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Battery Energy Storage Systems to support the large-scale integration of renewable energy

Case study #3

July - 2022

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1. Battery Energy Storage Systems supplying clean, affordable and secure energy

1.1 Context

Battery Energy Storage Systems (BESS) are used to store electrical energy as chemical energy in the short term. Typical uses include storing solar energy produced during the day for a delayed use at night or improving quality of supply of electricity at the end of a low voltage feeder or for frequency regulation.

According to a joint study published in September 2020 by the European Patent Office (EPO) and the International Energy Agency (IEA), between 2005 and 2018, patenting activity in batteries and other electricity storage technologies have grown at an average annual rate of 14% worldwide, four times faster than the average of all technology fields. The report, *Innovation in batteries and electricity storage – a global analysis based on patent data*[1], shows that batteries account for nearly 90% of all patenting activity in the area of electricity storage, and that the rise in innovation is chiefly driven by advances in rechargeable lithium-ion batteries, among the variety of battery technologies.

Indeed, lithium-ion batteries are increasingly used for non-stationary and stationary energy storage applications in particular in short-duration applications (below 4-6 hours) such as hourly balancing, peak shaving and ancillary services. They even have reached a market share of 90% for stationary electricity storage (if uninterrupted power supply batteries are not counted).[2] Other competing technologies not using critical raw materials are entering the market such as redox-flow batteries, sodium-ion or molten-salt batteries, with the possibility of increasing sustainability and value chain security.

Regarding the capacity installed, the European annual energy storage market (other than pumped hydro) grew from 0.6 GWh in 2015 to 1.7 GWh in 2020, with a cumulative installed base of 5.4 GWh across all segments[3].

According to the European Commission's Competitiveness Progress Report and its underpinning analysis on the clean energy technologies, grid scale applications of batteries will be approaching, by 2030, the importance of pumped hydropower (PHS) in EU stationary storage in terms of energy throughput. By 2050, batteries will cover close to half of the total need for storage within the EU energy system (more than 100 TWh annually), bypassing the currently dominant pumped hydro storage technology. The table below provides the foreseen capacity installed for stationary batteries and PHS[4].

Table 1: Storage capacity installed

Storage technology	Capacity installed by 2030	Capacity installed by 2050
Stationary batteries	40 GW	100 GW
Pumped Hydropower	64 GW	≥ 64 GW (limited further increase)

[1] Innovation in batteries and electricity storage – a global analysis based on patent data, IEA, September 2020.
[2] Energy Storage News (Andy Colthorpe), China's energy storage deployments for first nine months of 2020 up 157% yearon-year, 2020.
[3] EASE, EMMES 5.0 market data and forecasts - electrical energy storage, 2021.
[4] Commission staff working document Part4/5 Progress on competitiveness of clean energy technologies, 6&7 Batteries and Hydrogen electrolysers.

1.2 Benefits

Maturity, ease of implementation, declining costs and high-density characteristics of BESS enable a wide spectrum of uses for the distribution grid - supporting local weak grids or further integration of intermittent renewable generation and sustaining continuity of electric supply and for the demand by increasing local self-consumption (individuals or communities). Various configurations could be implemented for the full decentralised scheme with unit batteries at the end-user site to neighbourhood-or district-scale systems, or larger storage systems for security of supply and blackout avoidance.

Furthermore, research is ongoing on novel materials, interfaces for performance enhancement, cell design and smarter manufacturing processes, integration of smart functionalities for better monitoring of batteries parameters during cycling or new self-healing features. Looking at large-scale stationary battery projects, one should note that new capacities are entering into operation or planned in the context of renewable energy auctions, frequency response or balancing services for Transmission System Operators.

1.3 Pending challenges

When considering BESS application at the system operator or at the end user side, the above benefits have to be faced with challenges, most of them being non-technical. Indeed, both in terms of deployment and performance, energy storage is currently not on track to achieve the levels called in the IEA's Sustainable Development Scenario.

The deployment of BESS faces major challenges. When it comes to non-technological points, the following challenges can be outlined:

- Reducing battery energy system costs to half the current price is key for mass deployment (BESS price being disproportionally high comparing with automotive batteries)[5];
- Lack of standardised market platform to ease the participation of new players in the power system;
- Lack of expertise in optimal sizing and operation protocols enabling a strong coordination between RES generation and storage, considering the local energy context;
- Lack of storage-related local regulation ruling the ownership and modalities of use by a regulated actor, as well as lack of market incentives to operate such installations to provide grid flexibility;

The next pages illustrate how a selection of BRIDGE projects contribute to tackling these issues.

[5] Progress on the competitiveness of clean energy technologies, European Commission, 2021.

2. Setting up the conditions to BESS deployments

BRIDGE projects show that batteries provide a multitude of services to all market participants (service to consumers, distribution and transmission systems, renewable generation, conventional generation) and to a wide scale of systems (cross-border to building scale).

This case study focuses on three main building blocks that are investigated by a selection of H2020 funded projects dealing with BESS and renewable energy integration:

- **Knowledge for design and operation of Battery Energy Storage Systems** delivering ultra-high performance, beyond today's capabilities. This block includes methodologies for optimal sizing considering ageing, value of stored energy, available capacity, and efficiency.
- **BESS applications supporting the power system with increasing RES.** BRIDGE demonstrations enable to implement real-life tests and thus contributing to batteries' deployment (more flexible supply of renewables, peak shaving, arbitrage, frequency control, congestion management, etc.)
- **Market Design & regulatory framework** maximising BESS value. This block details how business models, market structures and incentives as well as regulatory adjustments could facilitate the implementation and operation of storage installations.

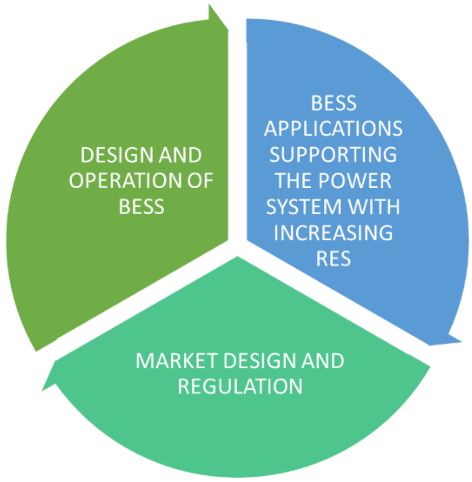


Figure 1: The three building blocks to explore BESS potential

The case study proposed focuses on seven H2020 projects that address those buildings blocks complementarily. One should note that H2020 smart energy system calls are technology neutral, even battery use as such is not prescribed and even less the use of specific chemistry. The following table gives an overview of the projects' objective, how they are addressing the battery integration in the energy system and the system level addressed, in which building blocks of the case study they are contributing to and the features of the batteries used[6].

[6] According to European Standard EN 50160 Low voltage (lower than 1kV), Medium Voltage (between 1kV to 35 kV), High Voltage (above 35 kV)

Table 2: Overview of the 7 BRIDGE projects considered in the case study

flexitranstore

Project overarching objective

FLEXITRANSTORE demonstrates capabilities of BESS to provide flexibility services and develops a new wholesale market infrastructure enabling increased cross-border flows.

How FLEXITRANSTORE addresses the battery integration in the energy system?

Transmission level - Interactions with distribution level and generation

The project looked at the coordination of frequency responses of BESS and Under-Frequency Load Shedding scheme. This is done through a modulation technique to handle conflict of controllers. FLEXITRANSTORE project develops a flexibility-oriented day-ahead market model, demonstrating how a system can cope with renewable sources with no incentive in the presence of storage.

Building blocks addressed

APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES

MARKET DESIGN AND REGULATION

Features of the batteries used in the project (demonstration site)

Demo site	Techno	MW/MWh	Voltage
Cyprus	Li-ion	1/2	High
Greece	Li-ion	4/2	Low
Belgium & France	Lead	10/2,5	Medium

- The project looked also at combination of RES with PHS

EU-SysFlex

Project overarching objective

EU-SYSFLEX develops a flexibility roadmap to support the implementation of cost-effective solutions. Its demonstrators include industrial-scale battery energy storage systems as well as customer-scale batteries.

How EU-SYSFLEX addresses the battery integration in the energy system?

Transmission level - Interactions with distribution level and generation

EU-SysFLex proposes a multi-service provision through aggregation of different assets. The demonstrations aggregate and coordinate various flexibilities connected to the distribution network at low and medium voltage to manage active and reactive power and deliver services to the system. The project demonstrations and trials have successfully developed a variety of decision support tools to improve the capabilities and performance of operators/aggregators in forecasting, estimation, and optimisation as well as tools for a closer coordination between TSO-DSO and between TSO-retailer-BESS interfaces. The project looked at industrial-scale BESS, customer and office scale batteries, electric vehicle charging systems and residential electricity storage heating loads.

Building blocks addressed

APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES

Features of the batteries used in the project (demonstration site)

Demo site	Techno	MW/MWh	Voltage

• Finland	• Li-ion	• 1,2/0,6	• Medium
• France	• Li-ion	• 2/3	• Low & Medium

Project overarching objective

CROSSBOW proposes a shared use of resources to foster cross-border management of variable RES and storage units. Thus, it enables a higher clean energies penetration whilst reducing network operation costs and improving economic benefits of RES and storage units.

How CROSSBOW addresses the battery integration in the energy system?

