integrated assets (incl. home energy management systems) achieved approx. €25/month savings (−30%) and 87 kg CO_2/house reduction during the project. • **Grid-oriented EMS tools:** optimisation and local control algorithms enabling LV/MV islanding for improved reliability and resilience (Tools for active management of distribution grids, Évora demonstration). • **EMS applications across pilots:** tested with real-time data for forecasting, grid optimisation, market participation, and building consumption optimisation (Integration, validation and conclusions from demonstrators). • **Residential EMS results:** enabled new customer services in Évora and reduced bills in Nottingham through self-consumption and load shifting (Évora & Nottingham demonstration). • **EMS ICT/monitoring:** included inverters, battery management, gateways, smart meters, and a remote monitoring system for storage devices (Remote monitoring system for storage devices, Analysis of ICT Storage Integration Architectures).
Data management structure (e.g., use of ontology, data space)	• Implemented an ICT data-exchange platform in the Évora demonstrator, which describes the actual ICT architecture deployed to support the use cases. • Key data-exchange building blocks in Évora include a Distribution Transformer Controller (DTC) that concentrates smart-meter data and issues DSM signals; smart meters with a HAN port to feed HEMS; and a pipeline of telemetry from homes and LV grid up to central systems. • Nottingham Demonstration deliverable mentions "consent and data management" and that a privacy notice was provided to participants (GDPR context), i.e., procedural handling of personal data rather than a technical data-management architecture.
Storage system(s)	• Project-wide, SENSIBLE's deployments explicitly span electro-chemical, electro-mechanical (flywheel), and electro-thermal (hot-water) storage families, as scoped in the "Overview of storage technologies" deliverable that underpins the three demonstrators. • At Évora (Portugal), the MV network included a ~480 kW (472 kVA) / 360 kWh battery energy storage system operated both for continuity-of-service reserve and grid support.

	• At the Évora LV substation, the DSO installed a 100 kVA electro-chemical battery and a 125 kVA flywheel on the LV busbar, plus four 30 kVA and two 10 kVA battery units along the LV feeders for loss reduction, voltage control and RES integration. • On the Évora residential side, homes were equipped with lithium-ion batteries (typically 3 kW / 3 kWh) and controllable electric-water-heater thermal storage, coordinated by HEMS. • In Nottingham (UK), 27 dwellings received home batteries comprising 11 systems with SMA Sunny Boy Storage 2.5 + Tesla Powerwall (Gen 1) and 4 systems with SMA Sunny Island + LG Chem RESU 6.5, alongside several homes using ImmerSun PV-to-hot-water diverters. • At Nottingham community sites, the School/Library hosted a Tesla Powerwall 2 with a 5 kW inverter, and Creative Energy Homes hosted a 34 kWh battery with a 30 kVA four-wire inverter. • In Nuremberg (Germany), the building-domain demo integrated a 31 kWh lithium-ion battery, thermal storage units with resistive heaters, a 10.5 kW geothermal heat pump, and a CHP unit rated 4.5 kW_e / 12.5 kW_t, all coordinated by a BEMS.
Risks related to technological weakness and lack of legislation	<u>Technological</u>: • No explicit information of technological risks. <u>Regulation</u>: • No explicit information of regulatory risks.
Best practices and key takeaways	• **Validate in the lab before field roll-out:** First test storage systems and power-electronic equipment in controlled environments, then install and validate them on-site. Use this two-step path to de-risk pilots. • **Design for grid resilience (incl. islanding) at LV/MV:** The Évora demo introduced advanced grid operation modes up to MV, especially islanding to improve reliability in extreme events; make resilience a design goal from the start. • **Use multimodal BEMS to tap energy markets:** In Nuremberg, a building EMS coordinated electrical/thermal storage, PV and Heating, Ventilation, and Air Conditioning (HVAC) and could participate in Day-Ahead and Balancing markets, achieving notable cost-saving potential through market participation in BEMS specifications. • **Integrate residential assets for citizen value:** In Nottingham and Évora, HEMS + batteries + flexible loads (e.g., water heaters, PV) delivered measurable bill savings and CO_2 reductions and supported a local EnC prioritise end-user value in home-level integration. • **Prototype market layers early (emulation + business models):** The project built/used a market emulation layer and defined storage-enabled business models so services for retailers, Energy Service Companies (ESCOs), DSOs and aggregators could be trialled before full market coupling, co-develop tech with business rules.

	- **Engage communities and stakeholders around go-live:** SENSIBLE ran local information days and broader dissemination/standardisation actions alongside demo commissioning, treat engagement as a workstream, not an afterthought. - **Plan for replication at scale with evidence:** The project coupled technical evaluation with cost/benefit and scalability analyses to inform wider roll-out, pair KPI tracking with explicit replicability studies.
Roadmap	- **Replication & scale-up plan:** Roll out local storage beyond the pilots based on the project's technical-economic study of energy performance, replicability and scalability. - **Commercialisation models:** Take SENSIBLE services to market using role-specific storage-enabled energy business models for DSOs, aggregators, retailers and prosumers. - **Market participation framework:** Connect the above business models with wholesale/balancing market processes and transactions so they can operate in real markets. - **Grid planning & investment method:** Guide DSOs on where/when to deploy storage next using a cost/benefit assessment methodology for network planning. - **Standards & ecosystem uptake:** Sustain adoption after project end via ongoing standardisation engagement and dissemination across partners. - **Vision & stakeholder mobilisation:** Promote future use-cases and replication through the public vision paper and workshop on small-scale storage.

2.2.10 TILOS

Project name	Technology Innovation for the Local Scale, Optimum Integration of Battery Energy Storage
Scope	Demonstration of local-scale battery storage serving multipurpose roles within island microgrids for residential and community energy supply
Duration	2015-2019
Pilot countries	Greece, Germany, Spain, France
Energy Management System	- **S4S system**: Storage for Sustainability, Smart Grid, Solutions, Security developed by Eunice Energy Group for real-time integration of meteorological, technical, load, and operational data - **Smart grid control system**: Real-time operation management by Younicos AG with seamless interoperability between microgrid components - **Advanced forecasting system**: Multiple reliable forecasting algorithms for load demand, wind power, and solar power production across different time horizons

	• **Extended microgrid simulator**: Advanced simulation tool for analysing different battery technologies and configurations with fully adjustable parameters • **Smart metering infrastructure**: Deployed to the majority of local households with bidirectional communication capabilities • **Demand side management platform**: Consumer monitoring and energy optimisation with automatic load management • **Multi-mode operation capability**: Supporting both stand-alone and grid-connected operations with seamless transitions • **Real-time data processing**: Continuous monitoring combining meteorological, technical, operational, and consumption data • **Predictive analytics**: Weather forecasting and demand prediction algorithms for optimal resource allocation • **Target performance**: 70% of local demand coverage in stand-alone operation, approaching 100% energy autonomy • **Environmental impact**: 640 kg CO2 saved per MWh of clean energy produced, nearly 1.5 kilotons of annual reduction
Data management structure (e.g., use of ontology, data space)	• **Real-time data integration**: Continuous monitoring of system performance with multi-source data combining meteorological, technical, operational, and consumption information • **Smart metering data management**: Household-level consumption monitoring and analysis with bidirectional data exchange • **Forecasting data systems**: Wind, solar, and load prediction data management with deterministic and probabilistic models • **Project monitoring platform**: www.tiloshorizon.eu with real-time data visualisation accessible to stakeholders • **Research database**: Collection of operational data for analysis and replication studies across different island implementations • **Information systems architecture**: Live system performance data with comprehensive monitoring capabilities • **Standard smart grid practices**: Implementation of conventional smart grid data management without specific ontology or semantic data space approaches • **Data applications**: Production forecasting, demand prediction, storage optimisation, and grid stability management • **Communication infrastructure**: Advanced communication systems supporting real-time data exchange between all system components
Storage system(s)	• **Primary battery technology**: FIAMM NaNiCl2 (Sodium-Nickel Chloride) molten-salt battery technology with 2.8 MWh total useful energy capacity • **Battery configuration**: Two battery containers of 1.44 MWh/400 kW each, operating at 300°C with β-alumina ceramic separator • **Power rating**: 800 kW total power capacity with 8 inverters of 20kW rated power each • **Technical specifications**: 2.58V per cell, molten sodium chloroaluminate (NaAlCl4) electrolyte, 85% round-trip efficiency

	- **Operational characteristics**: 4,500 full cycle lifespan, 15+ year operational guarantee, deep discharge capabilities - **System integration**: SMA Solar Technology AG inverters with Younicos AG intelligent battery control system - **Grid integration**: Seamless interoperability with renewable generation and load management systems - **Distributed heat storage**: Integration with domestic hot water systems for residential thermal energy storage - **Safety and sustainability**: 100% recyclable, eco-compatible, suitable for any installation location with high safety standards - **Advantages**: High temperature operation providing long cycle life, suitable for both stand-alone and grid-connected operations - **Performance metrics**: Successfully demonstrated up to 100% winter energy coverage and 70-75% summer coverage during peak tourism
Risks related to technological weakness and lack of legislation	Technological: - **Battery technology limitations**: Temperature management requirements for molten-salt batteries operating at 300°C, cycling efficiency limitations, and maintenance complexity in remote island conditions - **System integration complexity**: Challenges in coordinating multiple renewable energy sources (wind and solar) with battery storage and grid interface systems - **Grid stability concerns**: Managing grid stability with high renewable energy penetration (target 70-75% RES penetration) and seamless transitions between grid-connected and islanded operation modes - **Forecasting accuracy limitations**: Identified limitations in renewable energy forecasting accuracy affecting optimal energy storage system operation - **Remote location maintenance challenges**: Isolated Island location creating significant challenges for maintenance, spare parts availability, and technical support - **Skills gap**: Limited local technical expertise for advanced energy storage system operation and maintenance - **Cyber security vulnerabilities**: Smart grid components introduce potential cyber security risks requiring ongoing management - **Interoperability challenges**: Ensuring compatibility between different microgrid components and the demand side management integration complexity Regulation: - **Lack of clear regulatory definition**: Absence of comprehensive regulatory definitions for energy storage systems, creating uncertainty for project developers and operators - **Double grid charges**: Energy storage facilities facing discriminatory treatment, being charged both as consumers (when storing energy) and generators (when discharging) - **Unclear ownership rules**: Unclear ownership regulations for energy storage systems, particularly regarding classification and operational rights within grid infrastructure

	• **Missing market mechanisms**: Absence of appropriate market mechanisms for energy storage to provide ancillary services, including frequency regulation and grid stability services • **Limited balancing market participation**: Regulatory barriers preventing optimal participation of energy storage systems in balancing markets, limiting revenue potential • **Complex interconnection procedures**: Lengthy grid connection procedures creating significant regulatory barriers for hybrid renewable energy systems • **Licensing delays**: Significant delays in obtaining production licenses for hybrid renewable energy systems with battery storage • **Regulatory compliance costs**: Complex regulatory compliance requirements increasing operational costs and administrative burden
Best practices and key takeaways	• **Strong community engagement**: Comprehensive local population interaction throughout the project period, with 82% of residents showing a positive attitude toward sustainable energy technologies • **Quadruple Helix approach**: Successful collaboration between academia, industry, government, and civil society, accelerating innovation transfer • **Regulatory innovation**: Achievement of first hybrid PPA in Greece, demonstrating the importance of regulatory adaptation and pioneering legal framework development • **Multi-stakeholder collaboration**: 13 partners from 7 European countries creating effective knowledge transfer mechanisms • **Phased implementation strategy**: Implementing projects in phases, allowing for regulatory adaptation and learning • **Revenue diversification**: Development of multiple revenue streams through various grid services and market participation • **Technology transfer methodology**: Creation of standardised approaches for replicating successful projects in similar contexts • **Comprehensive monitoring**: Real-time system performance monitoring with advanced forecasting and predictive analytics • **Modular design approach**: Implementation of modular system designs allowing for scalability and technology upgrades • **Early stakeholder engagement**: Establishing continuous engagement with regulatory authorities, grid operators, and local communities • **Economic viability demonstration**: NPV becomes positive from the 6th year of operation with successful cost reduction in electricity production • **Environmental impact achievement**: 750 tonnes annual CO2 reduction and 220 tonnes annual fuel oil savings • **Awards and recognition**: 2017 EU Sustainable Energy Awards winner in the Energy Islands category and Citizens' Choice Award
Roadmap	• **Technology evolution**: S4S system development for prosumer and EnC integration with blockchain and IoT technology integration for enhanced energy management • **Electric mobility integration**: Planned integration with electric vehicle charging infrastructure using renewable energy systems

	• **Scaling strategy**: Replication across additional Greek islands (Anafi, Donousa, Leros, Fournoi Korseon) with total 2.5 MW guaranteed power • **Commercial development**: "Aftonomo by Eunice" residential and commercial system development for broader market application • **European-wide expansion**: Application potential for 2,000+ European islands with 15M+ inhabitants requiring similar energy solutions • **Short-term regulatory actions (1-2 years)**: Establish clear definitions for energy storage systems, remove discriminatory market barriers, implement fast-track permitting procedures • **Medium-term development (3-5 years)**: Comprehensive electricity market design reform, modernise grid codes, establish comprehensive ancillary services markets • **Long-term vision (5-10 years)**: Integrated energy system planning, cross-border coordination mechanisms, circular economy integration with battery lifecycle management • **Research continuation**: Multiple peer-reviewed publications, technical reports, and policy recommendation documents for wider technology transfer • **Standardisation development**: Creation of standardised approaches for regulatory compliance and technical implementation • **Market mechanism enhancement**: Development of revenue stacking opportunities and capacity mechanism integration for energy storage systems • **Knowledge transfer platform**: Continued collaboration with island communities across Europe for experience sharing and best practice dissemination

2.2.11 BD4OPEM

Project name	Big Data for Open Innovation Energy Marketplace
Scope	The overall objectives of BD4OPEM are to design, develop and deploy a marketplace for large-scale multi-party data exchanges, management, governance and real-time processing of energy-related data in smart electrical distribution grids.
Duration	2020-2023
Pilot countries	Spain, Slovenia, Turkey, Belgium/Denmark
Energy Management System	• Modular and scalable EMS framework rather than a single platform. • Services ranged from HEMS to grid-level demand response tools. • Novel HEMS developed with a focus on minimising environmental impact via Life Cycle Assessment (LCA). • Grid-level tools included flexibility aggregation, microgrid management, real-time monitoring, and localised controls.

