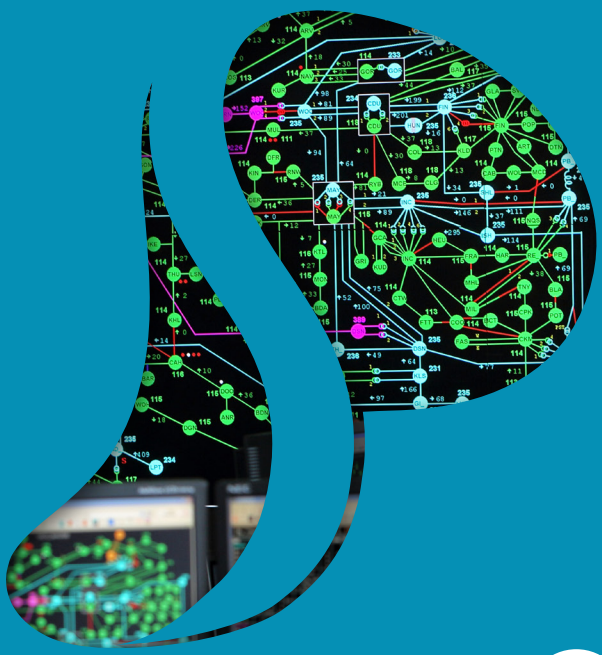
EU-SysFlex



DELIVERABLES
100

DEMONSTRATIONS
7

WORK PACKAGES
12

CONSORTIUM
34 organisations

HORIZON 2020 CONTRIBUTION
€20.5 million

TOTAL BUDGET
€26.5 million

DURATION
NOV 2017 - OCT 2021

System operation and flexibility solutions for integrating 50% renewables by 2030

Development of new approaches for system operation with a high share of renewables

EU-SysFlex has developed several scenarios where renewables meet at least 50% of the total annual demand in the pan-European Power System. There are two Core scenarios which have 50% and 65% RES-E as the referral to the EU goals. Network Sensitivities were also developed, either to reflect even more ambitious policies (e.g. for the Ireland and Northern Ireland power system) or to analyse the impact of some technology choices on any given power system, e.g. higher solar penetration for the Nordic system, or higher levels of distribution-connected renewables for the Eastern European area.
Various stimuli were applied while combining unit commitment models with network and dynamic models. As a result, thousands of simulations were conducted in order to identify technical scarcities emerging in the European System with the transition to high variable RES-E penetration levels. The scarcity analysis led to the conclusions below:

- With decreasing shares of synchronous machines in the power system, **inertia is falling** across Europe, as well as in the Nordic and the Ireland and Northern Ireland power systems. This is leading to **higher rates of change of frequency (RoCoF) and challenges with containing frequency and maintaining frequency stability** particularly in less interconnected areas, such as island systems and weakly connected peninsulas, but also in the Pan-European system where a system split occurs.

- In the systems for which steady state voltage regulation was studied, higher renewable penetrations exposed **a scarcity in voltage control**. The Ireland and Northern Ireland system exhibits a **clear deterioration of fault levels and a dynamic voltage regulation scarcity**. While the model and cases analysed for continental Europe did not demonstrate any conclusive evidence of a dynamic voltage scarcity, it is likely that further analysis with a higher level of renewables at a subnetwork level on the continental system would reveal associated scarcities.

- The studies show no global scarcity in stability margin in either system, when assessed through critical clearing times for faults that are cleared by primary protection operation. However, **local issues with rotor angle stability can appear for specific unit commitment combinations, as well as for certain contingencies**.

- **Decentralised renewable penetration increases power injections across all networks and impacts circuit loading.** Congestion management is needed in the transmission and distribution systems, as well as for cross-border flows.

- System restoration is not identified as critical, as long as the availability and reactivity of sufficient black start units are managed actively. **Non-synchronous resources or storage can be used in restoration plans** provided that their variability is anticipated.