Transmission level – Cross-border aspects

Among others, CROSSBOW investigates what combination of storage technologies is needed to tackle the challenges of variable RES integration. CROSSBOW proposes a solution in a form of hybrid ESS to tackle the frequency support of a modern power network with a high penetration of RES.
Furthermore, the project offers optimisation algorithm to support decision making e.g. for Virtual Storage Plants. The project tests regional storage coordination centres to support grid stability at regional level. These centres link geographically dispersed small storage units (such as residential units) using a variety of technologies.

The CROSSBOW project has been acknowledged for its 9 innovative products by the European Commission's Innovation Radar under the Innovation Topic "Smart & Sustainable Society".

Building blocks addressed

DESIGN AND OPERATION OF BESS | APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES | MARKET DESIGN AND REGULATION

Features of the batteries used in the project (demo, trials and simulations)

Demo site	Techno	kW/kWh	Voltage
• SGLab UNIZG (VSP)	• Li-ion	• 1 x 2.5/6.5 & 2 x 18/18	• Low
• Dalarma (SE)	• Li-ion	• 5000/6200	• High
• Kraftwerksgruppe Pfriemd (DE)	• Li-ion	• 12500/2600	• Medium
• SOLAR SAT	• Vanadium	• 3.3/18	• Low

- The project examined combinations with hydropower plants and water supply systems, as well as redox batteries, commonly considered as one of the most promising solutions.

Project overarching objective

OSMOSE investigates the optimal mix of flexibilities with a focus on the transmission grid, through four TSO-led demonstrations.

How OSMOSE addresses the battery integration in the energy system?

Transmission level - Interactions with distribution level and generation

OSMOSE looked at how precision in RES forecasting helps with optimum sizing of a storage system (in a demo, 50% improvement of forecast had 15% impact on sizing of the system). It also offers advanced controls and hybrid flexibility device (close to commercialisation), which includes Li-ion batteries, supercaps and statcom.

Building blocks addressed

DESIGN AND OPERATION OF BESS | APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES | MARKET DESIGN AND REGULATION

Features of the batteries used in the project (demonstration site)

Demo site	Techno	kW/kWh	Voltage
EPFL campus	Li-Titane	720/560	Medium
CENER facilities (Spain)	Li-ion	2000/500	Medium
	Li-ion	30/43	Medium
	Lead	50/10	Medium
	Vanadium	50/200	Medium

Project overarching objective

INSULAE aims to demonstrate RES-based power systems in geographic islands with full systems approach that augments synergies achieving lower operating costs with high-RES penetration

How INSULAE addresses the battery integration in the energy system?

Geographic islands level

INSULAE couples BESS flexibility with flexibility of transport, heating and water. The project reflected on issue as to when it is better to go for a minimum BESS and repower the system afterwards, as capacity fades or storage need increases, and when it is better to oversize the storage system from the outset. Cost reduction curve for BESS plays a role here.

Building blocks addressed

DESIGN AND OPERATION OF BESS | APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES | MARKET DESIGN AND REGULATION

insulae
Maximizing the impact of innovative energy approaches in the EU islands

Features of the batteries used in the project (demonstration site)

Demo site	Techno	kW/kWh	Voltage
Madeira	Li-ion	100/100	Low
Unije	tbc	tbc	High
Bornholm	LiFePO4	624/312 or 936/312	Low

Project overarching objective

MERLON introduces an integrated modular local energy management framework for the holistic operational optimisation of local energy systems in presence of high shares of volatile distributed renewable energy sources.

How MERLON addresses the battery integration in the energy system?

Local Energy Systems

MERLON proposes an integrated BESS management module and a multi-vector optimisation software to support high-level design of renewable energy communities. The sizing/ageing BESS model can be employed by BESS investors.

The project also looks at combination with thermal storage.

Building blocks addressed

DESIGN AND OPERATION OF BESS | APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES | MARKET DESIGN AND REGULATION

MERLON

Renaissance
RENEWABLE INTEGRATION & SUSTAINABILITY IN ENERGY COMMUNITIES

Project overarching objective

RENAISSANCE aims to demonstrate highly replicable design and management approaches for integrated local energy systems, that achieve high participation of local consumers, exceed at local level EU targets for renewable energy sources while decreasing the energy price for community members

How RENAISSANCE addresses the battery integration in the energy system?

Local Energy Systems

RENAISSANCE offers CO_2 assessment tool to help with choice between different storage devices. The tool allows to select between different types of technologies namely LFP, NMC, Na-ion, VRFB and lead acid batteries.
The project also looks at Storage-as-a-service business model.

Building blocks addressed

- DESIGN AND OPERATION OF BESS
- APPLICATIONS SUPPORTING THE POWER SYSTEM WITH INCREASING RES
- MARKET DESIGN AND REGULATION

Features of the batteries used in the project (demonstration site)

Demo site	Techno	kW/kWh	Voltage
• Manzadena	• Li-Manganese Oxide	• 20 kWh	• Low

- The project also looks at combination with thermal storage

3. KEY TAKE AWAYS: facts & figures

3.1 Knowledge for design and operation

Regarding Knowledge for design and operation, OSMOSE, MERLON, INSULAE, CROSSBOW and RENAISSANCE projects brought the following:

- Simulation-based sensitivity analysis and tools facilitate fast design of BESS in multiple applications
- Data sharing and analytics tools substitute specific testing for BESS predictive maintenance

Knowledge for design and operation	
Control strategy	Different control strategies may lead to a different optimal BESS size: it is therefore recommended to **clearly define the control strategy before determining the optimal size.** [**OSMOSE**, D7.1]
15 % size reduction	Improving RES power production forecast quality by 50% induced **a difference of 15% of the sizing indicator value** in one of the application cases studied in the OSMOSE project. [**OSMOSE** D7.1]
Data platform	**OSMOSE** developed a dedicated **platform to collect, store and share measurements data from on-field ESS,** coupled **with data analytics to support BESS operation** through diagnostic and prognostic analyses, performance evaluation and control improvements. The data analytics tools integrate a novel method along with a strategy to identify the factors impacting the ageing processes[7]. [OSMOSE D.7.7, 2021]
Sizing/ageing model	**MERLON** proposed a multi-vector optimisation software to support the optimal high-level design of renewable energy communities at any location worldwide. **The sizing/ageing model** can be employed by BESS investors to minimise the system lifetime costs and maximise reliability. [MERLON, D6.1]
15 years lifetime	The optimal capacity of the BESS increases, and the power rating decreases when the BESS lifetime is increased. The application of MERLON's model shows that for an anticipated 15 years of Li-ion battery lifetime, the optimal configuration of BESS operation for the Güssing distribution network (Austria) leads to an energy capacity of 295 kWh with 533 kW use at maximal capacity when energy prices were attractive [**MERLON**, D6.1 & Project coordinator, 2021].
Lessons learnt	The conceptual design of the **INSULAE** Unije BESS was constrained by the CAPEX. The project recommends considering a **careful balance between initial system over-sizing and repowering in future years** given the projected cost decline curve for a specific chemistry. [INSULAE, D4.2, 2021]
CO_2 modelling tool	The multi-vector optimisation software developed by the **RENAISSANCE** project allows to choose between different types of battery technologies to **assess the impact on CO_2 emission** of a particular system configuration. An online user-friendly version of the tool will be made available to the public via the RENAISSANCE website. [Project coordinator, 2021]

[7] The method is validated by using real-time measurements of the utility-scale 720 kVA/560 kWh BESS on OSMOSE WP3 demonstrator in Switzerland, while operating it to provide various grid-support

⇨ To learn more on the respective projects' achievements with regard to the above facts and figures, read the section 4.

3.2 BESS applications supporting the power system with increasing RES

Regarding BESS applications supporting the power system with increasing RES, FLEXITRANSTORE, EU-SysFlex, INSULAE, MERLON, CROSSBOW, OSMOSE, RENAISSANCE brought the following:

- Battery Energy Storage Systems have demonstrated ability to provide system services in various contexts
- Battery Energy Storage Systems support increased cross-border flows at TSO/DSO and regional interfaces
- The facilitator role of BESS in micro- or weak grids is assessed
- Advanced control systems enable an efficient operation of hybrid energy systems (BESS + RES generation)
- Local battery energy storage system could provide increased flexibility to energy communities
- Storage as a Service is demonstrated in combination with other distributed energy resources
- Battery Energy Storage systems offer grid forming capabilities on top of other services

BESS applications supporting the power system with increasing RES	
☑ **Active Distribution Node**	**FLEXITRANSTORE** shows how the installation of a 1MW / 2MWh BESS at the TSO/DSO interface can enable an Active Distribution Node to accelerate RES integration and increase cross-border flows from a market and system perspective. [FLEXITRANSTORE, project newsletter June 2020]
☑ **Handling Conflict of Controllers**	Coordination of frequency responses of BESS and Under-Frequency Load Shedding scheme are essential. In this respect, **FLEXITRANSTORE** demonstrates that a controller or modulation technique through a gain tuning approach appears to be an effective tool to handle conflict of controllers.
☑ **Profit for flexibility service provider**	KPI results obtained in real environment for the frequency containment reserve for normal operation (FCR-N) show how respective value correlate to the BESS size. Or **FLEXITRANSTORE** Industrial-scale BESS it has been shown that the asset was usable at 94.8%, with profits of service provision of 22k€ (2k€/month with high yearly variation). [EU-SysFlex, D6.9, 2021]
☑ **Hybrid flexibility devices**	A modular hybrid flexibility device including a new lithium-ion battery, super-capacitors and STATCOM, all of them coordinated by a master control system, in order to provide multiple grid stability and security services was validated in the **OSMOSE** Spanish demonstrator. This innovative combination is already commercialised by the manufacturer. [project website and newsletter, 2021]
☑ **Grid forming**	**OSMOSE** demonstrated a three-layer BESS control strategy from day ahead to real-time optimisation of the provision of multiple grid services (such as voltage and frequency regulation and dispatch tracking), under uncertainties. The demo was implemented on a 720kW/560kWh connected to a 20 kV distribution feeder on the EPFL campus hosting also stochastic loads and PV generation.