	• Enabled coordination of distributed assets like EVs, batteries, and smart appliances.
Data management structure (e.g., use of ontology, data space)	• Built around a **Data Lake** and **Data Intermediation Layer**. • Used a **4+1 View Model** for system architecture, ensuring security, modularity, and maintainability. • Support for both **open and secured (encrypted)** data streams. • Interoperability supported through: • Common data formats. • Synergies with projects like **GAIA-X**, **OMEGA-X**, and **BRIDGE**. • Use of established ontologies such as **SAREF**, **SEAS**, and **IEC CIM**. • Enabled secure analytics service transactions via the Open Innovation Marketplace ("energy app store").
Storage system(s)	• **Stationary Batteries**: Used for local and grid-level services like peak shaving and frequency regulation. • **EVs**: Used as mobile storage and integrated into **V2G** services. • Storage assets were central to enabling demand response and flexibility aggregation services. • Demonstrated in pilots, especially Denmark’s EV fleet flexibility aggregation.
Risks related to technological weakness and lack of legislation	Technological: • **Data Privacy & Security**: Addressed via encryption, GDPR compliance, and secure access controls. • **Interoperability**: Solved through common data formats and engagement with data space standardisation projects. • **Scalability & Performance**: Ensured by cloud-native architecture and big data technologies. • **AI Model Reliability**: Validated through five diverse large-scale pilots. Regulation: • **Data Governance & Ownership**: Tackled via engagement with EU policy bodies (e.g., BRIDGE). • **Flexibility Market Participation Rules**: Addressed by testing under current regulatory frameworks in pilots. • **TSO-DSO Coordination**: Solutions placed at the TSO-DSO interface; insights fed into policy discussions. • **Cross-border Harmonisation**: Pilots across five nations to test adaptability under different national rules.

Best practices and key takeaways	• **Open Innovation Ecosystem**: Encourages competitive and flexible development over monolithic systems. • **Structured Software Architecture**: The 4+1 View Model proved crucial in managing complexity. • **Large-Scale Pilots**: Validated platform in diverse regulatory and operational conditions. • **Strategic Ecosystem Engagement**: Alignment with EU initiatives (GAIA-X, BRIDGE, OMEGA-X) ensured long-term relevance. • **Lessons Learned Documentation**: Final reports synthesised learnings for future reference and replication.
Roadmap	• **Commercial Exploitation**: Marketplace infrastructure allows ongoing service provision and monetisation. • **Sector Benchmarking**: Platform to serve as a reference tool for energy market digitalisation. • **Policy Influence**: Aims to contribute to new EU energy data and flexibility regulations. • **Knowledge Dissemination**: All public results stored in open repositories (e.g., CORDIS, Zenodo).

2.2.12 ebalance-plus

Project name	Energy balancing and resilience solutions to unlock the flexibility and increase market options for the distribution grid
Scope	Development of a scalable, replicable energy balancing platform for grid flexibility. Targeted residential, commercial, and educational use cases.
Duration	2020-2024
Pilot countries	Spain, Italy, France, Denmark
Energy Management System	• Hierarchical, fractal-like architecture for scalability. • Includes multiple management layers (from end-user to substation). • **Elastic Energy Management (EEM)** algorithm: ○ Cost reduction for consumers. ○ Peak demand control for DSOs. • AI/ML for forecasting and flexible asset optimisation. • Interoperable design for multi-vendor device integration. • Cloud-based grid optimisation tools for DSOs (e.g., Volt/VAR control, fault detection).

Data management structure (e.g., use of ontology, data space)	• Data-centric middleware for seamless device/system integration. • API-based interoperability with external platforms. • Use of NGSI-LD standard (context information model aligned with ETSI). • Compliance with GDPR for data security and privacy. • Enables creation of a standardised flexibility market for prosumers and DSOs.
Storage system(s)	• **Stationary BESS** at building and district levels (exact specs not publicly detailed). • **EVs** with bidirectional charging for mobile storage. • **Power-to-Heat Systems** using heat pumps (thermal storage in Denmark).
Risks related to technological weakness and lack of legislation	Technological: • Lack of standard communication/data protocols (interoperability challenge). • Increased cybersecurity risks from connected assets. • Dependence on high-quality, real-time data for AI-driven decisions. • Difficulty in scaling solutions from pilot to grid-wide deployment. Regulation: • Unclear market rules for small-scale flexibility participation. • Data privacy concerns and strict GDPR compliance requirements. • Lack of standardised flexibility products across EU markets. • Need for stronger user engagement strategies to ensure adoption.
Best practices and key takeaways	• Fractal EMS architecture is effective for scalable flexibility management. • End-user engagement and intuitive interfaces are essential. • Interoperability and open standards are critical for integration and market formation. • Addressing social, regulatory, and economic barriers is as important as technical development. • Multi-stakeholder collaboration was key to success.
Roadmap	• Focus on market uptake and commercialisation of project technologies. • Strong emphasis on replicability and scalability across different European contexts. • Contribution to EU-wide standardisation of flexibility protocols and data models. • Insights to inform energy policy and regulatory development.

	- Foundation laid for future R&I in advanced control, business models, and DER integration.

2.2.13 2LIPP

Project name	2nd Life for Power Plants.
Scope	In this project, an operating CHP/power plant is retrofitted with a hybrid energy storage system combining molten-hydroxide salt thermal storage, second-life Li-ion batteries, and a flywheel, all orchestrated by an EMS to optimise charge and dispatch operations, reduce storage costs by reusing existing plant infrastructure, and provide grid-stability services across both electrical and heating sectors. Use case: industrial/utility (CHP/power plant & district heating context).
Duration	2023-2026
Pilot countries	Denmark (Bornholm CHP plant, Rønne).
Energy Management System	• The project defines a hybrid Energy Management System (EMS) that connects the three storage technologies so the entire storage system can balance the grid and supply stored energy when needed. • D1.2 further specifies EMS operation for heat delivery from the Molten Salt Unit to the District Heating Network, stating that, within the MSU's operational range, the DHO can request heat via the EMS. • The EMS is listed as one of the project's four core technologies ("Hybrid Energy Management System") used to integrate and dispatch the storage assets. • The storage technologies are "tied together by a hybrid energy management system from PINI Solutions" to balance the grid and deliver stored energy.
Data management structure (e.g., use of ontology, data space)	• **Operational data exchange occurs via the hybrid EMS:** The project developed an Energy Management System for optimal operation and market participation, implying asset-to-EMS data flows. • **Project data collected for simulation/modelling (not a DMS):** Plant data for the BEOF site was collected and implemented in Ebsilon to build process-flow diagrams, primarily to support WP5 and also WP4 activities.
Storage system(s)	• **Hybrid storage stack (3 technologies):** high-temperature hydroxide-salt thermal storage (HYME), second-life Li-ion battery storage (PLS Energy Systems), and a high-tech flywheel (QuinteQ). • **Thermal energy storage (HYME):** first-of-a-kind high-temperature hydroxide-salt storage for CHP, intended for long-duration, grid-scale storage.

	- **Second-life Li-ion battery system (PLS Energy Systems):** containerised battery using used car batteries for short-duration services; on-site delivery/installation at the Rønne CHP is documented by the project. - **Flywheel storage (QuinteQ):** short-duration storage for fast grid support as part of the hybrid stack. - **Site preparation for storage installation (Bornholm CHP):** public deliverable on "Site Preparation Process" records the works enabling installation/commissioning of the second-life battery and flywheel (site visits, environmental checks, cabling/civil works).
Risks related to technological weakness and lack of legislation	Technological: - Commissioning delay caused by non-compliant inverter hardware, requiring a redesign/exemption before the battery system could be energised (equipment conformance risk). - Supplier reliability issues delaying flywheel delivery (supply-chain/technology readiness risk). - Integration challenges across the hybrid stack and EMS, including a control-interface redesign for the molten-salt unit (system integration & interoperability risk). - Site readiness dependencies (civil works, cabling, electrical/thermal connections) that can hold up commissioning of storage units (installation/engineering risk). Regulation: - Need for regulatory exemptions due to technical non-conformities (e.g., inverter not meeting applicable regulations), creating a schedule and approval risk. - Pending permits and approvals for grid connection and environmental compliance; ongoing coordination with the local DSO and the Danish Environmental Protection Agency (permitting & compliance risk). - Regulatory documentation burden and evolving requirements during site preparation and commissioning (administrative/legislative complexity risk). - Regulatory barriers, security requirements, permits and agreements identified as part of site-preparation work at the existing CHP site (compliance & security risk domain).
Best practices and key take away	- Repurpose existing plant infrastructure to cut costs and speed deployment of hybrid storage while keeping grid stability/security of supply. - Do thorough site-prep up front (site visits, environmental assessments, digging/cabling, electrical & heat connections) to de-risk installation/commissioning. - Plan for hardware conformity and supplier-readiness risks (e.g., inverter non-compliance requiring an exemption path; delivery delays on

	flywheel); keep redesign options available (e.g., control-interface redesign) to unlock integration. • Maintain continuous, early dialogue with regulators and the DSO to secure grid-connection and environmental approvals (and any needed exemptions). • Define detailed use cases to guide EMS logic and the split of functionality across the hybrid stack (flywheel, 2nd-life batteries, molten-salt). • Co-create via stakeholder workshops to refine transition strategies and implementation roadmaps. • Develop business models in parallel with system design to capture revenue streams for both standalone assets and the combined hybrid system.
Roadmap	• Develop a roadmap for green energy conversion and simulation requirements to support replication beyond Bornholm (objective of the tech-transfer work). • Implement the Bornholm Energy Island programme with ≥3 GW offshore wind by early 2030s; option to add up to 50 MW PV by 2025; build an interconnected hub (Denmark–Poland–Germany–Sweden) targeting 5 GW offshore wind, green hydrogen production, and an initial 1 GW wind farm at Rønne Banke, enabling regional electrification. • Connect to the offshore installation system by 2026 (≈11 TWh/year) to fully shift electricity to RES; liberalise the 10H on-shore wind rule to unlock coastal wind; exploit biogas potential from farming and landfill (≈11.6% of regional demand); decarbonise district heating via gas CHP (transition), waste-to-energy with CHP, geothermal, solar thermal, heat pumps, decarbonised gases (biomethane/hydrogen), biomass, and electrification using RES; disseminate molten-salt storage experience from Bornholm as case studies for Polish/German sites. • Meet Thuringian Climate Act milestones toward a climate-neutral Thuringia by 2050 (GHG cuts of 60–70% by 2030, 70–80% by 2040, 80–95% by 2050) with expansion of RES to cover annual final energy needs by 2040; leverage technical RES potential (~5.6 GW wind, ~23.1 GW solar, plus hydro/biomass). • Prepare detailed case studies (Rønne CHP, selected sites in Germany and Poland) and a comprehensive roadmap enumerating technical, economic and regulatory steps; refine via stakeholder workshops.

2.2.14 MAESHA

Project name	Maesha
Scope	Demonstration of smart and flexible solutions for a decarbonised energy future in Mayotte and other European islands. Replication sites: St Barth, Favignana, La Reunion, Gozo and Madeira
Duration	2020 - 2025
Pilot countries	Mayotte (France)
Energy Management System	• EV EMS • Local energy communities EMS • PV EMS • BESS PMS (Battery Energy Storage System Power Management System)
Data management structure (e.g., use of ontology, data space)	• No centralised data management • Flexibility management through virtual power plants, and a flexibility trading platform
Storage system(s)	• Battery
Risks related to technological weakness and lack of legislation	Technological: • Cost of materials in islands • Shipment times • Theft and vandalism • Lack of education of the community • Lack of trust from the community • Affordability of solutions in impoverished communities • Lack of potential for demand response Regulation: • Investment regulation • Subsidized price of electricity
Best practices and key take away	• Not available yet
Roadmap	• Not available yet

2.2.15 ROBINSON

Project name	Smart integration of local energy sources and innovative storage for flexible, secure and cost-efficient energy supply on industrialized islands
Scope	The ROBINSON project aims to develop and deploy an integrated, smart, and cost-efficient energy system to help decarbonize islands, with a particular focus on those with industrial activities. Primary use cases: • Industrial: stable electricity and high-temperature heat supply for local industries. • Residential: renewable electricity for homes. • Transport: decarbonization through green fuels (biomethane, hydrogen) for land and marine mobility
Duration	2020-2025
Pilot countries	Norway, Greece, United Kingdom
Energy Management System	• The project is developing an optimized and intelligent Energy Management System (EMS) with an advanced control system. • This EMS will manage the integrated energy system, coupling thermal and electrical networks and utilizing local renewable resources. • It will consider weather forecasts, market fluctuations, and demand response to ensure grid stability, power balance, and security of supply. • The EMS will also manage non-electrical resources like biomass gasification and wastewater valorisation. • The system is designed to be user-friendly and highly modular to facilitate replication on other islands and in remote areas.
Data management structure (e.g., use of ontology, data space)	• The public project documentation does not provide specific details about the data management structure, such as the use of ontologies or data spaces.
Storage system(s)	• The system utilizes battery energy storage systems (BESS) to store energy for peak consumption or during power outages.
Risks related to technological weakness and lack of legislation	<u>Technological</u>: • Hardware procurement delays (e.g., gasification unit). • Economic volatility affecting system payback and competitiveness. • Complex system integration across diverse technology vendors. • Societal acceptance challenges for energy infrastructure.