Summary of the results from the technical scarcity identification studies

	Continental Europe	Ireland & Northern Ireland
Rate of Change of Frequency	Localised Concern	Inertia Scarcity
Frequency Containment	Evolving Characteristic	Evolving Characteristic
Steady Stage Voltage Regulation	Steady Stage Reactive Power Scarcity	Steady Stage Reactive Power Scarcity
Fault Level	No Scarcity Found	Dynamic Reactive Injection Scarcity
Dynamic Voltage Regulation	No Scarcity Found	Dynamic Reactive Injection Scarcity
Critical Clearing Times	Evolving Characteristic	Evolving Characteristic
Rotor Angle Margin	Not Analysed	Localised Concern
Oscillation Damping	Damping Scarcity	Damping Scarcity
System Congestion	Global Concern	Transmission Capacity Scarcity
System Restoration	Not Analysed	Evolving Characteristic

No Scarcity | Evolving Characteristic | Concern | Scarcity

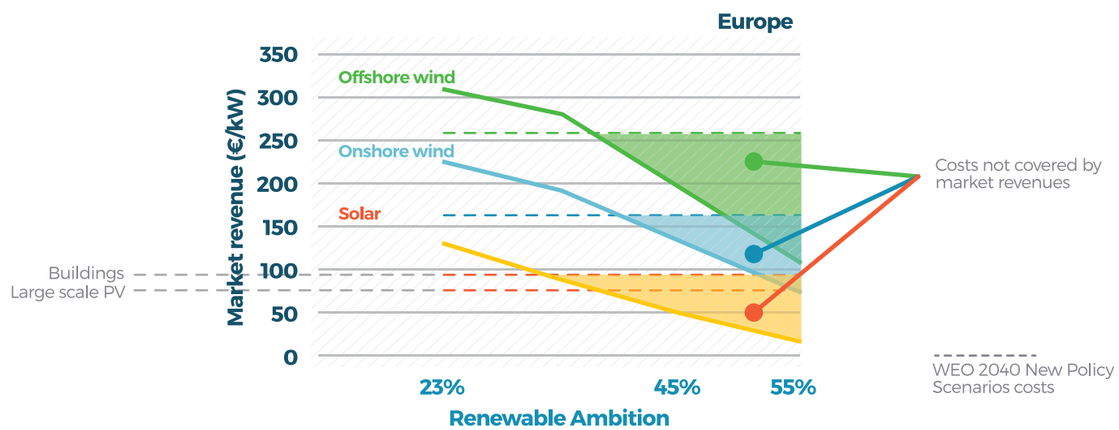
The analysis of the European power systems with high levels of RES-E, and more specifically variable non-synchronous RES-E such as wind and PV, clearly demonstrates a range of technical scarcities. These scarcities are more evident for the higher variable RES-E level targets in the Ireland and Northern Ireland system. These scarcities are indicative of the evolution of the power system and the need to adapt operational practices and policies and ensure there is sufficient capability in the portfolio of resources.
The challenges facing the evolving power system are not only technical; they are also financial. Economic analysis was performed in parallel to the technical simulations and a number of key challenges for the European Power Systems were identified:

- With increasing levels of renewables, it was shown that the capacity factors for peaking plants such as open cycle gas turbines (OCGTs) are also increasing. This indicates that **system operation is fundamentally changing with higher levels of RES-E where high net load ramps are possible and more flexible, fast responding units are a necessity**. While it is being seen that there is an increasing need for fast, flexible plants, it has been shown that if OCGTs are relied upon for providing the required flexibility at high penetrations of variable renewables, that the potential carbon emission reduction benefits from the renewables may be impacted and could taper off at high levels of renewables.

- There is a **downward trajectory of energy market prices** and an increase in time spent with zero marginal prices in future scenarios **leading to falling revenues**.

- There is an increase in the number of technologies not making a profit as a result at very high levels of variable renewables – and not just renewables, but also conventional technology. Clear evidence that an additional revenue stream and/or additional subsidies are required – **system services could be part of this revenue stream** (the value of which needs to be studied more widely but was found to be sufficient to fill the financial gaps for the Ireland and Northern Ireland power system). Additional externalities and positive benefits associated with transition to a power system with high levels of variable renewables exist that are not yet captured in the value of system services.