Multi-services provision	Two demonstrations of **EU-SysFlex** (FR, FI) validated experimentally the concept of **multi-resources aggregation for multi-services provision**. This improves the performance and reliability of services procured by RES in combination with energy storage: in particular, the efficiency of distributed batteries on ancillary services provision to the frequency containment reserve market. [EU-SysFlex]
Virtual Storage Plant	**CROSSBOW** proposes Virtual Storage Plant (VSP), **providing a distributed solution for the utilisation of the storage units of small capacity.** It solves the problem that such storage units are not permitted to participate in the ancillary service markets. It aggregates the storage units of different capacities (which are not big enough) and different types, which can be operated equivalently as a large, centralised storage plant. The VSP exploits advanced optimisation-based distributed control techniques **to maximise the technical benefits** provided by available distributed storage units **and reduce additional costs** stemming from non-optimal usage
Manager Energy for Hybrid Plants	**CROSSBOW's** Hybrid RES Dispatchable Units product (RES-DU) has a high flexibility, allowing to adapt Hybrid Power Plants (i.e. RES + storage) configuration to the most updated technology configuration. A relevant number of parameters allow to configure each technology in the **Manager Energy for Hybrid Plants (ME4HP) developed by the project, which is one of the main algorithms in charge of the optimised power production profile calculation for the hybrid power plant**. Consequently, technology evolution would not be a limitation for the scalability purposes, at least in the coming years. [Deliverable D16.4, D13.3]
Battery Management Module	**MERLON** project develops a **Battery Management Module** responsible for monitoring and controlling all sub-systems at the battery plant in combination with monitoring local energy system network parameters in terms of applying scheduling and optimisation strategies [Project coordinator, 2021].
Storage as a Service	**RENAISSANCE** : One of the project demonstrations (Manzadena ski resort in Spain) aims in particular to analyse and validate a **Storage as a Service business model** in combination with PV energy self-consumption and Demand Side Management strategies. [Project coordinator, 2021]
Stabilisation of weak & micro grids	The role of storage in stabilisation of weak grids and micrograds will be demonstrated by **INSULAE** project through the installation of a BESS in low-voltage substations to store the surplus of energy generated during off-peak hours. Providing a safe and guaranteed energy suppluy will open the doors to new business opportunities: revenue streams are foreseen from DSOs for the ancillary services to a weak low voltage microgrid as well as revenues from end users / consumers / prosumers paying for the value generated by a service providing stabilisation of weak microgrids.
Transition to DC grids	In **INSULAE**, the Bornholm Island demonstration explores transition to DC grids in an island context, implying network cost reduction and increased energy efficiency and more flexible use of batteries in the grid (charging time)..

⇨ To learn more on the respective projects' achievements with regard to the above facts and figures, read the section 5.

3.3 Market design and regulatory framework

Regarding market design and regulatory framework, OSMOSE, MERLON, RENAISSANCE and CROSSBOW projects brought the following:

- Various business model types are proposed for large-scale applications according to the BESS operator
- Energy storage profitability is improved when combining energy market value and facilitation value for the power system
- Solutions to organise the energy storage capacity market are proposed for experimentation
- Optimisation strategies are based on anticipation-type heuristics for operating BESS
- Market platforms constitute a core tool to offer and trade BESS-supported services

Market design and regulatory framework	
Profitability of multi-resources aggregation for multi-services provision	**EU-SysFlex** shows that aggregating several decentralised resources, e.g. wind turbines, energy storage, electric vehicles, heat pumps, including as part of a virtual power plant (VPP), and using a combination of coordinated controls and optimisation, **can greatly enhance** the overall reliability, performance and **profitability of the system services provided (covering investment and operating costs).** [EU-SysFlex brochure]
Market based integration of distributed resources in transmission system operation	The objective of the **EU-SysFlex** Finnish demonstrator was to increase the use of market-based concepts and virtual power plants to support the operation of transmission and distribution networks. The innovative aspect was to **integrate small distributed flexible assets (such as medium scale BESS of 0.1 MW and residential scale BESS of 40 kW) on the medium and low voltage grid to aggregation processes**. EU-SysFlex provides the technical proof of concept for a new market mechanism to manage reactive power at the TSO/DSO connection point. The Finnish demonstration has shown a strong case for scalability and replicability for industrial-scale BESS, with new developed IoT platform and optimisation tools. Multi-use of both industrial and office scale BESS when possible is strongly advised, along the development of ancillary market rules. [EU-SysFlex D6.9, 2021]
Optimisation algorithm	**CROSSBOW** proposes a **multi-service optimisation algorithm** to support the decision-making process of energy storage players (such as Virtual Storage Platform) in electricity markets. The developed algorithm considers a single Virtual Storage Plant (CSP) which optimises the provision of multiple services across different segments of the electricity market. In particular, the set of services includes price arbitrage opportunities in energy markets and provision of balancing services. [Deliverable D7.3, 2020]
Remuneration	**CROSSBOW** concludes that VSPs could merge two business models (provision of network services and market participation) at the same time, if a proper regulation is in place, to obtain full economic value. The project considers that the key players for storage penetration should be national regulators who should **determine a fair price to compensate (through TSOs) storage owners for the lost market opportunity** in a period when they fulfil network requirements. [Deliverable D7.3, 2020].

Flexibility-oriented day-ahead market model	**FLEXITRANSTORE** project develops a **flexibility-oriented day-ahead market model**, demonstrating how a system can cope with renewable sources with no incentive in the presence of storage. [ISH, 2019]
Flexible Energy Grid platform	**FLEXITRANSTORE** project developed the **Flexible Energy Grid (FEG) platform for wholesale market demonstrations and market design needs.** Thanks to the FEG platform, generators can directly offer the flexibility services supported by BESS (transforming variable generation into predictable and reliable generation) to multiple markets, TSO or DSO. [Project newsletter June 2020]
Business models	**MERLON** identifies four business model categories, focusing on the realisation of the stacked value that distributed flexibility possess in the context of an Island Local Energy System. The multiple value streams that are either unlocked or enhanced through the BESS operation are (i) the increase in Variable Renewable Energy Sources (VRES) utilisation, (ii) the provision of balancing services, (iii) the enhancement of security of supply during emergency conditions, and (iv) the deferral of capital-intensive investments in network reinforcement. [Project coordinator, 2022]

⇨ To learn more on the respective projects' achievements with regard to the above facts and figures, read the section 6.

4. Knowledge for design and operation of BESS

To reach sustainability goals, batteries must deliver ultra-high performance, beyond today capabilities. Ultra-high performance means energy and power performance approaching theoretical limits, outstanding lifetime and reliability, and enhanced safety and environmental sustainability. Given the high capital costs of BESS, an optimal design for their intended application remains critical.

4.1 Simulation-based sensitivity analysis and tools facilitate fast design of BESS in multiple applications

- **OSMOSE** WP7 developed a generic simulation-based methodology for optimal sizing and performance characterisation for BESS [Deliverable D7.1, 2020]. Applied to different use cases, the methodology enabled to distinguish, among the influencing factors investigated through sensitivity analysis, those whose impact has the same magnitude regardless to the application from those whose impact is application dependent. The conclusions of the sensitivity analysis on key impacting factors show that:
    - A variable efficiency behaviour can be approximated by an average efficiency single value without any impact on optimal sizing.
    - Ageing must be considered in optimal sizing.
    - Optimal sizing does not require a high degree of technical modelling of the system.
    - The influence of the simulation time-step on optimal sizing strongly depends on the application time constants related to the events impacting the operation costs or incomes.
    - Different control strategies may lead to a different optimal BESS size: it is therefore recommended to clearly define the control strategy before determining the optimal size.
    - If the main function of BESS is to compensate for forecasting errors in the renewable energy sources, forecast quality is of the highest importance for optimal sizing: it was shown that 50% improvement of the forecast quality induced a difference of 15% of the sizing indicator value in one of the application case studied.
- **MERLON** project developed a comprehensive model to size the Energy Storage System to minimise the system lifetime costs and maximise reliability [Deliverable D6.1, 2020]:
    - The **charging / discharging modelling of the battery storage (empirical modelling) using 30-minutes timestep** is defined to determine what amount of energy would be capable of absorbing/injecting the battery into the whole system and/or to anticipate the relationships between parameters that affect the charge and discharge efficiencies of the battery.
    - The **battery degradation is simulated by a global wear coefficient considering the effect of Depth of Discharge (DOD).**
    - The **sizing study** is implemented to fulfil multiple applications on the Güssing distribution network in Austria (on a 20 kV feeder). Given that it is computationally expensive to simulate the system operations over the whole BESS lifetime, **8 representative days** (a weekday and weekend day for each season) were used to implement the battery sizing study.
- The application of **MERLON's** model in the Güssing network concludes that the anticipated BESS lifetime significantly affects the BESS behaviour and optimal sizing results. The optimal capacity of the BESS increases, and the power rating decreases when the BESS lifetime is increased, with minor impact on the annualised cost that remains approximately the same. As an illustration, for an anticipated 15 years of battery lifetime, the optimal configuration of BESS operation over 8 representative days, leads to an energy

capacity of 295 kWh with 533 kW power rating for the Güssing distribution network, use at maximal capacity when energy prices were attractive. Frequency control service is ensured thanks to the battery by a participation time between 12am and 06am and under availability payments of 22.01 €/MW/h (Huo, Santos, Greenwood, Wade, & Resch, 2020).