	• TRL mismatches between mature and experimental components. Regulation: • Diverging regulatory frameworks across Norway, Greece, and the UK. • Vulnerability to policy shifts affecting subsidies, CO₂ pricing, and feed-in tariffs. • Permitting and land-use conflicts. • Incompatibility with centralized grid-oriented regulations. • Data governance and cybersecurity vulnerabilities due to smart EMS.
Best practices and key take away	• Multi-vector integration increases system resilience and resource efficiency. • Circular economy principles enhance local value and sustainability. • Early and detailed baseline analysis ensures appropriate, accepted design. • Use of LCA and techno-economic modeling supports optimal solutions. • Knowledge-sharing tools (Web Evidence Base, Roadmap Tool) broaden impact. • Hybrid storage design ensures technical and economic flexibility. • Modular EMS architecture supports wide replication across islands. • Emphasis on process (e.g., stakeholder engagement, adaptability) is as important as the technology.
Roadmap	• Implemented via the Replication Roadmap Tool with 6 key steps: ○ Identify local energy needs and resource potential. ○ Form an action group with stakeholders. ○ Match needs with appropriate ROBINSON technologies. ○ Analyze local legal, economic, and social contexts. ○ Adapt the system to local specifics and develop business models. ○ Conduct feasibility studies and prepare implementation. • Long-term goal: full decarbonization of Eigerøy's energy system by 2030. • Business model exploration includes revenue from local sales, avoided grid upgrades, and carbon markets.

2.2.16 SERENE

Project name	Sustainable and Integrated Energy Systems in Local Communities.
Scope	Develops and demonstrates cost-effective, customer-centric local energy systems that integrate multiple energy carriers (e.g., electricity, heat, e-mobility) in villages and small cities. It combines smart technological, socio-economic, institutional and environmental solutions for local management of integrated systems, high shares of local renewables, and active consumer engagement. Demonstrations target

	residential households, public/commercial buildings (e.g., schools/complexes), and transport/EV charging, with demand response and control schemes validated at the pilot sites.
Duration	2021-2025
Pilot countries	Denmark, the Netherlands and Poland
Energy Management System	• Employs a decentralized energy management system that uses flexibility from local assets for different market opportunities and power-system services. • Energy management system module optimally schedules, regulates, and manages cross-interactions among energy units in the integrated local energy system. • Smart homes communicate with a committed EMS at the aggregator level to establish flexibility in power flow and coordinate local PV, storage, EV charging, and thermal loads. • The project’s objectives include developing an intelligent Community Energy Management System (CEMS) for optimum operation of local resources. • In the Polish demonstrator (school & arena), all devices are connected by an EMS that manages energy storage and EV charging and provides energy balancing to minimize energy cost. • For the same use case, the EMS is developed by STAY-On with support of IMP and will include EV chargers, energy storage, PV systems, and heat pumps. • The aim of the EMS is to increase self-consumption from PV and reduce peak-hour load to lower energy costs in the municipal building.
Data management structure (e.g., use of ontology, data space)	• Operates a centralized, encrypted data-collection and storage stack where a broker links all IoT devices to services, measurements/actions are stored in an InfluxDB time-series database, and Grafana is used for analysis and visualization. • Home Energy Management Systems stream measurements via a message-queuing service into the central platform and share data with partners through an API, with all communications carried over encrypted connections. • Smart-meter and sensor data are ingested from DSMR P1 ports and submeters; additional comfort/occupancy data arrive via a private LoRaWAN gateway, and all data are uploaded securely to the platform. • A formal system architecture is defined to “collect all data using an encrypted connection” and to support digital-twin simulations (DEMKit) that consume the collected data for forecasting and control. • The framework adopts SGAM-style interoperability layers; data exchange relies on standard communications (PLC, LAN, and IoT protocols) with data-handling procedures specified at the information layer.

	• Data-management and communications are explicitly considered for cloud-based versus distributed/local architectures, with user access via control panels or mobile/web apps.
Storage system(s)	• Multiple storage carriers in the local energy systems (battery energy storage, heat storage and water-storage systems) alongside demand response. • Relocatable Li-ion ($LiFePO_4$) “all-in-one” system rated 25 kW / 64 kWh; used to relieve PV curtailment and to trial storage at multiple grid points; later combined with the Vanadium redox flow battery (VRFB) as a hybrid storage setup for the sports hall microgrid. • Containerised unit planned at Arena Przywidz; two VRFB modules totalling 20 kW / 96 kWh; selected for very high cycle life (20,000+), full usable SoC range (0–100%), and integration with PV, EV charging and heat-pump systems. • Techno-economic studies modelled a 30 kWh battery with PV at the public kindergarten to increase self-consumption and shift load from peak hours. • Planned placement of a battery at a LV/MV pump-station substation to demonstrate community-scale services (peak shaving, reactive power support, voltage regulation) and explore DSO/community ownership models. • At the school/sports-centre complex, a hybrid battery (50–100 kWh class) integrated with EV chargers, PV and heat-pump systems under a site EMS was planned; the specific VRFB (20 kW/96 kWh) and mobile Li-ion (25 kW/64 kWh) configurations were then detailed for implementation.
Risks related to technological weakness and lack of legislation	<u>Technological</u>: • Aging/limited grid capacity in Poland leading to connection refusals and PV curtailment risks (distribution networks “outdated,” rising refusals for new RES connections; over-voltage/thermal overload issues from sudden RES production). • Local PV curtailment challenge at LV level (Use Case 1 explicitly aims to reduce curtailment using a mobile storage unit at a district connected to a single secondary substation). • Dutch grid congestion constraining new renewables and consumer connections (parts of the grid “become congested,” reinforcing the need for flexibility to avoid grid upgrades). • Operational limits from strict grid-code compliance for storage/generators (country frequency/voltage windows and ROCOF tripping requirements that storage must meet). • Multi-energy integration can trigger cascading effects across carriers (timing/geographic misalignment of electricity/heat/fuel markets plus physical coupling can propagate disturbances). • Need for locally controllable EV charging to match PV in real time at the Dutch site (requirement stated for the selected 22 kW chargers to be locally controllable to track PV).

	Regulation: - Regulatory uncertainty from incomplete transposition of new EU energy directives (mismatch between legacy rules and what's needed for local energy systems; conditions for EnCs not yet settled). - Poland: ancillary services not open to DR and no legal role for independent aggregators (market access barriers limit flexibility/DSR participation). - Netherlands: third-party aggregators can only participate via BRP/retailer (limits direct market access and complicates DR business models). - Denmark: difficult environment for independent aggregators (no independent aggregators yet; need bilateral agreement with BRP/retailer; compensation for BRP imbalances unresolved). - Municipal energy trading restrictions in Poland (EV chargers initially not open to the public because of legal issues with "trading or giving energy from installations belonging to the municipality"). - Rules for community energy cluster governance still need to be established (financial/organisational rules must be "fully established" before mechanisms like blockchain settlements are analysed; "dynamically changing" legal situation makes setting up a reasonable community challenging). - Planning/zoning and higher-level policy specificity can constrain local systems (legal/regulatory issues reported "across the board," including spatial/zoning regulations and non-specific higher-level rules).
Best practices and key takeaways	- Use a digital-twin toolchain (single code-base from simulation to hardware-in-the-loop) so algorithms can be validated and deployed quickly, with data stored on a scalable platform. - Prioritise short-term batteries, smart EV charging/sharing, and intelligent control of hot-water/heat buffers to cut grid imports and emissions; seasonal storage is presently infeasible or marginal. - Optimise flexibility against clear objectives (cost, CO_2, peak-shaving): in the Dutch demo, this cut annual imports 65.7→48.1 MWh, CO_2 35.0→19.7 t, with current savings ≈ €925 and up to €3,521 in a future setup. - Run a proactive EMS using forecasts and human-in-the-loop interaction (tips before action) to boost user acceptance and effectiveness. - Align flexibility with emerging local congestion markets/DSO needs to create value and relieve grid stress (peak-shaving, flatter import profile). - Build bottom-up EnCs: community clusters can be economically beneficial and accelerate transition, but designs must adapt to differing national regulatory and social contexts. - In Poland, expect policy fluidity: current rules limit community types, yet momentum is growing—use visible demonstrations (e.g., school site) to raise awareness and support. - Embed social-science baselining (community surveys on motivations/poverty, inclusive governance, regulatory sandboxes) to de-risk implementation across sites.

	• Structure designs on an SGAM-based, multi-carrier architecture with a decentralised EMS, standard PLC/LAN/IoT communications, and clear roles for aggregation and grid/market services.
Roadmap	• No Roadmap

2.3 Other sources review

2.3.1 European Commission recommendations on Energy Storage - 2023

As described in PARMENIDES D6.3 "Standards and legislation for the market introduction of the PARMENIDES results" [3] the transition toward a sustainable, decarbonised, and resilient energy system is a cornerstone of the European Union's Green Deal[8] and REPowerEU[9] strategy. Recognising the pivotal role of energy storage in balancing supply and demand, integrating renewable energy sources, and enhancing grid stability, the European Commission issued recommendations (EU) C/2023/1729 on energy storage in 2023 [34]. The recommendations provide a strategic framework to accelerate the deployment of energy storage technologies across the EU, addressing both technical and regulatory barriers.

The main ideas of the recommendations for the member states are:

1. To consider the double role (generator-consumer) of energy storage when defining applicable regulatory framework and procedures.
2. To identify the flexibility needs of their energy systems in the short, medium and long term.
3. To ensure that energy system operators further assess the flexibility needs of their energy systems when planning transmission and distribution networks, including the potential of energy storage and whether energy storage can be a more cost-effective alternative to grid investments.
4. To identify potential financing gaps for energy storage, including behind-the-meter and other flexibility instruments, and if a need for additional flexible resources to achieve security of supply and environmental objectives is identified
5. To explore whether energy storage services are sufficiently remunerated, and whether operators can add up the remuneration of several services.
6. To consider competitive bidding processes to reach a sufficient level of flexibility in source deployment.
7. To identify any specific actions, regulatory and non-regulatory, necessary to remove barriers to the deployment of demand response and behind-the-meter storage.
8. To accelerate the deployment of storage facilities and other flexibility tools in areas with insufficient grid capacity, unstable or long-distance connections to the main grid.

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[8] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[9] https://commission.europa.eu/topics/energy/repowereu_fr

9. To publish more real-time and detailed data to facilitate investment decisions on energy storage facilities (e.g., network congestion, market prices, installed energy storage facilities).
10. To continue supporting research and innovation in energy storage, as well as guiding these technologies and products to the commercialisation stage.

2.3.2 ETIP SNET: R&I Roadmap 2022-2031

The roadmap sets a 10-year path (2022–2031) to move Europe toward a strongly renewable energy system by 2031 and, ultimately, a fully CO_2-neutral energy system by 2050. It introduces nine High-Level Use Cases (HLUCs) and associated Priority Project Concepts (PPCs) to guide concrete research, demonstration, and deployment actions. These HLUCs translate policy goals into practical projects, with outcomes geared to real-world demonstrations and staged via successive Implementation Plans (2022–2025, 2025+, 2026+, and later), recognising prerequisites and tasks that must be prepared earlier and deployed later on the 2030–2040 horizon.

EMS

The document defines EMS as modular systems that manage power stations and the network, and places EMS within “Control Center technologies” alongside platforms, operator training, and coordination among control centres under System Operation research themes. This situates EMS at the core of supervisory control, state estimation, short, medium, and long-term control, operational planning, preventive control/restoration, and next-generation control-room capabilities for TSOs and DSOs.

Energy storage

The roadmap stresses that energy storage technologies from electricity and thermal storage to synthetic liquids and hydrogen must improve grid integration to meet decarbonised system challenges. It calls for R&I to demonstrate technical and economic feasibility, co-optimise operation and planning of multi-energy systems, and enable real-time balancing and flexibility management across energy vectors (e.g., P2X/X2P). It also assigns PPCs to quantify the value of cross-sector integration and storage, develop control and operation tools, and ensure reliability and resilience standards for future infrastructures, backed by validation and demonstration activities over the 2022–2031 window.