Annual Market Revenues Fall with Increasing Variable Renewable Share



Innovations in product and market design

A detailed overview of different system services and products (including detailed specifications) for the countries in scope has been realized. A questionnaire has been issued covering innovations in product and market design for future system services. For each system service, the innovation potential with respect to future products providing this service was defined. Examples of existing products were provided as possible blueprint for a generic product or in case no product exists, proposals for new system services were designed. In particular for congestion management, it was observed that no specific products were yet available. Multiple products for congestion management are proposed offering different procurement times to answer the need for congestion management in different time frames.

Business Use Cases for the demonstrations of the project have been elaborated using the roles and product definitions identified above. In addition, a detailed comparison of the different use cases was elaborated to lay a foundation for the research on market design options in the next step. One of the main observations and differences between the demos were the different roles assigned to the distribution system operator (DSO) in the context of procurement and activation of flexibility.

The process to acquire flexibilities for system needs under different selected market and optimisation options was investigated. The results present an analysis of advantages and disadvantages of regulated or market-based procurement for different scarcities. Various approaches for the organization of the flexibility bid selection are examined spanning the range from centralized and decentralized optimization to a distributed market organisation. Additionally, the impact of grid constraints, driven by an increase in renewable energy sources connected to the distribution grid is considered in the flexibility procurement process; then the process itself to solve grid constraints is evaluated for different services. Moreover, the possibility to have joint procurement of different services, in particular the frequency control products (mFRR) and congestion management is discussed as an example accompanied by evaluation of the current market data:

- **Market-based vs regulated organization**

  If market-based is the preferred solution, a regulated organization could still be preferred in some cases, i.e. a regulated approach could be considered in case of insufficient liquidity or transparency, difficulties in pricing of the service, risks related to secure and reliable delivery of the service or the risk of gaming. The relative merits and suitability of regulated and market-based solutions strongly depend on the technical characteristics of the service to be provided.

- **Optimisation methodologies and grid constraint management**

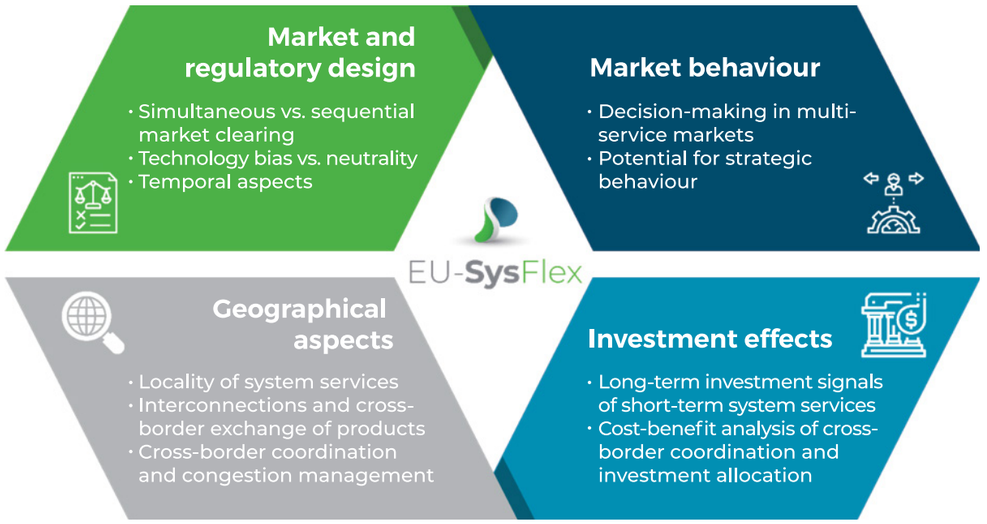
  A new role, the Optimisation Operator – has been introduced in order to separate the process and perform the selection of flexibility bids and analyse the allocation of this task to different stakeholders. Such optimization (also called market clearing) can be carried out in a centralized or decentralized manner and is separated from market organisation. The results show that both centralised and decentralized optimizations can be applied for selecting flexibilities for a large set of products. Different options, regarding the amount and type of grid data shared between the System Operator and the Optimisation Operator have been assessed.