- To measure the impact of the **MERLON** project as well as the effectiveness of the technology, three KPIs are proposed [Project coordinator, 2022]:
  - *Smart Storage Capacity:* The smart storage capacity includes all the energy storage technologies including electrical and thermal. This KPI presents the impact of the project in the use of smart energy storage systems.
  - *Battery degradation rate*: The KPI illustrates the capacity losses of the batteries used in the project. This KPI concerns the effectiveness of this technology and the need for maintenance.
  - *Storage Energy Losses:* This KPI illustrates the energy losses because of battery storage. The conclusions of this KPI concern the effectiveness of this technology.

- **RENAISSANCE** project developed a **multi-vector optimisation software** to support the optimal high-level design of renewable energy communities at any location worldwide. This tool serves to **size** the electricity and heat generation installations, and **storage systems that would allow to minimise the annualised costs of energy supply or the related CO_2 emissions for any configuration of a renewable energy community**. It can consider different types of tariffs and demand response potential to define optimal profiles for energy generation and consumption. Energy community can be represented as a single node or multiple nodes with different tariffs and environmental conditions. This option allows the assessments of systems not only as energy islands but also as clusters of energy islands. Moreover, the software relies on a series of state-of-the-art modules to create predefined generation profiles (e.g., of the most common non-dispatchable renewable energy sources such as wind and solar photovoltaic power), as well as direct integration with the most accurate reanalysis data sets to make it directly usable by projects at any location in the globe. BESS are implemented as dispatchable assets that provide flexibility to an energy community. The tool also allows to select between different types of technologies namely LFP, NMC, Na-ion, VRFB and lead acid batteries to assess the environmental impact in CO2 of a particular system configuration. An online user-friendly version of the tool - the Renergise tool- will be made available to the public via the RENAISSANCE website. [Project Coordinator, December 2021]

BESS's parameters required for the Renergise tool

Mandatory parameters

- Min SOC(%) Max SOC(%) Initial SOC (%)
- Charging & discharging efficiency
- C-rate charge and discharge (1/h)
- Static loss (%/timestep)
- CAPEX (€/kWh), OPEX (€/kWh/year)
- Lifetime (years)

Sizing

- Min Capacity (kWh)
- Max Capacity (kWh)

If asset exists

- Capacity (kWh)

Figure 2: BESS necessary parameters
(ageing is included using theoretical models based on the state of charge and number of cycles)

- In **INSULAE,** the Unije BESS to be jointly located with the 1MW Solar PV has been sized to meet local demand while providing real-time grid stabilisation to the network, allowing excess electricity generated from the Unije PV farm to be stored in the BESS during times of high irradiance or low-demand.
  - The **conceptual design of the Unije BESS was constrained by the CAPEX**. Several factors influence the CAPEX of a BESS and must be considered when determining BESS pricing. However, consideration of these factors may result in an oversizing of the initial usable energy capacity to allow the required usable energy capacity to be sustained for several years while accounting for expected degradation rates that will result with use. This "oversizing" would increase the CAPEX, **a**

careful balance between initial system over-sizing and repowering in future years given the projected cost degradation curve for a specific chemistry should be considered.

  - The 1MW/1MWh BESS established during the initial feasibility assessment of the project was verified to provide a high-level indication of availability against the assumed demand profile in addition to offering a solution at a CAPEX point which is expected to align with the project budget. We note that subsequent analysis was undertaken to assess if increased utilisation and further local demand could be met through the modification of the BESS energy to power ratio. In the deliverable D4.2, it is outlined that the annual performance of a 0.4MWW/1.6MWh BESS reduce the local demand not served while adhering to CAPEX limitations of the project. [Deliverable D4.2, 2021].

- Finally, a literature review of possible future distributed and centralised storage technologies in the Southeast Europe region (SEE) has been presented in **CROSSBOW** WP6. This review presents the existing large-scale assets in the region as well as an overview of different storage technologies that could possibly be deployed focusing on technical and market constraints impacting the feasibility of cross-border energy storage. Out of all discussed future technologies, **Li-ion battery technologies appear to be the most promising technology to form VSPs and is expected to expand in the near future due to their various technical features** (e.g., high efficiency, high energy density, quick response in second time frame and flexibility, security sealed, electronical monitoring) **and continuously decreasing costs** prerequisite for its massive expansion in large scale applications. Moreover**, Li-ion batteries today are designed to have a long lifespan without maintenance**. A couple of projects on battery storage have been announced or are under construction in the SEE region.

4.2 Data sharing and analytics tools substitute specific testing for BESS predictive maintenance

- **OSMOSE** WP7 also developed a **dedicated platform** to share BESS performances in operation. This platform constitutes a database with data models and information system, coupled with **data analytics tools** aiming at BESS operating aid through diagnostic and prognostic analyses, performance evaluation and control improvements. The sharing platform enables to collect, sort, store, and share measurements data from on-field ESS for analyse purposes along to the calculated indicators regarding these measurements for assessing BESS performances. This platform is open to integrate BESS outside OSMOSE project to assess their performances.

  - The data analytics tools integrate a novel method to **identify the parameters of a BESS equivalent circuit model parameters without requiring any specific tests**, along with a strategy to identify the factors impacting the ageing processes. The method is validated by using real-time measurements of the utility-scale 720 kVA/560 kWh BESS on OSMOSE WP3 demonstrator in Switzerland, while operating it to provide various grid-support [Deliverable D.7.7, 2021].

  - The data analytics tools also enable (among other) BESS efficiency calculation, power, SOC and current distributions, and State of Health calculation through two methodologies. Linked to the developed information system, results from the analytical tools include graphical representation of BESS use and performances on the service(s) supplied.

5. Battery Energy Storage System applications supporting the power system with increasing RES

BESS can be considered as a technical enabler to increase RES penetration in a given power system thanks to their energy/power buffering functions. Indeed, all intermittencies of renewable generation or variability of electricity demand could be 'smoothed' by adequate operation possibly in coordination with system operators. This section details knowledge gained by projects' demonstrations on typical BESS operations features and their value for parties (system operators, users/storage operators).

5.1 Battery Energy Storage Systems have demonstrated ability to provide system services in various contexts

- **FLEXITRANSTORE** demonstrates capabilities of BESS to support the provision of ancillary services by renewable energy sources at points such as the TSO/DSO interface, wind farms and gas turbine plants. Categorising load shedding stages into vital and non-vital enables to measure the appropriateness of the BESS response. To do so, the integration of **a 50 MW, 100MWh BESS to the Cypriot transmission grid, equipped by Synchronous Power Controller with tuneable inertia has been modelled**. Conflicts of the BESS control parameters, performance measures and Under-Frequency Load Shedding (UFLS) actions have been verified over simulations. It was shown that **a controller or modulation technique through a gain tuning approach is essential to coordinate the BESS and UFLS scheme frequency responses to handle conflict of controllers** [ISH 2019 - (Mojtaba Eliassi, 2020)].

- The **OSMOSE WP4 demonstrator in Spain** designed, implemented, and tested a **modular hybrid flexibility** device combining lithium-ion battery, supercapacitors and statcom, all of them coordinated by a master control system, in order to provide multiple grid stability and security services (inertia, voltage control, congestion management, frequency regulation…) [project website and newsletter, 2021]:

    - Within this hybrid flexibility device, a new lithium-ion battery at 1260 Vdc output was validated and is already commercialised by the manufacturer.
    - The demonstrator provides different **grid services for stability support** (inertia emulation, fast-fault current injection, power oscillation damping), voltage and frequency control (power-frequency regulation, voltage control, reactive power setpoint) and optimal flexibility devices management (setpoint tracking, program management, congestion management). The battery system plays a fundamental role in the provision of these services that requires sustained active power supply.
    - The **Master Control** determines the setpoints of the different devices to provide the required flexibility services. It optimises the devices ageing, manages optimally the State-Of-Health (power and energy availability). It also guarantees grid security and enable higher levels of feasible renewable penetration.

- In its French demonstrator, **EU-SysFlex** project provided practical evidence for successful portfolio management of several distributed resources for joint participation in the energy market and coordinated provision of various flexibility**.**

    - A full storage system including a **2.3-MW/1h lithium-ion battery** as well as an ENERCON E-Storage 2300 power conversion system was part of the portfolio of resources together with RES generation assets (**12MW wind farm and a PV farm)**. [Deliverable D8.1 and project brochure]

- In this demonstration, an Energy Management System (EMS) allowed to manage power flows of these three resources by providing day-ahead and intraday schedules as well as short-term program adjustment capacities. It allowed to validate the concept of advanced battery and wind generation local controllers for multi-services provision and activation, and to perform **VPP scheduling optimisation for the provision** of:
    - the energy arbitrage using all the resources;
    - a symmetrical FCR (Frequency Containment Reserve), provided by the BESS only.
    - With the system developed, the performance of different services can be individually assessed while simultaneously activated. **System operators are thus in position to verify whether the storage provides effective contributions** by responding correctly to the different indicators of power system needs.