Cybersecurity and data privacy

The roadmap highlights that growing digitalisation raises cybersecurity threats across the whole chain (from production and transmission to distribution and consumers), requiring continuous effort, investment, and identification of ICT services, systems, and products at risk, along with risk assessment of technical and non-technical factors. It points to expected outcomes such as a network code for cybersecurity and adaptation of gas and hydrogen networks to cyber-attack risks.

Regulation and market

It also notes regulatory and governance needs: market-driven, transparent TSO–DSO–system-user cooperation; platforms with clear governance; and new market designs and legislation (e.g., roles for DSOs in flexibility procurement) to enable cross-sector trading and balancing. Additionally, the text flags permitting bottlenecks for large RES projects and calls for clarifying responsibilities, building administrative capacity, setting deadlines, and digitalising applications.

Interoperability

Across the HLUCs, the document emphasizes practices that recur as enablers: open, interoperable, and secure data exchange; a one-stop shop entry point for consumers and citizens; plug-and-play conditions instead of proprietary lock-ins; and the creation of a common European energy data space to support participation of EV smart charging, virtual power plants, EnCs, smart buildings, and smart heating by 2050.

User engagement and skilled people

It underlines the need to hide system complexity for users while enabling competitive service switching, and to reinforce skills and workforce development, so operators can fully use the new digitalised infrastructure.

Roadmap

The roadmap structures work through nine HLUCs and more than fifty PPCs, each placed on a time-bar from 2022 to 2031 and grouped under successive Implementation Plans (2022–2025, 2025+, 2026+, later). For example, in HLUC1 (Cross-sector Integration & Grid-Scale Storage), early PPCs quantify storage value and build control tools (2022–2025), mid-term PPCs address hydrogen/CO_2-neutral gases and regulatory frameworks (2025+), and later PPCs target cross-sector resilience, future cross-vector infrastructure design, and validation/demonstration (2026+). Likewise, HLUC7 (System Supervision & Cyber Security) advances “next-generation control rooms” for TSOs/DSOs as products by 2031 and integrates new control concepts, data management, and cybersecurity requirements, again scheduled across IP 2022–2025, 2025+, and 2026+. The overall sequence links immediate R&I needs to staged demonstrations, preparing deployments through the 2030s on the way to the 2050 climate-neutral target.

2.3.3 ETIP SNET: Energy communities’ impact on grids - 2024

The document explains how EnCs affect electricity grids and markets, and it sets out the technical, economic, regulatory, and organisational changes needed to integrate EnCs at scale. It describes grid impacts and opportunities for TSOs and DSOs, compares architectural approaches (centralised, microgrid, VPP, and the holistic LINK paradigm), reviews barriers and enablers, and proposes a staged roadmap of actions to move from basic to fully integrated operation of EnCs. The study emphasises that DSOs can procure local flexibility and that a fit-for-purpose architecture is needed so the whole system remains safe, reliable, resilient, and economical as DER penetration grows.

EnC monitoring and control

The document shows that EnC integration requires secure monitoring and control platforms at the DSO level and coordinated control across grid levels. In architectures based on VPPs, the DSO technical platform includes the tools and services for observability and control, specifically SCADA and distribution management systems to manage the distribution grid securely, negotiate flexibility requests, and support reliable operation. VPP controllers exchange data with DSO SCADA, field equipment, and market actors, receiving set-points from higher layers while acting autonomously within operational limits. In the holistic LINK architecture, decentralised control with “Secondary Control” coordinates different grid levels, producers, and storage, and it foresees redesigned market arrangements aligned with the power-system structure (TSO-facilitated national markets, DSO-facilitated regional markets, and EnC-facilitated local markets).

Storage

Storage is treated as a core element of EnC operation and of the LINK architecture. The LINK model defines explicit “Storage-Links” alongside “Producer-Links,” with technical interfaces that allow coordination with the grid and with markets; this enables storage to participate in flexibility and ancillary services regardless of size or technology. The report also notes that EnCs can manage distributed generation together with storage and vehicle-to-grid interactions more efficiently and securely, and it points to batteries (including electric-vehicle batteries) as part of “advanced operation” within EnC boundaries.

Risks and challenges

The report identifies several risks that stem from unclear definitions, immature frameworks, and technological limits.

- It warns that EnC definitions and legislation are still very general and focused on basic, independent operation, leaving roles vague and making financing, administration, and market positioning difficult; competition or unclear interactions with aggregators can add further complexity.
- On the market side, today’s structure does not enable direct participation by small actors, regional and local markets are not foreseen, and costs and benefits are uncertain due to the few applied cases and changing rules.
- On the technical side, DSOs face risks such as voltage limit violations, thermal congestion, unintended islanding, harmonics, protection adaptation needs, and planning challenges, while TSOs face new balancing demands, the need to adapt load-shedding schemes, voltage reactive power issues across TSO/DSO boundaries, n-1 security challenges, and changing system dynamics as DERs and controllable loads expand.

Deployment takeaways

The document highlights several practical takeaways for wide-scale EnC deployment. First, establish a holistic architecture that clearly describes elements, relationships, behaviors, and dynamics; treats TSOs, DSOs, EnCs, and end-users equally; and guarantees data privacy and cybersecurity. Second, investigate all grid-related challenges in distribution and transmission and define countermeasures before scaling up. Third, run pilots of fully integrated EnCs and then use measured KPIs to perform cost–benefit, scalability, and replicability analyses, following guidance from JRC and BRIDGE task forces, to support business plans and regulatory discussions. Finally, the report stresses social and organisational enablers, trust, motivation, and continuity as essential to start and sustain EnCs, with DSOs acting as market facilitators so participation is non-discriminatory and effective.

Roadmap

The report presents a phased roadmap for moving from concept to large-scale, fully integrated EnCs.

- It begins with a six-year "Preparation and Pilot Phase" to define and test a holistic architecture, adapt EU-level regulation and market rules (including standards for local market creation and transparent integration rules), address all grid challenges, and launch fully integrated pilot communities.
- The next step is "National Strategies" over one to two years to finalise roles and structures, secure the legal framework and resources, complete technology and standards, and build participation models and capacity with trusted intermediaries.
- The third step is a five-year "Fast Promotion" phase to accelerate large-scale deployment through local support schemes and standards, the launch of local electricity markets, periodic updates of technical norms and R&D, and broad stakeholder engagement and dissemination to support roll-out.

In parallel, the report outlines the operational evolution of EnCs from basic operation to advanced operation with flexibility from batteries (including EVs), to integrated operation with P2P trading under an enabling regulatory framework, and finally to fully integrated operation supporting demand-response at distribution and transmission levels.

2.3.4 ETIP SNET: Energy Storage Systems (KPI assessment and prioritisation of R&I targets) - 2023

The report "KPIs for Energy Storage Systems and prioritisation of R&I targets," prepared by ETIP SNET WG2, analyses different energy storage and conversion technologies, focusing on the specific challenges they face and prioritizing R&I actions to overcome them, introduces Performance Goals and maps them to a set of KPIs, and sets quantitative targets for two timelines 2025 and 2031 aligned with the ETIP SNET Implementation Plan 2022–2025 and Roadmap 2022–2031; batteries are not included in the analysis, as that topic is covered by Batteries Europe ETIP.

Use cases

It adopts a use-case mapping that explicitly highlights Customer-side needs and states that on the Customer side, "Peak shavings," "Maximization of self-production and self-consumption", and "Continuity of energy supply" will need to be maximized in scenarios with high penetration of renewable energy sources.

Performance goals

The performance goals used to assess storage and conversion technologies are listed, below some examples:

- load response for short duration (seconds–minutes), mid-duration (1–18 hours), and long duration (days–weeks)
- power quality

- reliability (including ability to provide power after long inactive periods)
- robustness
- long lifetime
- scalability to cost-effectively build different-scale systems
- compactness (improved energy and power density)
- safety
- efficiency (conversion efficiency high enough for cost-effective integration)
- high material efficiency and sustainable end-of-life management
- flexibility to integrate into infrastructure
- modularity to combine with other storage technologies
- support to decarbonization of industrial,
- power production
- transport and residential needs

The KPIs and metric definitions selected to track Performance Goals include lifetime in number of cycles and in years, specific power and specific energy (power and energy density), efficiency (round-trip efficiency), safety (number of events and severity), maturity of technology (TRL-MRL) and dependencies, time for deployment (months–years–decades), duration across short/long/seasonal terms expressed in hours–days–weeks including time to charge and time to discharge, time response and ramp rate, availability, and CAPEX/OPEX on an energy (€/kWh) and power (€/kW) basis with the report noting exclusions and boundary-condition caveats for LCOE/LCOS comparisons.

Pumped storage

For Pumped Storage Hydropower the report recommends shortening delivery time from about 10 years to 5 years through an acceleration programme covering permitting/authorizations and construction, including task parallelization and sustainability criteria (IHA/Green Deal) agreed via consensus, improving long-term visibility via economic models, processes and rules that consider long-term needs and grid security for a technology with long lifetime, low O&M and high upfront CAPEX, identifying all potential sites in Europe including existing, new and marine options and using clustering/partial standardization to accelerate deployment, improving variable-speed technology which can put large power on the grid in very short times (lower than a second) through R&D on materials, hydraulics and processes to reduce cost and delivery time, and complementing these with long-term PPAs and concessions as well as hybridization with floating PV (TRL 8/9) and batteries (TRL 7/8).

The operational characteristics stated for Pumped Storage Hydropower are that with synchronous machines it is today possible to move from full pump mode to full turbine mode in less than 60 seconds with R&D recommended to decrease the time response further, availability is >95% (96–98%) with digitalization, the average time before first refurbishment is 42 years and lifetime can be extended to over 100 years, although flexibility-driven operation may induce fatigue mitigable by improved hydraulic design/materials/forecasting, round-trip efficiency is 75–80% with specific actions to upgrade existing plants to ~80% and new plants up to 82% in the best case, and the EROI is stated as 80–200 with noted interest in modular hybridization with batteries and floating PV to provide high-quality electricity and reduce machine fatigue.

Compressed air energy storage

For Compressed Air Energy Storage the paper reports that existing hundreds-of-MW plants Huntorf (Germany, 310 MW) and McIntosh (USA, 110 MW) are diabatic with round-trip efficiency of 42% and 54% respectively, that the Zhangjiakou 100 MW Adiabatic Compressed Air Energy Storage (A-CAES) plant with over-ground tanks claims >60% round-trip efficiency, and sets targets in Table 5 of 10 hours duration for >100 MW plants by 2025 increasing to 18 hours by 2031, scaling to 500 MW up to TRL 8 with CAPEX <200 €/kWh by 2025 and to 1 GW up to TRL 8 with CAPEX <250 €/kWh by 2031, enabling <100 MW non-geological small-scale/industrial cogeneration options at CAPEX <150 €/kWh up to TRL 8–9, and improving round-trip efficiency from 70% (2025) to 85% (2031) via advances in A-CAES, isobaric A-CAES, Isothermal Compressed Air Energy Storage (I-CAES) and air/heat-flow regulation.

Thermal storage

For Thermal storage the targets in Table 16 include developing new high-temperature insulation to reduce thermal losses by half and new salts with melting/crystallization points below 120 °C to improve storing period and reliability after long inactivity, demonstrating >10,000 cycles for packed-bed sensible systems and >5,000 cycles for latent-heat technologies, achieving CAPEX below 10 €/kWh for high-temperature sensible storage, below 25 €/kWh for high-temperature latent storage, and below 60 €/kWh for low/medium-temperature latent storage with MW-scale demonstrators for PHP and PH, and improving compactness and efficiency via energy density increasing from 200 kWh/m³ (2025) to >350 kWh/m³ (2031) alongside next-generation molten salts reaching 600–700 °C and packed-bed systems >800 °C; the reference projects listed include Gemasolar (15 h) and NOOR III (7 h).

Superconducting magnetic energy storage

For Superconducting Magnetic Energy Storage the document states that SMES has very high performance in short-duration, high-power and high-cycle applications with millisecond-range response used for power quality in high-tech industries, most manufacturers declare a 30-year lifespan independent of duty cycle and SMES is easily combined with other flexibility sources, while proposed targets in Table 8 include for >1 MW units increasing mid-duration performance up to 3 hours by 2025 and up to 6 hours by 2031 and reducing CAPEX from <2,000 €/kWh in 2025 to <500 €/kWh by 2031 given current barriers of low energy density and expensive, complex MW-scale manufacturing and cooling.

Key takeaways

The report’s key takeaways are that not all technologies are able to meet all requirements across generation, transmission, distribution and customer use-cases and therefore the solution is often a combination of different storage and conversion technologies, and that the outcome of the report is a set of targets for each analysed technology with the mapping exercise used to prioritize KPIs to measure the effectiveness of R&I efforts and make each technology suitable for the decarbonization path of the European energy system.

2.3.5 EASE: Energy Storage Targets 2030 and 2050 -2022

The report sets EU-level energy-storage needs for a renewable electricity system and explains why formal targets are required. It argues that Europe cannot rely on renewables alone, because variable wind and solar still need flexible, dispatchable support. Energy storage provides the essential “energy-shifting” service to move excess renewable electricity to the hours, days, or seasons when it is needed. The document reviews literature and Commission studies, and proposes EU storage requirements for 2030 and 2050 to guide policy, investment, and system planning.

It does not describe EMS platforms, SCADA functions, or control-room operations. Its focus is on system needs, policy targets, and technology roles for energy storage; it does not set EMS design or operational requirements.

Storage roles

The report follows the EU Clean Energy Package definition of storage and distinguishes between two roles.

- “Power-to-X-to-Power” solutions are bi-directional: they store electricity and feed it back later (the core “energy-shifting” service).
- “Power-to-X” solutions provide one-directional flexibility by converting electricity into another carrier without feeding it back (for example, power-to-gas or power-to-heat).

Energy strategy

The text lists representative technologies across durations from seconds to seasons, including batteries, flywheels, supercapacitors, SMES, pumped-hydro storage, gravity storage, compressed-air and liquid-air storage, vehicle-to-grid, electrolysers in P2G2P chains, and thermal energy storage in P2H2P chains.

The report explains that higher solar shares increase the need for daily storage, while wind-dominated systems need more long-duration storage for multi-day low-wind events. This country-by-country generation mix affects the balance of hourly, daily, weekly, and seasonal storage needs.

The report warns that relying on fossil-fuel backup locks Europe into gas use and exposes it to high and volatile prices; without enough storage, renewable growth will lead to curtailment and missed climate goals. It states that many studies still use outdated climate targets and cost assumptions, which underestimates storage needs and delays action. It stresses that without clear policy intervention and an EU storage strategy, energy-security risks will worsen and deployment will lag the required pace.

Recommendations

The report’s main recommendation is to adopt EU-level energy-storage targets and an accompanying strategy, similar in ambition and scope to the Hydrogen Strategy, to give clear signals to investors and industry. It asks the Commission to mainstream storage in REPowerEU implementation and the Electricity Market Design review, and to remove barriers that still slow deployment and operation. It notes that targets help Member States reflect storage in NECPs, drive learning-by-doing for regulators and utilities, and accelerate cost reductions as happened for wind and solar.

The report estimates that Europe will need around 200 GW of energy storage by 2030 (including ~60 GW already installed, mainly pumped hydro) and at least 600 GW by 2050. Within the 2050 figure, it identifies about 435 GW from bi-directional Power-to-X-to-Power solutions for energy shifting, complemented by 165 GW from one-directional Power-to-X flexibility.

To meet the 2030 need, the report calls for a ramp-up of at least 14 GW of storage per year over the next nine years, compared with 0.8 GW/year of battery storage deployed in 2020. It presents this as necessary to avoid curtailment and fossil-fuel lock-in while renewable electricity expands rapidly.

Explain that many modelling studies exclude key technologies, apply outdated climate and renewables targets, or assume large roles for gas turbines in 2030. It highlights that cost and innovation data for storage are evolving and must be updated in planning to reflect available options across all durations.

Roadmap

The report sets a simple timeline anchored in targets. By 2030, storage should reach ~200 GW to provide energy shifting and fast-response flexibility for a system with very high shares of wind and solar. By 2050, storage should reach ≥600 GW, with a substantial share from long-duration, bi-directional solutions to cover multi-day and seasonal needs; one-directional Power-to-X flexibility fills the remainder. The document links this roadmap to adopting EU-level targets and a dedicated strategy so that storage deployment proceeds in parallel with renewable build-out.

2.3.6 EASE: Local Flexibility at DSO level and multi-service business case - 2022

The report explains why Europe needs local flexibility to integrate fast-growing renewables and electrification, and how DSOs and TSOs can use flexibility options to manage congestion, voltage, and other operational needs. It reviews active network management, flexible connections, market-based flexibility services, the legal framework in EU law, and lessons from UK pilots to show how energy storage can support secure, reliable, and cost-effective grid operation.

Flexibility management and monitoring

In current practice, instructions are issued from the control room and executed by Active Network Management (ANM) control systems located at the provider's site, which gives the network operator high certainty of response and lets them maximise use of existing capacity. Flexibility services are procured for specific locations ("flexibility zones"), with visibility platforms (such as those used in the UK) publishing zone needs, capabilities, and service periods; providers are paid availability and utilisation fees, and contracts can run up to seven years depending on the zone. The document stresses the need for

- clear primacy/precedence rules between TSO and DSO,
- better coordination of procurement cycles, and
- information sharing so services can be stacked without conflicts.

Energy storage

Energy storage is presented as a key local flexibility provider that reduces redispatch costs, shifts low-carbon energy in time, and helps manage EV-driven peaks and other short- to medium-duration events. The report lists the stack of services that can support a storage business case across ancillary services (frequency response, reserve, black start), network-asset services (constraint management, reactive power), capacity/adequacy and arbitrage, imbalance and day-ahead markets, and customer backup, while noting that long-term contracted revenue is scarce and revenue certainty remains limited.

DSOs and flexibility

EU rules require DSOs to procure flexibility through transparent, non-discriminatory, market-based procedures (Electricity Directive 2019/944, Article 32). EU Regulation 2019/943 sets obligations to minimise downward redispatch of renewables and includes limits and conditions around curtailment and balancing capacity contracting. The paper uses these provisions to frame how flexibility services and market design should evolve and how storage should be able to participate on a level playing field.

Risks and challenges

The document highlights several risks:

- curtailment volume risk for RES and storage under flexible connections,
- difficulties forecasting curtailment beyond five years,
- reduced service availability and revenue when connection firmness is weak,
- lack of a mechanism at the DSO level to tackle generation over-supply, and
- silos in current flexibility markets that hinder multi-service stacking (for example, limited voltage-regulation products).

It also points to uncertainty from short contract durations, gaps in standard product definitions, locational issues, limited competition, and missing transparent methodologies to compare ANM, flexibility services, and reinforcement factors that can delay investment and create asset-stranding risk.

Best practices

Good practice includes:

- designing flexibility markets that allow long-term capacity-style contracts where justified, while also keeping options for shorter auctions;
- enabling multi-service stacking (including demand turn-up for congestion and curtailment mitigation);
- ensuring neutral market facilitation and full transparency on needs, constraints, and expected value; and
- adopting clear rules for TSO–DSO coordination so whole-system outcomes are achieved.
- The paper also recommends standardised documentation and open standards to ensure technology compatibility across the industry.

For storage, the report calls for more revenue certainty (especially for multi-hour systems), multi-year contracts based on capacity payments in local markets with low liquidity, standardisation of demand turn-up services, and automatic correction of wholesale imbalances when storage provides DSO services. It also proposes enabling curtailment trading and creating tools and “sign-posting” to help providers understand stackable revenues across DSOs and the TSO.

Roadmap

Instead of a dated timeline, the paper sets a sequence of actions: (1) monitor and implement the EU requirement to procure flexibility; (2) develop standardized flexibility markets that can procure peak demand, congestion, voltage, and stability products and that align with net-zero goals; (3) establish harmonized, transparent methodologies to compare ANM, flexibility services, and reinforcement; (4) improve procurement cycles with clear primacy rules, aligned tender windows, and pre-qualification processes; (5) increase data transparency on constraints, curtailment forecasts, and DER levels; and (6) enable market features that unlock storage value such as demand turn-up, curtailment trading, multi-year capacity-type contracts, and stack ability with other services.

UK flexibility markets developed through Ofgem’s Smart Systems and Flexibility Plan and ENA’s Open Networks Programme show that standardised services, defined flexibility zones, mixed availability and utilisation payments, and contracts up to seven years can work in practice. The case study also underlines the need for neutral facilitation, transparent evaluation methods, and strong TSO DSO coordination so storage can stack services without being locked out by conflicting rules.

2.3.7 EASE: Business Case Taxonomy of Behind-the-Meter Battery Energy Storage Systems in Europe (Stand-Alone and Co-Located BESS Solutions) - 2023

The report sets out how behind-the-meter (BtM) battery storage alone or co-located with solar PV creates savings for users, enables self-consumption, supports peak shaving and load management, and can provide market services where national rules allow. It also explains why a clear regulatory framework and technology-neutral policies are needed so consumers can play a more active role in the energy system.

Behind-the-meter battery

The document shows that BtM batteries are operated for self-consumption, bill management, demand-charge reduction, and (where permitted) participation in energy and balancing markets. Operation depends on local tariffs, metering, and market access, and software can be used to identify peaks and control charging and discharging to achieve savings. Advanced metering (smart meters and submeters) is highlighted because it enables real-time monitoring and optimization of BtM services.

BtM storage can be stand-alone or co-located with PV so that excess solar is stored and later used on-site, increasing self-sufficiency and reducing purchases from the grid. The paper also recognizes other BtM storage options such as thermal storage that can support decarbonization when combined with renewables. The authors emphasize technology neutrality so that different users can adopt the solutions that best fit their needs.

Business cases

The document lists the main business cases and gives simple formulas for each.

- For self-consumption with PV, unit savings equal the avoided retail cost multiplied by round-trip efficiency minus any foregone PV export remuneration.
- For tariff arbitrage, the unit saving compares the discharge value at high prices with the charge cost at low prices, adjusted by one-way efficiency.
- For demand-charge management, savings depend on the power tariff, the shaved peak, and software effectiveness.
- For energy/balancing markets, unit revenues reflect the spread between selling at a high price and buying at a low price, again adjusted by efficiency.

Risks and challenges

Several obstacles are identified.

- In some countries BtM export of energy is restricted or not allowed, which blocks market revenues;
- complex taxes and administrative procedures increase costs and delay projects;
- regulated retail prices, inconsistent feed-in tariffs, and net-metering/net-billing can distort signals and reduce the value of storage;
- limited data and planning practices (including issues like double charging of access) reduce investment confidence; and
- short contracts, non-standard products, and limited competition make revenue stacking difficult.

These barriers vary widely across Member States and require tailored solutions and EU-level effort.

Enablers

The report points to concrete enablers:

- legally recognize prosumers and their rights;
- set supportive, technology-neutral rules for BtM participation (clear connection codes, metering access, fair tariffs);
- streamline permitting;
- introduce well-designed financial incentives (grants, tax credits, loans) where socioeconomic analysis shows value;
- roll out smart metering and other enabling technologies; and
- promote time-of-use and dynamic pricing that reward flexibility, while acknowledging the higher price-volatility risk for consumers.
- Neutral market facilitation, transparency on needs and value, and the ability to stack services across products and levels are presented as essential.

Electricity market

The Electricity Market Design (EMD) revision proposes an "active customer" definition that underpins BtM participation in energy and balancing markets and limits new net-metering schemes, which can strengthen the case for self-consumption. The Commission also recommends that Member States promote demand response and BtM storage, although the paper notes that this guidance is general and may lead to uneven implementation. Other relevant files mentioned include the Battery Regulation, the Renewable Energy Directive, and the Energy Performance of Buildings Directive.

Roadmap

Instead of a dated timeline, the document lays out a sequence of actions: remove export restrictions and enable fair remuneration for BtM services; simplify and digitize permitting; set technology-neutral, standardized market products that allow long- and short-term procurement and revenue stacking; ensure transparent data on constraints and value; expand smart metering and supportive R&I; and align national rules with the EMD's "active customer" approach so BtM BESS and BtM BESS+PV can reliably participate in markets.

2.3.8 EASE: European Market Monitor on Energy Storage (EMMES) 9.0 - 2025

EMMES 9.0 provides updated views and forecasts on European energy-storage markets to 2030, with in-depth analysis for 15 core countries and forecast coverage for residential, commercial & industrial, and utility-scale electrochemical storage; it also collects data for pumped hydro, electrochemical, thermal, and other storage technologies.

European energy context

Europe has roughly ~89 GW of installed storage capacity across technologies, including about 53 GW of pumped hydro and 35 GW of electrochemical storage. In 2024, new installations amounted to 4.9 GW / 12.1 GWh front-of-the-meter and 7.1 GW / 9.8 GWh behind-the-meter. EMMES also notes >1 million homes with batteries across Europe.

EMMES projects an additional 128 GW / 300 GWh of electrochemical storage on European grids by 2030, taking cumulative electrochemical power capacity from 35 GW (2024) to 163 GW (2030).

Compared with the prior edition, EMMES 9.0 found BtM 2024 deployments were ~1.9 GW higher than forecast, mainly because the decline in the residential markets of Italy and Germany was smaller than expected, visibility improved average power and energy per system, and there were variances in other markets. Europe counts 17 million solar homes and 3.4 million battery homes at end-2024.

Storage

EMMES highlights softer demand from H2 2023 onward as the energy crisis became a weaker driver; higher borrowing costs and cost-of-living pressures further subdued 2024 demand. Looking ahead, PV market developments, changes to subsidies, and dynamic tariffs and remuneration for solar PV will influence deployment and may increase incentives in the future.

Commercial & industrial segment

In the commercial & industrial segment, electrification is creating new use-cases and a need for storage. A slower PV rollout has weighed on growth, especially for smaller systems, but the outlook for most market drivers improves by 2030, with access to flexibility revenues an important factor.

Delays

For 2024, FoM deployment came in lower than EMMES 8.0 forecast due to project delays in Great Britain (including 1.1 GW with T-1 capacity-market contracts not connected as expected) and some larger differences in Italy and Sweden; most other markets aligned with expectations.

Average FoM project duration increased from ~1.5 h to ~2.5 h in 2024; EMMES forecasts a temporary dip to ~1.9 h in 2025, with project scale growing strongly by 2030. Battery co-location with conventional generation is common, while co-location with renewables is growing and expected to expand strongly by 2030.