- The objective of the **EU-Sysflex Finnish demonstration** was to increase the use of market-based concepts and VPP to support the operation of transmission and distribution network. **Industrial-scale BESS, customer and office scale batteries**, electric vehicle charging systems and residential electricity storage heating loads, have been integrated in medium and low voltage grid and offer flexibility to TSO and DSO's needs.
Enabling the operation of small assets in the flexibility markets is mandatory for the provision of active power to TSO's ancillary services. **Forecasting and optimisation tools were developed for each asset type as well as control logics and communication systems between assets and different systems, and interfaces to the markets.**

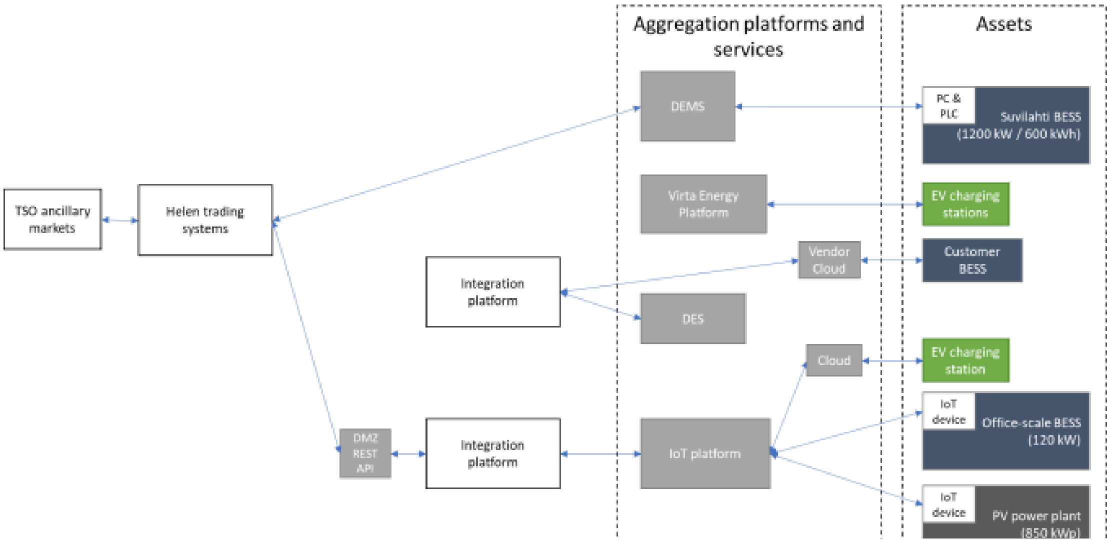


Figure 3: Overview of the developments in systems and interfaces in EU-SysFlex Finnish demonstration
(source: EU-SysFlex D6.9)

KPI results obtained in real environment for the frequency containment reserve for normal operation (FCR-N) show how respective value correlate to the BESS size [Deliverable D6.9, 2021]:

- *Industrial-scale BESS 1.2 MW, 600 kWh (Suvilahti BESS):* The BESS operated in FCR-N market successfully. The increase in revenue for flexibility service provider was about 45 k€ (4.1€/month with high yearly variation). The asset was usable at 94.8%, with profits of service provision of 22k€ (2k€/month with high yearly variation). It has been concluded that the **solution is scalable for future high-RES grid**.
- *Medium-scale BESS 120 kW ("office-scale"):* The BESS successfully operated in FCR-N market and enabled peak shaving and reactive power compensation. The increase in revenue for flexibility service provider was about 7.6 k€ (634€/month with high yearly variation). The asset was usable at 99.47%, with customer's profits of service provision of 5.5k€ (464€/month).
- *Customer-scale batteries, flexibility demo & calculated cases*: The technical test estimated an increase of revenue of 943€, with profits of service provision of 62€/year. The integration of this kind of assets didn't fulfil the requirements of FCR-N market and appears to be uneconomical for customers and the flexibility service provider.

Further research on artificial intelligence and smart utilisation of the battery reserve capacity would be promising to optimise battery performance considering ageing and short-term benefits.

5.2 Battery Energy Storage Systems support increased cross-border flows at TSO/DSO and regional interfaces

- In its Cypriot demonstration, **FLEXITRANSTORE** project showed how the installation of a 1MW / 2MWh BESS connected through a MV cabinet to the existing 11/132kV substation of Athienou at **the TSO/DSO interface can enable an Active Distribution Node (ADN) to accelerate RES integration and increase cross-border flows from a market and system perspective**. This demonstration features TSO operating batteries as they are serving its needs, while battery system ownership being at the DSO as installed in its facilities. The benefits of the Active Distribution Node are as follows [FLEXITRANSTORE, project newsletter June 2020]:

FLEXITRANSTORE DEMO 1 (Athienou, Cyprus) - BESS CHARACTERISTICS

- Power: 1MW / Energy: 2MWh
- Complete BESS installed in a 40ft container where batteries and PCS are installed, being part of a single unit container following a plug and play concept.
- BESS includes all the auxiliary equipment needed (FSS, HVAS, UPS) to ensure a safe and reliable battery system operation since the beginning of the installation at site.

  - The ADN utilising the BESS participates in the frequency regulation at the transmission level;
  - It enables to manage energy at the distribution level to optimise its use and to increase the flexibility of the system by shifting the demand from one time to another;
  - It could regulate voltage regulation and transient stability;
  - The ADN could implement an aggregator role with energy storage capacity and offering ancillary services.

- **CROSSBOW** project tackles the **interest of RES producers in storing the excess of production in neighbouring countries** – due to low demand in the origin RES production country or due to curtailment rules in that country. The project proposes a **regional storage coordination center (STO-CC)** to foster the cross-border usage (at national and regional level) of energy storage (ESS) infrastructures in Southeast

Europe (SEE region), to improve the stability of the system and enable multiple services provision. [project website]

- CROSSBOW demonstrates how a set of small storage units, geographically dispersed and from a variety of capacities and technologies, can be used by system operators in a coordinated way with the STO-CC to support grid stability at regional level. In this context, CROSSBOW designed a Virtual Storage Plant (VSP), a platform capable of integrating the characteristics and limitations of the distributed individual storage units. [Deliverables D7.3, 2021; D13.3, 2022]
    - The VSP can be regarded as an aggregator that enables the use of distributed storage units for grid support provision.
    - The VSP exploits advanced optimisation-based distributed control techniques to maximise the technical benefits provided by available distributed storage units and reduce additional costs stemming from non-optimal usage. It ensures safe and steady operation without violating individuals' privacy.
    - In addition, compared to traditional control method, VSP algorithms are more scalable and thus can coordinate an arbitrarily large number of storage devices.
    - The project concludes that a VSP can be considered when large storage is not available to absorb the excess of RES production in the same country or in a neighbouring one.
    - Finally, a VSP aggregating small systems (like a group of residential-scale Lithium-ion batteries with 6.5kWh capacity) should be regarded as a unit of energy storage to be managed internally by the CROSSBOW VSP and to be coordinated with other ESS units as one among other storage units within the STO-CC. Market participation of VSP is enabled through TSO/DSO cooperation.

5.3 The facilitator role of BESS in micro- or weak grids is assessed

- In **INSULAE** project, the Madeira **demonstration focuses on stabilisation of weak grids and microgrids thanks to storage and power electronics.** Indeed, grid instabilities are likely to appear at small scale (e.g. in islands with small disturbances having potentially a much greater impact than for larger networks). Demonstration in Madeira (Curral das Freiras-an isolated valley microgrid with minimal interconnectedness) will prove that grid stability will result from a smart energy management, additional grid protection and an installed BESS 100 kW/100kWh storage system on low-voltage substations: the surplus of energy generated during off-peak hours will be stored and prevent flows from LV to MV and ensure the shifting to a later consumption.

- The business case built by Elecricade da madeira (EEM) and EFACEC Electric Mobility (EFACEC) upon this use case foresees revenue streams from DSOs for the ancillary services to a weak low voltage microgrid as well as revenues from end users / consumers / prosumers paying for the value generated by a service providing stabilisation of weak microgrids. [Deliverable D9.1, 2020].

- In **INSULAE**, coupling BESS flexibility with flexibilities of different origins -transport, heating, and water - to increase RES share is proven as technically viable in islands.

- **Unije island** in Croatia aims to become a self-sufficient island and has deployed a specific use case in **INSULAE** project developing BESS and field testing **joint management of hybridised RES and energy storage** : a 1.4 MW Photovoltaic (1MW grid connection) and a 0.4MW/1.6 MWh BESS with power electronics are to be installed and tested for generation flexibility, the overall goal of INSULAE being to prove the feasibility of RES-based power systems in geographic islands lowering operating costs with high RES penetration, possibly using BESS. Note that Unije island is considered in the context of its interconnectedness within the Cres Losinj archipelago and to the mainland, assessing the associated risks and how the best investments can be made.

- BESS being operated as an energy buffer for the whole archipelago and for security of supply in the case of interconnection failure. Flexibilities are provided to the interconnected island system when BESS are combined with **Unije** water system and its desalination plant. Visualisation tools and easy to use interfaces with the households (in Unije) foster their engagement to further enhance the functionality of the RES/BESS combination [project website and project coordinator, September 2021].
- Still in **INSULAE** project, the **Bornholm Island** demonstration explores transition to DC grids in an island context. Indeed, such a DC grid implies network cost reduction and increased energy efficiency and more flexible use of batteries in the grid (charging time). The demonstration has an installed novel 288kWh BESS coupled to 61kWe of PV production and 2 EV fast charging stations (combined 150kWe) in a Bornholm DC microgrid seeking a gain of efficiency with respect to more traditional PV connections as well as maximisation of local independence/self-consumption. In Bornholm the ultra-fast charging of EVs is allowed by the BESS capacity.