Risks and challenges

EMMES flags project delivery challenges and pipeline execution risks in several years of the outlook. It also points to borrowing-cost pressure on residential adoption, policy-timing effects (e.g., support-scheme cycles), and delays that can shift FoM commissioning. These issues appear in the analysis of 2024 outcomes and the 2026–2029 forecast narrative.

Takeaways

A few practical messages stand out from the slides: commission existing queues, address grid-connection and delivery bottlenecks, and watch policy levers that can change project economics (capacity-market schedules, flexibility targets, support-scheme windows, and cost trends). Co-location, especially with renewables, is accelerating, and project durations are lengthening over time, shaping business cases toward multi-hour assets.

Fundings

Outlined four relevant state-aid avenues: investment aid to accelerate RES rollout (open to electricity and thermal storage), non-fossil flexibility support schemes (direct grants via competitive bidding, with measures expected from 2027 and contracts up to 10 years), capacity mechanisms (with co-optimised procurement if flexibility schemes also exist, expected from 2025), and aid for industrial decarbonisation (direct grants and financial instruments).

On 26 February 2025, the European Commission announced the Action Plan for Affordable Energy. EMMES highlights initiatives with indicative timelines, including new network-tariff design (e.g., addressing double charging; launch by Q2 2025, impact around 2026), Energy Taxation Directive revision (prohibition of double taxation for storage; Q4 2025 launch, impact around 2027), permitting guidance and legislative proposals to speed storage (Q2 2025/Q1 2026), a European Grid Package for shorter grid-connection times (Q1 2026), and counter-guarantee programmes for PPAs (launch by Q2 2025).

The market outlook shows near-term commissioning of a large construction queue and grid-booster projects in 2025, a 2026 peak driven by support schemes and the Recovery and Resilience Facility, a dip in 2027 as delivery challenges grow, and further additions through 2028–2030 as Polish capacity-market contracts are delivered, CAPEX drops, and EMD flexibility targets take hold. Policy measures from the Clean Industrial Deal and the Affordable Energy Action Plan are expected to lift deployment mostly from 2027 onward by reducing costs, expediting projects, providing investment support, and opening revenue streams.

2.3.9 ENTEC: Study on Energy Storage - 2023

The report explains why flexibility becomes critical as wind and solar grow, and it examines energy-storage technologies, their business cases, and the policy and regulatory practices that can enable deployment in Europe. It covers technology costs and performance, market value, and revenue/cost gaps through 2030, and eight policy topics (targets and regulatory frameworks, market design, long-duration storage, double taxation and grid charges, non-discriminatory network planning, guarantees of origin, contributions of thermal storage, and permitting).

Does not describe control-room platforms or EMS architectures. Instead, it defines storage “use cases” by linking technologies to services (generation/bulk, TSO support, DSO support, ancillary services, and behind-the-meter energy management) and by identifying the actors who provide them. It also lists the minimum technical characteristics per service, such as storage duration of one hour or more for distribution support and power thresholds for behind-the-meter management.

Five families of storage are analysed: mechanical, electrochemical, electrical, chemical, and thermal, split into 50 specific technologies with KPIs like CAPEX (€/kW, €/kWh), OPEX, round-trip efficiency, lifetime, cycles, response time, and dependence on critical raw materials. A high-level grouping for modelling distinguishes short-, medium-, and long-term options (e.g., Li-ion for short-term, pumped hydro for medium-term, hydrogen for long-term). The report shows capital-cost ranges that indicate which technologies are more competitive for long durations (e.g., PHS, CAES, hydrogen) versus short durations (e.g., Li-ion, lead-acid, sodium, flow batteries) and displays TRL levels, noting that several sub-technologies have already reached TRL 9 while others are still developing.

- The annual European market for stationary battery storage rose from 0.6 GWh in 2015 to about 9.4 GWh in 2022, with a doubling from 2021 to 2022. Around 30% of the 2022 market was residential, ~2% was C&I, and ~70% was front-of-the-meter.
- Pumped-hydro storage remains much larger in absolute terms, at ~44 GW of power and >200 GWh of energy in Europe, and additional PHS is under development.
- Thermal storage is widespread and diverse; examples include ~6.8 GWh of CSP-related TES in Spain and an estimated ~189 GWh of solar-thermal-related TES stock in 2020.

Power-market arbitrage became profitable in 2021-2022 as average prices and spreads increased; however, with today's costs, 2030 arbitrage alone still shows cost gaps in calculations, and results remain sensitive to future price expectations. Ancillary services currently offer the highest revenues: reported FCR earnings reached €76,000/MW in 2020 and €190,000/MW in 2021 in Austria, with aFRR/mFRR adding further value though with limited market size. Storage can also earn project-based payments for network support, capacity-market payments (e.g., the UK clearing price for 2025–2026 delivery was £18/kW-year, ≈ €20,000/MW-year), reduced peak-capacity/grid-fee charges, and stacked combinations of use cases. Future profitability improves with technology cost reductions, longer lifetimes/more cycles, phase-out of conventional flexibility, and increasing renewable shares; higher interest rates, certain regulatory designs (e.g., net metering), and competition from other flexibility (e.g., heat-pump load shifting, EVs) can reduce attractiveness.

Barriers

Surveyed stakeholders ranked regulation and market access as the top barriers, followed by financial constraints, missing long-term policy signals, double taxation and grid charges, and absent frameworks for local flexibility markets; technological barriers were rated least important. The study also flags non-remuneration of some non-frequency ancillary services (e.g., voltage control, black start) in many systems, limited procurement beyond certain markets, and uneven access to spot/balancing markets across Member States. For long-duration storage, needs for weekly and seasonal flexibility will increase, but the exact requirement is uncertain, given competition with other solutions, specific support should be justified by demonstrated flexibility needs. Permitting remains a significant obstacle for large projects, and double-charging of stored electricity can penalise business cases if not addressed.

Recommendations

Several measures stand out in the analysis and expert inputs:

- adopt clear national goals supported by financing/programmes and tenders,
- continue removing market-entry barriers so storage can access spot and balancing markets on a level playing field,
- develop DSO flexibility procurement frameworks and contracts that enable value stacking,
- ensure non-discriminatory network planning that fully considers storage (not only large assets) in development and adequacy assessments,
- address double taxation and grid-tariff discrimination,
- improve capacity-mechanism design and forward-market liquidity,
- consider how GOs might evolve toward higher temporal granularity (noting today's limited basis and demand), and
- streamline and digitalise permitting with clear time limits.

Thermal Energy Storage (TES) already contributes at multiple scales from domestic hot-water tanks to district heating and industry, helping integrate renewable electricity and thermal energy, moderating the need for new electric generation, and potentially providing ancillary services. Data gaps are noted, but the study cites large existing stocks and identifies TES as an area where further research and EU-wide data collection would be valuable.

Ninety-three respondents reported that storage already supplies a wide range of services, with arbitrage the dominant revenue stream overall, followed by ancillary services; services to TSOs/DSOs currently form a smaller share, and behind-the-meter revenues are modest compared with other categories. Respondents are optimistic about growth to 2030 and expect more diverse, stacked business models rather than wholesale shifts in dominant services. The most desired action is fair, technology-neutral market access across the EU, including remuneration of system services that are not yet valued.

Roadmap

The report points to a forward path rather than a date-by-date plan: continue reducing technology costs and increasing durability, expand market access and remunerate needed services, design DSO procurement and contractual arrangements that enable stacking, resolve double taxation/charging through EU legislation, embed storage in network planning and adequacy assessments, refine capacity mechanisms and forward markets, develop policies for long-duration storage only where system flexibility analyses justify it, and streamline permitting to shorten delivery times. Together, these steps support sustained growth toward and beyond 2030 while preparing for rising weekly-to-seasonal flexibility needs.

3 European best practices

This section aims to summarise European best practices related to the following topics: smart districts, data management, energy storage, hybrid storage, and EMS. A focus was also placed on identifying that can support the understanding of the European market and upcoming innovation milestones.

This section will try to answer the following question based on the literature review done in the previous section and the other studies performed in the PARMENIDES project as Deliverable 6.3 on regulation and standardisation:

- What are the challenges, gaps, and risks identified by the reviewed projects?
- What are the identified best practices related to EnC, EMS, energy storage, and hybrid storage?
    - Technological weaknesses
    - Lack of legislation

3.1 Risks and challenges

This section presents a synthesis of the technical and regulatory risks identified by the European projects studied in the context of this task. A summary of each project analysis can be found in section 2.2.

The end dates for these projects range from 2019 to the present. The challenges identified below should therefore be taken with a pinch of salt, as some are no longer relevant and others are in the process of being resolved, such as with the adoption of new European regulations and directives. However, even though some are in the process of being resolved, they stay relevant, particularly at the national and local levels.

The studied project allowed the identification of a list of challenges, which could be covered by these main titles:

Table 6: Risk and challenges categories

Aspect	Risks/Challenges categories
Technical	• Interoperability and integration risks • Cybersecurity and data protection risks • Grid stability and energy management risks • Data and infrastructure limitations • Cost and economic viability risks • Scalability and deployment challenges • Maintenance and operational complexity • Technical control and aggregation risks • Supply chain and external dependencies • Societal and market risks
Regulatory	• Lack of legal and regulatory framework risks • Cross-border and compliance risks • Grid connection and interconnection risks • Approval and licensing risks • Market and revenue uncertainty risks

	• Data governance and cybersecurity risks • Market mechanism and flexibility risks • Role and responsibility uncertainty • Safety and technical risks • User engagement and social risks • Business model and investment risks

3.1.1 Synthesis of technical risks

Interoperability and integration risks

- Interoperability standardisation gaps: Lack of harmonisation across interoperability standards, data models, and fragmented smart metering protocols.
- Vendor heterogeneity: Complex integration due to diverse technology vendors, protocols, and platforms.
- Advanced control needs: Requirement for sophisticated control systems to manage hybrid storage configurations effectively. Difficulties in coordinating multiple storage technologies with existing grid infrastructure and legacy devices.
- Connectivity risks: Reliance on internet transport and cloud bandwidth for data acquisition and services, introducing performance risks. This will become increasingly important with dataspaces and the edge-cloud continuum in the context of the European energy digital spine.

Cybersecurity and data protection risks

- Vulnerabilities: High exposure risk to cybersecurity threats and privacy risks across a “European energy digital spine” based on IoT, cloud-edge continuum, dataspaces and blockchain. Risks associated with EMS and data sharing require robust security/privacy and configuration measures. Security risks from heterogeneous IoT environments with inadequate device protections.
- Evolving threats: Cybersecurity remains a dynamic risk due to the increasing sophistication of cyberattacks (e.g., AI systems) and the growing attack surface as grids become more interconnected. Similarly, this is also the case for privacy with the use of data available for AI training and the associated data protection threats.

Grid stability and energy management risks

- Forecasting limitations: Local-level forecasting dependency and inaccuracies affecting energy management and storage optimisation.
- Grid capacity constraints: Limitations in integrating renewables due to grid capacity and infrastructure constraints.

Data and infrastructure limitations

- Data quality challenge: Forecasting and distribution level constraints could degrade tool performance and thus customer outcomes.

- Aging infrastructures: Heterogeneous and end-of-life assets are complicating the integration of new technologies.
- Uncertainty in planning: Difficulties in leveraging new technologies due to infrastructure variability and maturity gaps.
- Lack of standards for energy storage systems: Absence of standardised technical and safety requirements for distributed energy storage systems

Cost and economic viability risks

- High (initial) costs: Elevated upfront costs for storage solutions compared to conventional grid options.
- Economic viability risk: Lack of economic viability study of the project and its local context (e.g., regional thermal profile, available facilities). Network-related charges materially affect the viability of local energy systems and have to be evaluated alongside business models.
- Energy price variability: Thin profitability margins, low IRR (internal rate of return) threatened by energy price variability
- Dynamic and inconsistent costs structure: Dynamic and inconsistent costs structure (grid, supply, flexibility incentives) between countries makes it difficult to formulate reusable efficient control strategies, especially in the context of the overall system.
- Demand response limitations: Insufficient economic potential for demand-side flexibility and participation.
- Grid congestion and limits: Grid limits and constraints, such as on new renewable and consumer connections, reinforce the need for grid flexibility and energy storage.

Scalability and deployment challenges

- Pilot-to-scale transition: Technical hurdles in scaling solutions from pilot projects to widespread deployment.
- Technology maturity: Lack of maturity for components needing further development for commercial readiness.
- Performance variability: Inconsistent performance across different storage technologies and operating conditions.

Maintenance and operational complexity

- Lack of specialised expertise: Need for skilled technical personnel to operate and maintain complex systems.
- Remote location challenges: Logistical difficulties in maintenance, spare parts availability, and technical support for isolated or remote sites.

Technical control and aggregation risks

- Aggregated device control: Technical difficulties in managing and controlling distributed devices.
- AI trustworthiness risks: Limited transparency, explainability, potential bias, and unreliable outcomes under stress (e.g., automated trading/smart contracts).