5.4 Advanced control systems enable an efficient operation of hybrid energy systems (BESS + RES generation)

- **FLEXITRANSTORE** integrates a 2MWh Li-ion BESS in an existing Wind Park Plant located in Greece in order to regulate frequency, voltage and storage capacities. A local SCADA has been designed to monitor the status of the batteries and converters and to show the different measured values involved in the BESS converters control. The system has the option to change the operation mode between local and remote. The objective of this Greek demonstration was to design and implement an innovative active substation for improving the regulating reserves of the transmission network and reducing active power peaks that the wind technology generates.
- **CROSSBOW** has developed a renewable energy source dispatchable unit (RES-DU), a product offering: (1) new services to the market, (2) new power plant management options to the Generators, and (3) new functionalities to the System Operators, among other power system actors.
- These new services are based on the proper analysis of weather and market conditions, considering System Operator requirements, and allowing to manage and design future Hybrid Power Plants (i.e.; RES (PV, Wind, Biogas, Biomass) + storage units connected to a common coupling point) according to the optimal criteria showed by RES-DU product. The main functionalities are described as follows:
    - To provide ancillary services when they are requested by the System Operator, through the proper management of Hybrid Power Plants (HPPs).
    - **To increase generator revenues from HPPs**, adapting the energy/power supply to the best market prices of electricity sale when possible, and applying different sale energy strategies like energy time shifting.
    - **To provide quality services from storage technologies** included in HPPs to support black-start response (after a black-out).

- To supply the required power according to different demand power profiles established by the Market, through HPPs, in a similar way compared to conventional power plants (thermal, nuclear, etc.).
- **To design new HPPs, i.e., to retrofit existing RES or Storage Units integrating them into a Hybrid Power Plant**, according to the requirements of each System Operator and the corresponding national regulatory framework.

- A relevant number of parameters allow to configure each technology in the Manager Energy for Hybrid Plants (ME4HP), which is one of the main algorithms in charge of the optimised power production profile calculation for the hybrid power plant. Consequently, technology evolution would not be a limitation for the scalability purposes, at least in the coming years. [CROSSBOW Deliverables D5.1, 2021; D16.1 & D13.3, 2022]

- **MERLON project develops a Battery Management Module** responsible for **monitoring and controlling all sub-systems at the battery plant** in combination with monitoring local energy system network parameters in terms of applying scheduling and optimisation strategies. BESS Management Module will be able to interface between various battery technologies and systems and ultimately offer the monitorability and controllability of BESS for the provision of multiple services in energy markets. Certification and further testing will have to be performed to achieve interoperability with BESS of different technology providers [Project Coordinator, 2022].

- In **INSULAE, customer switchgear / control room** allows the site operator to **isolate and control the export power from the PV and BESS**. It is where the control-centre operating system is located. Due to the dispatchable nature of the BESS, the control system will be required to modify the BESS output to ensure equipment and grid operational limits are not breached. **The dispatch priority of the BESS may be required to change with time** (as the demand profile of the island changes) in order to achieve similar levels of utilisation in addition to ensuring the BESS State of Health (SoH) degradation is properly managed and understood. One example of where the **control system could be refined to ensure the longevity of the asset would relate to BESS average SoC during a low demand Scenario** [Deliverable D4.2, 2021].

5.5 Local battery energy storage system could provide increased flexibility to energy communities

- **RENAISSANCE** demonstrations are using batteries with specific objectives as described below:
  - **The RENAISSANCE Pilot Site in Eemnes** in the Netherlands aims to **validate the value of a local energy market based on flexible prices** and with currently more than 120 participating households by showcasing lower energy prices for the participants of energy community compared to the current offering from traditional utilities. The pilot site is currently installing a **battery system for energy storage which will reduce imbalances between demand and supply and address the RES intermittency**.
  - The optimisation strategy of the Dutch Pilot Site includes, among others, the utilisation of the generated electricity for PV batteries charging and the utilisation of the surplus energy of PV batteries for flexible trading on the energy market. [Deliverable D3.1]
- **RENAISSANCE** project used the 'Arenten & Bellekom, 2014' classification to map the various demonstration scenarios according to segmentation factors such as the local factor and the degree of autonomy of the energy system.

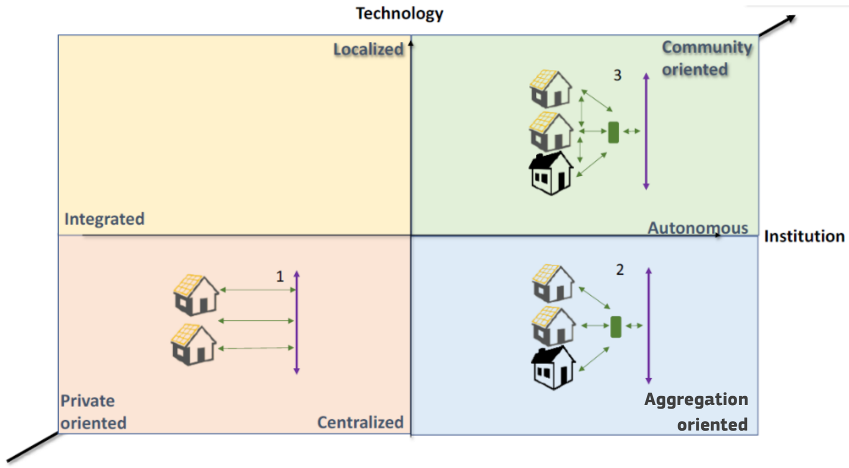


Figure 4: The classification of technology- business used for the Emmes demonstration in RENAISSANCE (*Source: Renaissance D2.1*)

This figure helps positioning the role of electric storage in these configurations. **RENAISSANCE** considered electric storage only for the 'Energy Community' with two implementation options, first as single user storage (2-6 kWh), second as Community Storage (accumulated storage) with storage possibilities considered as shared investments [Deliverable D2.1].

- In **MERLON**, energy community engagement to support the local grid operation was advocated. The active participation of prosumers guides the developments of the project. The Battery Energy Storage system is involved in two use cases as flexibility component (UC1: Integration of battery storage systems in local energy system - Network constrains management; UC2: Local distribution network management with battery storage solution). In case of UC1, **Battery Energy Storage systems is scheduled to optimise the energy of the community**. For this purpose, the BESS must communicate periodically the State of Charge to **the scheduling module** in order to be aware of the behaviour that can be expected of scheduling module. In case of the UC2, **the BESS, in addition to communicating the state of charge, can detect situations of imbalance.** This behaviour causes a **rectification of the scheduling of the flexibility resources in the Energy Community, playing a leading role in this case**. [Project coordinator, 2022]

5.6 Storage as a Service is demonstrated in combination with other distributed energy resources

- **RENAISSANCE** project is currently setting up a promising demonstration in the rural ski village Manzaneda in Spain. Three PV plants connected to MEISA[8] to support apartment buildings and infrastructures consumptions: 80 kWp in a canopy structure, 20 KWp with a 20kWh battery in the ski lift storage building roof and 50 KWp in the restaurant roof. The energy storage system will support the management of demand and PV production: **the Demand Side Management (DSM) will be based on the battery storage system, as Electrical storage batteries installed at different consumption points will simultaneously improve PV energy self-consumption and allow DSM strategies** (consumption load shifting, peak load reductions).

- Demonstration aims to **analyse and validate a Storage as a Service business model** and to demonstrate an operational system at the site ´Manzaneda´ operated by Everis Engineering. Assessment will detail the technical and financial characteristics of the SaaS business model, the architecture of the energy management system and main software components and more generally, the Spanish regulatory and market context, and conclude on the opportunities and barriers for storage as a service model.

[8] MEISA, a public owned company created to operate the Manzaneda Ski Resort

- The administration procedure to purchase the battery faced some delays resulting during the commissioning and installation stages due to a technical issue in terms of communication between system components and to delays due to administrative authorisations for batteries to be installed in apartments. Return of experience for demonstration projects including BESS show the criticality of the specification and installation stage of energy systems involving the end user. [Project Coordinator, 2021]

5.7 Battery Energy Storage systems offer grid forming capabilities on top of other services

- **OSMOSE WP3 demonstrator in Switzerland** validated experimentally control framework for set-point tracking and provision of ancillary services (such as voltage and frequency regulation) by a BESS taking into account grid measurements, BESS status and converter capability curves. The demonstration was implemented on a 720 kVA/500 kWh Lithium Titanate BESS[9], connected to a 20 kV distribution feeder on the EPFL campus hosting also stochastic loads and PV generation.

- **MERLON** has investigated the technical feasibility, reliability benefits, and economic advantages of installing a battery energy storage system with grid-forming capabilities into an integrated local energy system [Project coordinator, 2022].

  - The technical feasibility of a grid-forming battery energy storage system was investigated through the **development of an islanding control system and real-time simulation models** of the pilot sites. The preliminary results illustrate how the **BESS can actively improve the system's resilience by enabling the islanding mode scenario.** Both voltage and frequency were kept within the operational requirements. The controller was able to maintain the reference signals even after the loss of the connection with the upstream network.
  - The **MERLON reliability evaluation module** enables the quantification of the reliability benefit of a grid forming ESS within an Island Local Energy System (ILES). The figure below shows that the capacity and availability of the battery have a material impact on the number of hours per year in which the ILES would be unable to meet customer demand.