- Systemic risk from algorithmic collusion and oscillations: The adoption of AI-driven EMS and trading platforms (e.g., BSP) operating on the grid could pose a risk of them interacting in ways that may be detrimental to the stability of the system. Examples:
- AI systems may learn to engage in anti-competitive or market-manipulating behaviours, exploiting existing inefficiencies of the market.
    - Different algorithms with potentially conflicting optimisation objectives may lead to undesirable oscillations or even to feedback loops that may cause system failures.
- No resilience – in case of blackout: Energy is unavailable, equipment (mostly) cannot work standalone.

Supply chain and external dependencies

- Supplier reliability: Delays in delivery and shipment issues impacting project timelines.
- Geopolitical and market risks: Supply chain vulnerabilities persist due to geopolitical tensions, raw material dependencies, and market fluctuations.
- Spatial and logistical challenges of energy storage systems: Spatial and logistical challenges due to the size and safety risk of installations (e.g., hydrogen storage).
- Site readiness: Dependencies related to civil engineering works, cabling, and connections, which are delaying storage unit commissioning.
- Theft and vandalism: Physical security risks for infrastructure and equipment.

Societal risks

- Community acceptance: Lack of trust or societal resistance to energy infrastructure projects or change in general. A lack of minimum electricity market knowledge among the community should be addressed to support local implementation and acceptance.

3.1.2 Synthesis of regulatory, processes and policy risks

Lack of legal and regulatory framework risks

- Insufficient legal framework: Lack of clear, comprehensive legal frameworks for EnCs, citizen participation, and distributed energy storage deployment across the EU.
- Regulatory fragmentation: Fragmented and inconsistent regulations across EU member states, complicating market entry and deployment of innovative energy technologies and business models.
- Blockchain legal uncertainty: Evolving legal landscape for blockchain (e.g., GDPR compatibility, right to erasure vs. immutability) requires continuous monitoring.

Cross-border and compliance risks

- National regulatory complexity: Diverse and complex regulatory frameworks across EU member states create deployment challenges and increase compliance costs.

Grid connection and interconnection risks

- Complex and inconsistent grid connection procedures: Lengthy, unclear, and inconsistent grid connection processes create significant regulatory barriers for distributed energy storage, and more specifically, hybrid ones.
- Double grid charges: Energy storage facilities face discriminatory treatment, being charged both as consumers (when storing energy) and generators (when discharging).

Approval and licensing risks

- Lengthy and unclear approval processes: Significant delays in obtaining production licenses and approvals for distributed storage and hybrid renewable energy systems.
- Complex permitting and land-use conflicts: Stringent permitting processes, land-use restrictions (e.g., cultural heritage sites), and technical requirements for building suitability create barriers for project deployment.

Market and revenue uncertainty risks

- Unclear revenue streams: Ambiguity in revenue streams from grid services and energy markets, particularly for EnCs and cooperative models.
- Limited policy support: Insufficient policy support and financial/organisational rules for EnCs and local flexibility business models.
- Market recognition: Insufficient recognition and monetisation of the full value of storage services and flexibility, limiting business case viability.

Data governance and cybersecurity risks

- Data governance and ownership: High compliance burden due to GDPR and national laws for managing personal consumption data; need for secure data exchange and anonymisation.

Market mechanism and flexibility risks

- Lack of market mechanisms: Absence of appropriate market mechanisms for energy storage and local flexibility, including demand response and ancillary services. This is specifically at the national level.
- Lack of products offering flexibility potential: A lack of standardised flexibility products across EU markets.
- Limited balancing market participation: Regulatory barriers preventing optimal participation of energy storage systems in balancing markets, reducing revenue potential. Insufficient recognition and monetisation of the full energy storage services value.

Role and responsibility uncertainty

- Unclear roles and responsibilities: Future market roles, functions, and processes for decentralised flexibility are not yet clearly defined, creating implementation uncertainty.

- DSO neutrality and limitations: DSOs must act as neutral market facilitators without direct consumer contact. However, regulatory updates are needed to support their evolving roles. DSOs' limitation to be remunerated for avoided costs through flexibility, limiting DSO-centric business models.

Safety and technical risks

- Strict safety regulations: Particularly for technologies like hydrogen (H2), which impose additional compliance and operational burdens.

User engagement and social risks

- Need for stronger user engagement: Strategies to ensure adoption and participation in EnCs and flexibility markets are essential.

Business model and investment risks

- Business model adaptation: Local flexibility business models must adapt to current market/regulatory frameworks or require novel arrangements, which may only be viable under broader market uptake.
- Vulnerability to policy shifts: Changes in subsidies, CO_2 pricing, and feed-in tariffs can impact the viability of local energy projects and business models.

3.1.3 Conclusion

The analysis of the selected European projects has enabled the identification of four main types of challenges and barriers:

- Adequate technical solutions,
- Legislation and regulation,
- Social engagement, and
- Adequate market structure.

Some of them are being addressed thanks to the implementation of new European regulations, standards, recommendations, or through increased maturity and technological readiness. However, this list of risks must be taken into account because even if things are changing, they are not always completely resolved, and for sure, are not covering the overall picture (e.g., national level).

3.2 European best practices

Following the synthesis of the technological and regulatory risks identified thanks to the literature review, this section details European best practices related to the following topics: smart districts, data management, energy storage, hybrid storage, and EMS. It especially covers identified strategies for the reduction of risks due to technological weakness and the lack of legislation.

Table 7: Risk and challenges categories

Aspect	Best practices sorted by risks/challenges categories
Technical	• Interoperability and integration risks • Cybersecurity and data protection risks • Grid stability and energy management risks • Data and infrastructure limitations • Cost and economic viability risks • Scalability and deployment challenges • Maintenance and operational complexity • Technical control and aggregation risks • Supply chain and external dependencies • Societal and market risks
Regulatory	• Lack of legal and regulatory framework risks • Cross-border and compliance risks • Grid connection and interconnection risks • Approval and licensing risks • Data governance and cybersecurity risks • Market mechanism and flexibility risks • Role and responsibility uncertainty • Business model and investment risks

3.2.1 Technical best practices

Interoperability and integration risks

- Standardise data & semantics early: Define a Common Information Model (CIM) and establish an interoperability & data-management framework to ensure component/actor interoperability.
- Interoperable and secure data exchange: Bridge the interoperability gaps to avoid increased interoperability and integration risks through the integration of heterogeneous devices and subsystems over multiple protocols/APIs.
- Strategic ecosystem engagement: Alignment with EU initiatives (e.g., GAIA-X, BRIDGE, OMEGA-X, JRC CoC ESA) ensured long-term relevance.
- Gap identification: Identify standardisation gaps and disseminate the findings.
- Structure designs: It is crucial to define a clear architecture (e.g., SGAM-based) and roles (e.g., for aggregation and grid/market services), and to use as much as possible standardised communications.

Cybersecurity and data protection risks

- Data privacy and cybersecurity by design: Consider privacy and cybersecurity considerations and implementation in the early development phase.
- Secure data exchange: Sensitive data and Personal Identifiable Information (PII) must be anonymised before sending and exchanged over secure connections, by adding security/configuration risk. Ingestion clients must be built and operated to extract/anonymise/publish metering data to the cloud platform, creating operational/ICT risk.
- Need for robust measures and controls: Requirement for Role-Based Access Control (RBAC), encryption, secure protocols, breach response plans, and Data Protection Impact Assessments (DPIA).
- Cybersecurity and data privacy watch: These two areas are constantly evolving and must be monitored in order to remain secure.
- Open-source use: Strategic, selective use of open-source middleware with added security.

Grid stability and energy management risks

- Use of a unified flexibility model: For example, the FlexOffer format standardised the description, aggregation, optimisation and trading of flexibility across heterogeneous prosumers.
- EMS - Market Coupling: xEMS (HEMS/FEMS/CEMS/CDEMS) generated FlexOffers for FOA/FM modules and the ATP, enabling automated local flexibility market operation for DSOs.
- Comprehensive monitoring: Real-time system performance monitoring with advanced forecasting and predictive analytics is required.
- Local forecast: Local forecasting is a cornerstone for limiting inaccuracies for energy management and storage optimisation.
- System trustworthiness by design: Consider trustworthiness characteristics (e.g., transparency, explainability, potential bias, and unreliable outcomes) directly in early development phases.

Data and infrastructure limitations

- Digital-twin validation: Use a digital-twin toolchain (single code-base from simulation to hardware-in-the-loop) so algorithms can be tested, validated and deployed quickly, with data stored on a scalable platform. It is especially relevant in the context of hybrid-storage systems, with a multitude of possible configurations depending on the regional, thermal, and energy context.

Cost and economic viability risks

- Economic viability validation: An upstream economic viability assessment is necessary to ensure the potential, relevance, and structure of a project. This is particularly the case with purchasing storage systems, as the initial cost is very high.
- Standardise costs: Standardise cost structure parameters (grid charges, supplier tariffs, surcharges, incentives) across the EU space.

- Local, thermal, cultural flexibility: Hybrid storage design ensures technical and economic flexibility. It is also highly relevant to adapt the structure and strategies of the systems to the regional and thermal context.
- Existing infrastructure reuse: Repurpose existing plant infrastructure to cut costs and speed deployment of hybrid storage while keeping grid stability/security of supply.
- Cost-effective use: Prioritise cost-effective use of existing appliances (thermal flexibility).
- Revenue diversification: Development of multiple revenue streams through various grid services and market participations.
- Life cycle assessment: Evaluate holistically and feed back into design: run impact assessment and cost–benefit analysis (incl. user-experience) after each roll-out phase to prioritise what works.

Scalability and deployment challenges

- Modular design approach: Use and implementation of modular system designs allowing for scalability and technology upgrades, service-oriented architecture for adaptability. For example, modular EMS architecture supports wide replication across islands which do not have the same constraints and strengths
- Build bottom-up EnCs: community clusters can be economically beneficial and accelerate transition, but designs must adapt to differing national regulatory and social contexts.
- Transfer methodology: Creation of standardised approaches (e.g., technologies, processes, governance, user engagement, business models) for replicating successful projects or architecture in similar contexts.
- Real-world validation: Multi-country deployment in operational grids, controlled loads and offering flexibility. Actual deployment in the operational grid provides crucial validation data and feedback.

Maintenance and operational complexity

- Personnel training: The deployment and maintenance of EnCs (including hybrid-storage and EMS) requires specialised expertise, which is very rare on the employment market.

- Define PMV early: establish a Performance Measurement & Verification (PMV) methodology and baselines up front to monitor post-intervention impact consistently.

Technical control and aggregation risks

- Short-term storage prioritisation: Prioritise short-term batteries, smart EV charging/sharing, and intelligent control of hot-water/heat buffers to cut grid imports and emissions. Seasonal storage is presently infeasible or marginal.

Supply chain and external dependencies

- Sufficient site preparation: Do thorough site-prep up front (site visits, environmental assessments, digging/cabling, electrical & heat connections) to de-risk installation/commissioning.

- Anticipate compliance, availability and integration risks: Plan for hardware conformity and supplier-readiness risks (e.g., inverter non-compliance requiring an exemption path, delivery delays). Keep redesign options available (e.g., control-interface redesign) to unlock integration.

User engagement and social risks

- Early stakeholder engagement: Establishing continuous engagement with regulatory authorities, grid operators, and local communities
- Industry-Academia Partnership: Strong collaboration between research institutions and industry partners is essential.
- Intuitive interface and user feedback: End-user engagement and intuitive interfaces are essential. User-friendly, non-intrusive dashboard design.
- Integrate residential assets for citizen value: Monitor and deliver measurable bill savings and CO_2 reductions to the stakeholders (e.g., citizens).
- Foster collaboration: Multi-stakeholder collaboration is key to success.

3.2.2 Regulatory and policy best practices

Lack of legal and regulatory framework risks

- Regulation watch: Ensure a regulation watch to detect when certain regulatory constraints will be overcome. But also, for regulatory uncertainty from incomplete transposition of new EU energy directives (mismatch between legacy rules and what's needed for local energy systems; conditions for EnCs not yet settled).
- Regulatory gaps identification: Identifying gaps is an efficient way to support the Commission and change things. It is important to ensure an efficient dissemination of the findings.
- Barriers priority: Addressing social, regulatory, and economic barriers is as important as technical development.

Cross-border and compliance risks

- Maintain a standardisation punch-list: derive grid-integration and standardisation recommendations after each roll-out phase to align with evolving codes and practice.

Grid connection and interconnection risks

- Maintain continuous, early dialogue with regulators and the DSO to secure grid-connection and environmental approvals (and any needed exemptions).
- Flexible Approach: Adaptability to address emerging technical and regulatory challenges

Approval and licensing risks

- Permit and validation anticipation: Anticipate permits and space constraints for street-level equipment, and start municipal approvals early.

Data governance and cybersecurity risks

- GDPR compliance: Ensure contracts and automations respect GDPR.
- Human oversight: keep a human-in-the-loop for automated decisions affecting data subjects.

Market mechanism and flexibility risks

- Local flexibility market creation: Support the creation of Flexibility markets at local/regional level.

Role and responsibility uncertainty

- New market roles clear definition: Define clear future market roles, functions and processes for decentralised flexibility, avoiding implementation uncertainty.
- Allow DSO-centric business models: Allow, for example, DSOs to be remunerated for avoided costs through flexibility.

Business model and investment risks

- Business model adaptation: Local flexibility business models must adapt to current market/regulatory frameworks or require novel arrangements, which may only be viable under broader market uptake.
- Support deployment: A regulation of flexibility would support investment for actors driving deployment.
- Link the industry with business/regulation: define business models early, reassess them with pilot evidence and network-charge impacts, and issue policy/market reform recommendations.
- Policy recommendations: Policy evolution is critical to unlock the economic value of flexibility (e.g., residential).

3.2.3 European recommendations on energy storage

This section maps the risks and challenges identified in the studied European projects in section 2.2 and the recommendations on energy storage made by the European Commission in [34] and studied in section 0.

Table 8: Mapping between the EU Commission recommendations and challenges identified in the study

Risks/Challenges identified in studied EU projects	EU Commission recommendation
• Double grid charges: Energy storage facilities face discriminatory treatment, being charged both as consumers (when storing energy) and generators (when discharging).	1) To consider the double role (generator-consumer) of energy storage when defining applicable regulatory framework and procedures.
• Grid congestion and limits: Grid limits and constraints like on new renewable and consumer connections, reinforcing the need for grid flexibility and energy storage.	2) To identify the flexibility needs of their energy systems in the short, medium and long term.

• DSO neutrality and limitations: DSOs must act as neutral market facilitators without direct consumer contact. However, regulatory updates are needed to support their evolving roles. DSOs' limitation to be remunerated for avoided costs through flexibility, limiting DSO-centric business models.	3) To ensure that energy system operators further assess the flexibility needs of their energy systems when planning transmission and distribution networks, including the potential of energy storage and whether energy storage can be a more cost-effective alternative to grid investments.
• Support deployment: A regulation of flexibility would support investment for actors driving deployment. • High (initial) costs: Elevated upfront costs for storage solutions compared to conventional grid options.	4) To identify potential financing gaps for energy storage, including behind-the-meter and other flexibility instruments, and if a need for additional flexible resources to achieve security of supply and environmental objectives is identified
• Demand response limitations: Insufficient economic potential for demand-side flexibility and participation. • Unclear revenue streams: Ambiguity in revenue streams from grid services and energy markets, particularly for EnCs and cooperative models. • Limited policy support: Insufficient policy support and financial/organisational rules for EnCs and local flexibility business models. • Market recognition: Insufficient recognition and monetisation of the full value of storage services and flexibility, limiting business case viability.	5) To explore whether energy storage services are sufficiently remunerated, and whether operators can add up the remuneration of several services.
• Lack of market mechanisms: Absence of appropriate market mechanisms for energy storage and local flexibility, including demand response and ancillary services. This is specifically at the national level.	6) To consider competitive bidding processes to reach a sufficient level of flexibility source deployment.
• Insufficient legal framework: Lack of clear, comprehensive legal frameworks for EnCs, citizen participation, and distributed energy storage deployment across the EU. • Regulatory fragmentation: Fragmented and inconsistent regulations across EU member states, complicating market entry and deployment of innovative energy technologies and business models. • Limited balancing market participation: Regulatory barriers preventing optimal participation of	7) To identify any specific actions, regulatory and non-regulatory, necessary to remove barriers to the deployment of demand response and behind-the-meter storage.

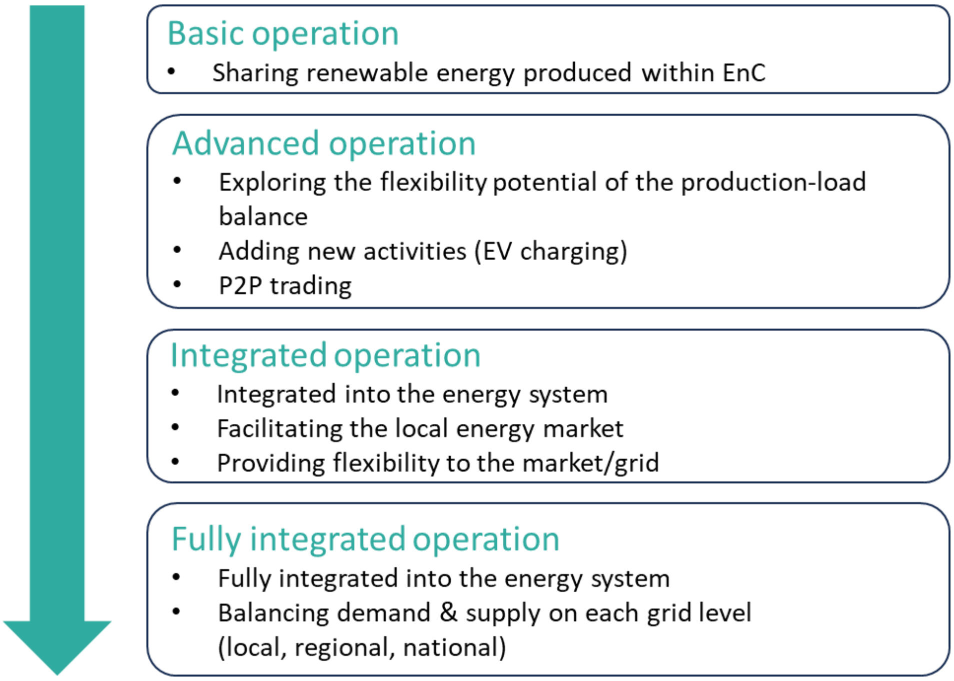
energy storage systems in balancing markets, reducing revenue potential. Insufficient recognition and monetisation of the full energy storage services value. ● Unclear roles and responsibilities: Future market roles, functions, and processes for decentralised flexibility are not yet clearly defined, creating implementation uncertainty.	
● Grid congestion and limits: Grid limits and constraints, such as on new renewable and consumer connections, reinforce the need for grid flexibility and energy storage.	8) To accelerate the deployment of storage facilities and other flexibility tools in areas with insufficient grid capacity, unstable or long-distance connections to the main grid.
● Demand response limitations: Insufficient potential for demand-side flexibility and participation. ● Grid congestion and limits: Grid limits and constraints, such as on new renewable and consumer connections, reinforce the need for grid flexibility and energy storage.	9) To publish more real-time and detailed data to facilitate investment decisions on energy storage facilities (e.g., network congestion, market prices, installed energy storage facilities).
● Pilot-to-scale transition: Technical hurdles in scaling solutions from pilot projects to widespread deployment. ● Technology maturity: Lack of maturity for components needing further development for commercial readiness. ● Performance variability: Inconsistent performance across different storage technologies and operating conditions.	10) To continue supporting research and innovation in energy storage, as well as guiding these technologies and products to the commercialisation stage.

This table clearly illustrates the importance of identifying and sharing challenges and best practices in projects, as these are analysed after review to inform European policy.

3.3 EnCs roadmap and recommendations on innovation and research activities

This section focuses on EnCs and the associated roadmaps for their development and market launch.

The development of an EnC is described in [36] as a four-stage process, as shown by Figure 11. This figure describes an EnC implementation roadmap which has the objective to ensure convergence of R&D results and to enable the development of fully integrated EnCs.



Basic operation

- Sharing renewable energy produced within EnC

Advanced operation

- Exploring the flexibility potential of the production-load balance
- Adding new activities (EV charging)
- P2P trading

Integrated operation

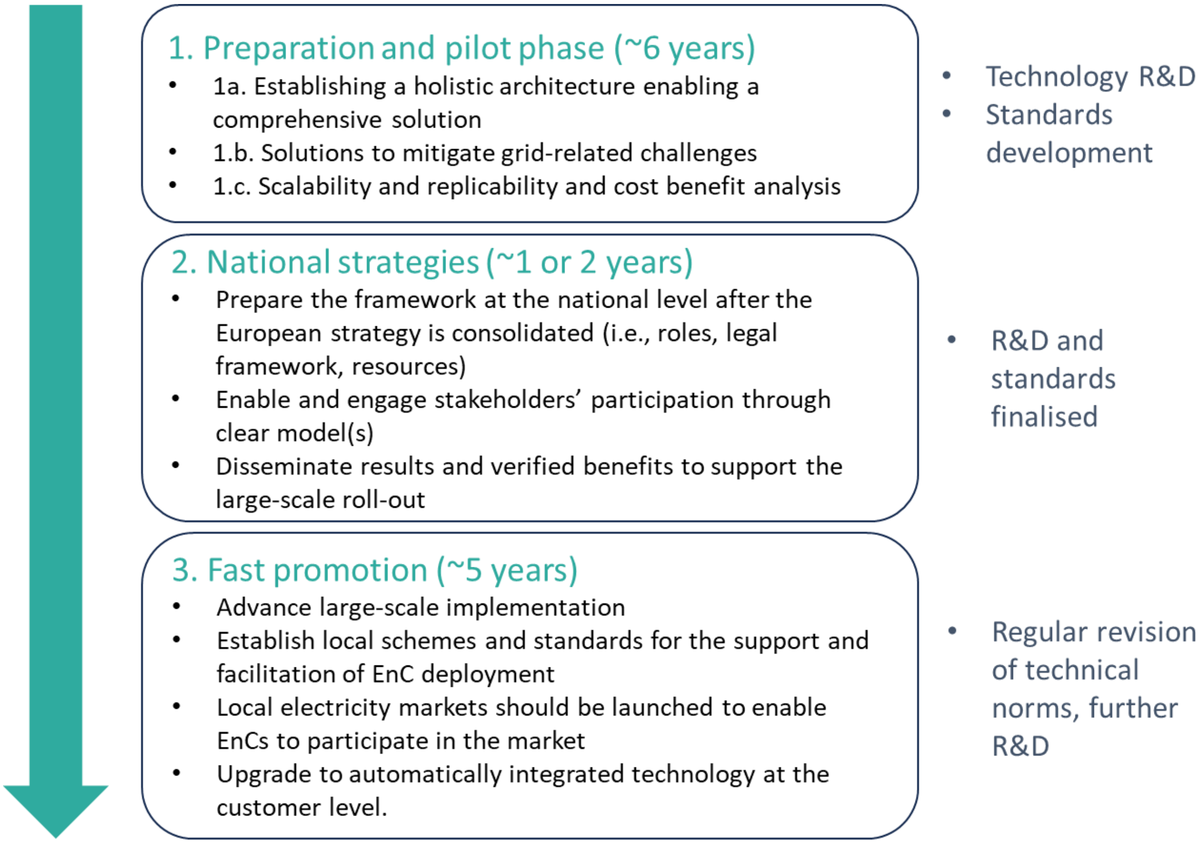
- Integrated into the energy system
- Facilitating the local energy market
- Providing flexibility to the market/grid

Fully integrated operation

- Fully integrated into the energy system
- Balancing demand & supply on each grid level (local, regional, national)

Figure 11: EnC development and implementation phased

To ensure the convergence of R&D results and facilitate the development of fully integrated EnCs the ETIP SNEP report [36] has identified a roadmap in three main phases.



1. Preparation and pilot phase (~6 years)

- 1a. Establishing a holistic architecture enabling a comprehensive solution
- 1.b. Solutions to mitigate grid-related challenges
- 1.c. Scalability and replicability and cost benefit analysis

- Technology R&D
- Standards development

2. National strategies (~1 or 2 years)

- Prepare the framework at the national level after the European strategy is consolidated (i.e., roles, legal framework, resources)
- Enable and engage stakeholders' participation through clear model(s)
- Disseminate results and verified benefits to support the large-scale roll-out

- R&D and standards finalised

3. Fast promotion (~5 years)

- Advance large-scale implementation
- Establish local schemes and standards for the support and facilitation of EnC deployment
- Local electricity markets should be launched to enable EnCs to participate in the market
- Upgrade to automatically integrated technology at the customer level.

- Regular revision of technical norms, further R&D

Figure 12: EnC market introduction roadmap

The above diagram presents a phased roadmap for moving from concept to large-scale, fully integrated EnCs. It begins with a six-year "Preparation and Pilot Phase" to define and test a holistic architecture, adapt EU-level regulation and market rules (including standards for local market creation and transparent integration rules), address all grid challenges, and launch fully integrated pilot communities. The next step is "National Strategies" over one to two years to finalise roles and structures, secure the legal framework and resources, complete technology and standards, and build participation models and capacity with trusted intermediaries. The third step is a five-year "Fast Promotion" phase to accelerate large-scale deployment through local support schemes and standards, the launch of local electricity markets, periodic updates of technical norms and R&D, and broad stakeholder engagement and dissemination to support roll-out.

4 Conclusion

The PARMENIDES project has conducted a comprehensive literature review of a selection of 16 EU projects to better understand the challenges, risks, and best practices around EnCs, energy storage, and EMS. Beyond that, it aims to support the introduction of PARMENIDES results on the EU market, as well as other European products market introduction, EnCs development, and EU initiatives (e.g., BRIDGE). To consolidate this overview, reports from the European Commission, ETIP SNET, EASE and EnTEC were selected. This analysis offers valuable insights into technical, regulatory, and policy risks, as well as the most effective strategies identified across Europe. It highlights development and deployment roadmaps for EnCs. The findings emphasise, for example, the need for standardised and interoperability frameworks, complete regulatory frameworks, policy support, modular and scalable design, economic viability, cross-sector collaboration, and adaptive policies to accelerate the transition toward a sustainable and resilient energy system. This document serves as a strategic resource for stakeholders, guiding future research and innovation.

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Annex

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PARMENIDES

Plug&plAy eneRgy ManagEmeNt for hybrID
Energy Storage