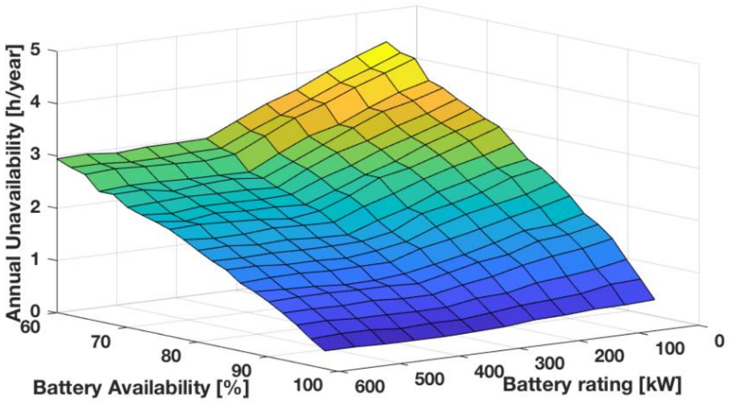


Figure 5: Relation between network annual unavailability, battery rating (50-600 kW), and battery availability (60%-98%) – MERLON project.

  - The economic advantages of the grid-forming BESS comprise three components: **reducing reliability costs, reducing operational costs, and gaining revenue through provision of**

[9] This specific type of Lithium electrochemistry cells is among the most suitable for stationary grid application purposes, as it can perform up to 20,000 complete charge-discharge cycles at their maximum C-rate of 4C, being this index a representation of the amount of power flowing into/out from the battery over its nominal capacity.

ancillary services. However, these objectives may be in conflict; if the BESS uses its power and energy capacity to deliver ancillary services or to reduce the operating costs of the system (by reducing grid imports, increasing renewable energy yields, and reducing network losses) it has a lower probability of being able to support the network in island mode after a fault. Reducing the probability of constraints violation means operating the system further from its limits and reducing the economic benefits from ancillary services and more efficient system operation. **MERLON's results show that an optimal trade-off between the objectives can be reached for a given value of lost load.**

6. Market design and regulatory framework

Energy storage represents a power system asset able to act as both generation and load. As such, it requires new regulation, market structures and incentives as well as new business models to operate storage installations and to ensure that the full value of energy storage can be utilised to the benefit of all stakeholders and ease the implementation of clean energy packages.

6.1 Various business model types are proposed for large-scale applications according to the BESS operator

Business modelling enables to understand the mechanisms of value creation by a systematic description of the involved stakeholders all along the value chain, the information and value flow between them as well as the financial flow capturing (or not such values). Typology of business models allow categorising similar business models into families.

- FLEXITRANSTORE defined three families of business models for high potential combination of large-scale storage applications [Deliverable D3.3]:
    - ***Conventional Plant + storage*** helps optimise operation of gas-based generation units and increase revenues captured from the ancillary service markets by providing flexibility. Revenue streams are based on ancillary services and the compensation by grid operators/utilities. This compensation included a fixed fee and a utilisation fee calculated based on quantity supplied for duration as requested by the grid operator.
    - ***Renewable energy generation + storage*** supports Feed-In-Tariff regression and solves RES integration at source.
    - ***System operation + storage*** reduces need for long-term trades and increases utility confidence in short term trading. This model combined schedule optimisation with direct or indirect revenues from services. In this case, ownership and operation are discussed given that storage projects may or may not be owned by TSO or DSO and operated by the owner or not.
- **MERLON** identifies four business model categories, focusing on the realisation of the stacked value that distributed flexibility possess in the context of an Island Local Energy System (ILES).[10]
    - The multiple value streams that are either unlocked or enhanced through the BESS operation are (i) the increase Variable Renewable Energy Sources (VRES) utilisation, (ii) the provision of balancing services, (iii) the enhancement of security of supply during emergency conditions, and (iv) the deferral of capital-intensive investments in network reinforcement.
    - Key **market-related issues** that constitute potential obstacles towards the development of local energy systems **with BESS** have been identified as follows:
        - High capital costs
        - Absence of financial incentives
        - Missing whole-system benefits in electricity market design
        - Imposing restrictive constraints on electricity market participation
        - Neglecting the time-specific and location-specific value of flexibility in electricity market design
        - Lacking efficient capacity remuneration mechanisms

[10] More information and exhaustive analysis of the business model categories, the barriers and the applicability potential on MERLON pilot sites will be available in D10.7. Socio-Economic and Regulatory Obstacles have been presented in D3.2.

6.2 The current legal framework would need to be adapted to maximise benefits from ESS operation

Energy Storage Systems have been identified as a promising solution in the energy transition. However, **under the current regulative framework, ESS are classified as generation assets limiting their widespread usage**. Additionally, the provision of single services such as energy arbitrage only is not sufficient to reach its economically viability and would thus requires **extending the value proposition of BESS**.

- **EU-SysFlex** highlights that aggregation of decentralised resources enables access to a wider range of flexibility options, including the participation of residential customers, and a range of distribution-connected assets.
  - Aggregating several decentralised resources, e.g. wind turbines, energy storage, electric vehicles, heat pumps, including as part of a virtual power plant (VPP), and using a combination of coordinated controls and optimisation, can greatly enhance the overall reliability, performance and profitability of the system services provided.
  - The **French demonstrator,** shows that by **aggregating RES and storage abilities, additional revenue streams could be generated** and would help to overcome the insufficient revenues from a single service (i.e. one single resource providing only one service) to cover investment and operating costs. [project brochure and WP8].
- **CROSSBOW project provides some ideas of development to maximise benefits from ESS operation** in terms of various services provision and congestion management, this remains valid for BESS [Deliverable D7.1, 2019]:
  - Participation in the **balancing market** may lead to a substantial revenue stream due to their fast responses time;
  - **Multiple service provision** could form a profitable business case: the income of ESS can grow and open new market perspectives. In this case, **the allocation of ESS capacity between different functions is of paramount importance**;
  - **Harmonising rules in the involved regions** will allow an effective cross-border operation of centralised ESS. This means translate and directly implement relevant EU legislation "without changes to the structure and text other than translation";
  - Market coupling among the SEE countries might significantly simplify the cross-border operation of a STO-CC (regional storage coordination center) and thus further improve the economics of ESS.

- **In INSULAE**, while the BESS has been assessed to reduce Unije intermittency, the commercial benefit and utilisation of the grid connection through the current time-shifting and load following focused use case will be limited. RINA-UK note that **future scenarios (following the update of applicable regulation) could enable increased revenue stacks through a bi-directional connection agreement**. If these ancillary services are expected to be introduced in subsequent years of operation, these should be considered within the control system at tendering stage. [Deliverable D4.2, 2021]

6.3 Energy storage profitability is improved when combining energy market value and facilitation value for the power system

- In **CROSSBOW** project, the **commercial application of the Virtual Storage Plant (VSP) product** has been investigated by introducing archetype business models, aiming to cover sets of services in which VSP may participate. Business models have been developed for the following three cases:
    - Participation on the Day-ahead/Intraday market (price arbitrage) and balancing markets (capacity and energy for frequency regulation);
    - Provision of services to the TSO (voltage control, congestion management and system stability);
    - Storage of renewable energy sources surplus.
- In its market analysis, **CROSSBOW** concludes that VSP could merge two business models (provision of network services and market participation) at the same time, if a proper regulation is in place, to obtain full economic value. The project considers that the key players for storage penetration should be regulators who should determine a fair price to compensate (through TSO's) storage owners for the lost market opportunity in a period of time when they fulfil network requirements. [Deliverable D7.3, 2020]

6.4 Solutions to organise the energy storage capacity market are proposed for experimentation

- The Spanish pilot site in **RENAISSANCE** (Rural Ski Village Manzaneda) tests an energy storage capacity market with the acquisition of "space of storage" of an energy storage system owned by a third party. Such solution enables individual prosumer auctioning storage capacity in the local energy community for the lifetime of the storage. The energy storage capacity market is organised around a multiparty energy storage capacity smart contract service supported by blockchain technology.

‣ The ‘Supervisor’ is the agent that supervises the smart contract services within the **local Energy Exchange Market**. It sets techno-economic limits to the battery operation based on the information sent by the Storage owner. It also manages the members taking part on that market through the local energy storage smart contracts.

‣ The ‘Storage owner’ has purchased of the energy storage system and is able to **sell a storage value capacity** in kWh in the form of **Ecoins** to be used by the prosumers.

‣ The ‘Prosumer’ is a local agent able to buy “space of storage” from an energy storage system buying capacity and remunerate the Storage owner in Ecoins. A **smart contract** rules the energy store and withdraw function of the prosumer.

‣ The ‘PV Generator’ is a local generator that could buy capacity of storage from the Storage owner to support its own offer (e.g. **guaranteeing power** without intermittency to its consumers).

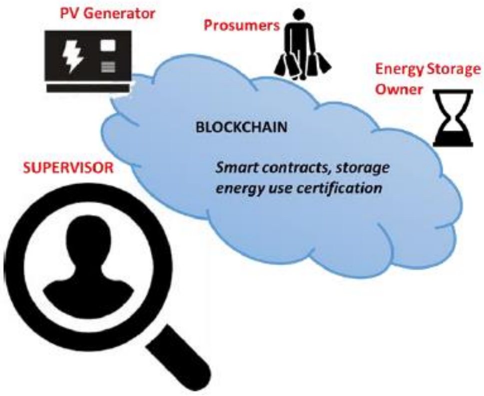


Figure 6: the four actors of the energy storage capacity market in Renaissance project

- Within **CROSSBOW,** an optimisation algorithm to support the **decision-making process of energy storage players** (such as VSP) **in electricity markets** has been developed. [Deliverable D7.3, 2020]
    - The developed algorithm considers a single VSP which **optimises the provision of multiple services** across different segments of the electricity market.
    - In particular, the set of services includes price arbitrage opportunities in energy markets and provision of balancing services. Price differentials in the day-ahead energy market create arbitrage opportunities which can be seized by the VSP. Thus, by taking advantage of low prices to buy energy in the day-ahead energy market and sell it back at higher energy prices, the VSP can make an **arbitrage profit**.
    - The developed algorithm has been applied in a simulation environment of national markets of the SEE region to quantitatively investigate the potential revenues of VSP in the region (especially in Bulgaria, Croatia, Greece, Romania and Serbia). In all five examined countries, the balancing revenues counterbalance the reduced energy arbitrage revenues and yield **significantly higher overall revenues for the VSP**, improving substantially its business case in the market.

6.5 Optimisation strategies are based on anticipation-type heuristics for operating BESS

Optimising the operating of the battery system consists in making the best and anticipated use of available technical and market information, while respecting the operating constraints of the battery and the regulatory context. Anticipation-type heuristics include:
- Avoidance of undesired situation with high Frequency Containment Reserve (FCR) expectations and battery unable to provide services
- Market anticipation of ahead FCR prises (through forecasting of price signals) for optimal bidding strategy
- Compliance to electrochemical physics as constraints for resilience and ageing and application needs constraints

- Consideration of the taxes upon the electricity flows discharged from the battery, while regulation-dependent, that impact overall profitability.

Several projects address these elements. They model how value is created by the BESS operated according to a predesigned protocol and formulate prerequisites (e.g., anticipation tool) and recommendations for further R&I.

- **EU-SysFlex** in WP6 aims to analyse and test the exploitation of decentralised flexibility resources connected to the distribution grid, respecting to the needs of both DSOs and TSOs. The operation of an industrial scale battery (1.2 MW, 600 kWh) in the FCR-N market[11] has been one of the key objectives of the EU-SysFlex Finnish Demonstration. **It shows how small, distributed flexibility resources connected to the low or medium voltage distribution network can be aggregated to be traded on existing TSO marketplaces and/or for DSO's reactive power compensation needs**. The industrial scale battery being connected to Helen's distribution grid (local DSO) through an aggregation platform, **no taxes were paid by the flexibility service provider as the discharged electricity flows directly to the consumer.** However, if customer-scale batteries are considered and if the electricity flows back to the grid, the customer has to pay additional costs from transmission fees and taxes.

- **Eu-SysFlex** project recommends optimising the charge or discharge of the battery in order to bring it back closer to a SoC (State of Charge) of 50 %. In the optimisation, a balance must be found between the benefits of allowing the BESS to provide its services during more time periods on one hand and the costs of running the battery as well as imbalance costs on the other. **To find the balance and enable optimisation, a forecasting tool is needed**. It aims to minimise the impact of the times/prevent situations where the battery is unable to provide frequency containment reserves in normal operation (FCR-N) and to find optimal bidding price/strategy to maximise the income from the FCR-N market [Deliverable D6.9, 2021].

- **FLEXITRANSTORE** project develops a flexibility-oriented day-ahead market model, demonstrating how a system can cope with renewable sources with **no incentive in the presence of storage**. The model considers three BESS units, two wind plants and twelve non renewables sources. Specific services and operational patterns for the BESS have been considered. **FLEXITRANSTORE simulations show the reduction in loading of the lines when storage enters the operation** (i.e. incorporating three sources of flexibility: reserve, renewable and storage) **while similar prices are obtained, demonstrating how adding storage can relieve some stress from transmission lines in overall**. When incorporating demand into a day-ahead operation, FLEXITRANSTORE model shows that aggregated BESSs start charging when there is a large amount of renewables and discharge in high load hours and near peak and peak hours (arbitrage condition) and that the BESS remains out of operation solely for four hours in the whole day, both features contributing positively to profitability. (Peyman Mazidi, 2020)

6.6 Market platforms constitute a core tool to offer and trade BESS-supported services

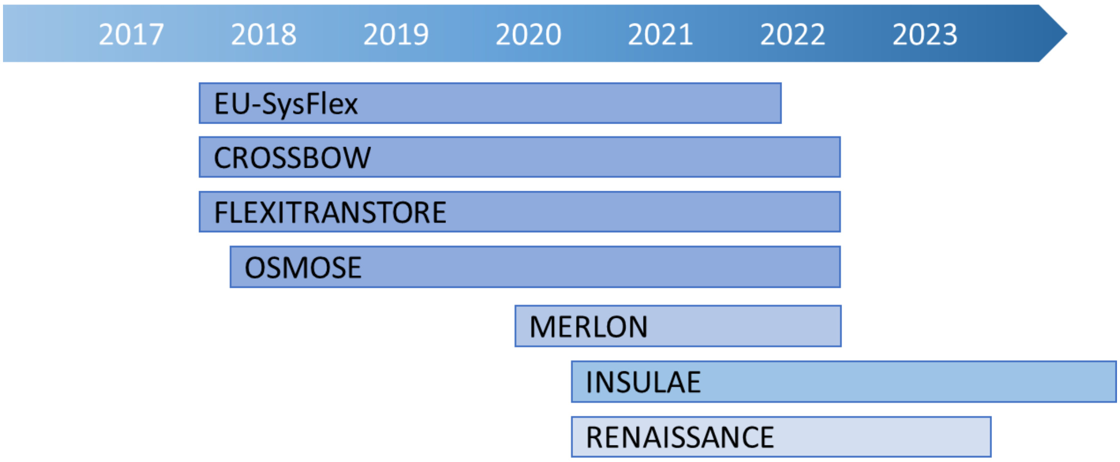
- **The Flexible Energy Grid (FEG) platform, was developed in FLEXITRANSTORE project** for wholesale market demonstrations and market design needs (quarter-hourly trading to decrease balancing energy needs or exploiting the potential of new order types on liquidity and social welfare). **Generators can directly, via the FEG platform, offer the flexibility services supported by BESS** (transforming variable generation into predictable and reliable generation) to multiple markets, TSO or DSO. TSOs will use grid technologies and storage for balancing the network, whereas DSOs will aim at deferring network investments and capital expense optimisation. [Project Newsletter, June 2020]

[11] Frequency Containment Reserve in normal operation

- In **EU-SysFlex**, the ‘**Flexibility Platform’** is a single marketplace concept whereby any flexibility buyer can meet any flexibility service provider to trade any flexibility product. It supports seamless cooperation of DSOs and TSOs without direct interaction between them. A demo of this flexibility platform has been developed as part of the WP9.

References

Timeline of the projects studied:



Projects information

Bridge project	Call	Goal	Website	Coordinator / Contact
Renaissance RENEWABLE INTEGRATION & SUSTAINABILITY IN ENERGY COMMUNITIES RENewAble Integration and SuStainAbility iN energy CommunitiEs	LC-SC3-ES-3-2018-2020 - Integrated local energy systems (Energy islands)	RENAISSANCE aims to demonstrate highly replicable design and management approaches for integrated local energy systems, that achieve high participation of local consumers, exceed at local level EU targets for renewable energy sources while decreasing the energy price for community members.	https://www.renaissance-h2020.eu/	VRIJE UNIVERSITEIT BRUSSEL (BE)
MERLON Integrated Modular Energy Systems and Local Flexibility Trading for Neural Energy Islands	LC-SC3-ES-3-2018-2020 - Integrated local energy systems (Energy islands)	MERLON introduces an Integrated Modular Local Energy Management Framework for the Holistic Operational Optimisation of Local Energy Systems in presence of high shares of volatile distributed RES	https://www.merlon-project.eu/	HYPERTECH (EL)

insulae – Maximising the impact of Innovative energy approaches in the EU Islands	LC-SC3-ES-4-2018-2020 - Decarbonising energy systems of geographical Islands	INSULAE aims at helping islands find locally produced, sustainable and low-cost energy sources. Through 7 replicable use cases at 3 Lighthouses, it aims to demonstrate their capability to evolve RES-based systems up to 70 % cheaper than diesel. The project also designs an investment planning tool to be displayed at four Follower Islands.	http://www.insulae-h2020.eu/	FUNDACION CIRCE (ES)
OSMOSE – Optimal System-Mix Of flexibility Solutions for European electricity	LCE-04-2017 - Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	OSMOSE addresses flexibility for the integration of renewable energy sources, through a holistic approach to capture "silo-breaking" synergies across needs and sources flexibilities.	http://www.osmose-h2020.eu	RTE (FR)
EU-SysFlex – Pan-European system with an efficient coordinated use of flexibilities for the integration of a large share of RES	LCE-04-2017 - Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	EU-SysFlex develops new types of services that will meet the needs of the system with more than 50% of RES	https://eu-sysflex.com	Eirgird PLC (IE)
flexitranstore – An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources	LCE-04-2017 - Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	FLEXITRANSTORE aims to develop the next generation Flexible Energy Grid (FEG), which will provide the technical basis supporting the valorisation of flexibility services and enhancing the existing European Internal Energy Market (IEM).	http://www.flexitranstore.eu/	EURODYN (BE)
crossbow – CROSS BOrder management of variable renewable energies and storage units enabling a transnational Wholesale market	LCE-04-2017 - Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	CROSSBOW proposes a shared use of resources to foster cross-border management of variable RES and storage units, enabling a higher clean energies penetration whilst reducing network operation costs and improving economic benefits of RES and storage units.	http://crossbowproject.eu/	ETRA I+D (ES)

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