- **Joint procurement of manual frequency restoration reserves (mFRR) and congestion management product**

  Joint procurement of congestion management and mFRR energy products appeared to be the most relevant to be studied due to the similar characteristics of the underlying needs. Possible cases of synergy were identified, and different options were assessed.

Advanced power system and market modelling studies have been deployed, considering both long-term and short-term impacts of these designs on the pan-European power system. The figure below provides an overview of the relevant topics examined within EU-SysFlex.

Overview of research questions related to market design

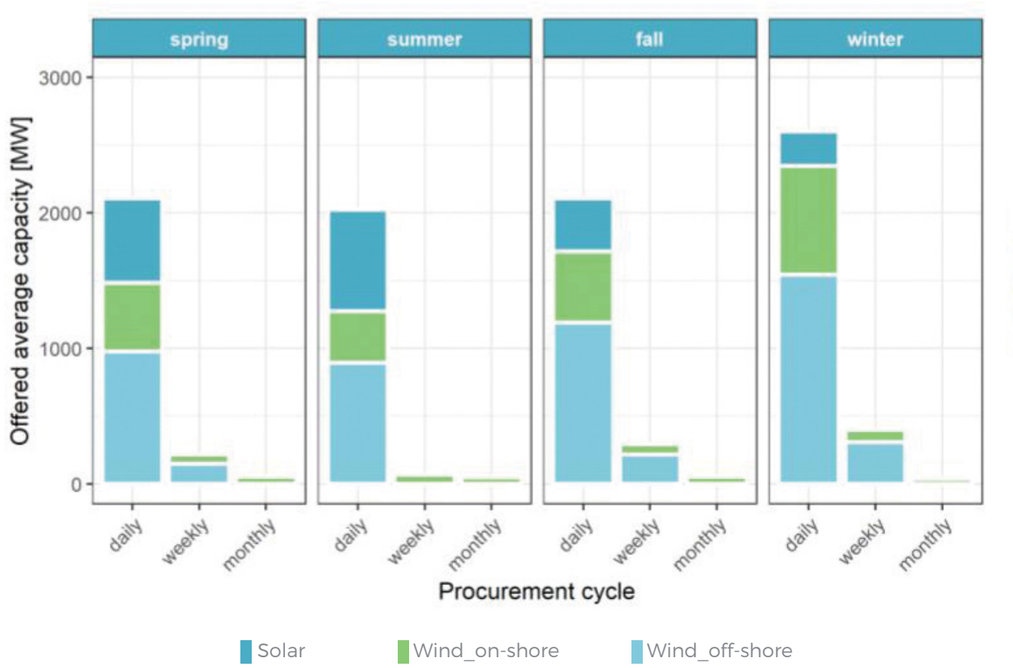


A range of advanced models was used, ranging from flexible Unit Commitment models (stochastic/deterministic, adaptive in terms of considered technologies, interconnections, geographical and temporal scope, etc.) over game theoretic approaches (equilibrium models, bi-level optimization, etc.), agent-based simulations to investment models.

The crucial points of attention are the trade-off between optimality and complexity of the market and control mechanisms, and the role of DSOs in enabling the use of distributed resources. A more complex market clearing algorithm, combining e.g. energy and reserve needs, has to be weighed against the operational and economic benefits. Important elements in the granularity of system service products are the following: the sizing frequency and resolution, the procurement frequency and contract duration.

A weighting between the development of more complex products and market designs against the potential welfare benefits is required. The extent to which market designs allow to fully translate the technical potential into market value is a crucial performance indicator for the market design options. The figure below illustrates the impact of the procurement cycle on the offered capacity of RES-E to provide frequency control. A shorter procurement cycle might increase operational complexity, but this is less important compared to the welfare gains due to higher RES-E participation.

Impact of procurement cycle on the offered capacity of RES-E for frequency control



More complex cross-border market coordination results in an increase in social welfare, however, this may lead to a reduction of security margins (through joint reserve sizing). The mechanisms and benefits of a coordinated network management and investment in network assets including phase-shifting transformers might be broader than the directly affected control zones. Hence, methodologies to share costs and benefit beyond the directly affected control zones offer new possibilities. The impact of system service markets on long-term investments is becoming increasingly crucial. Investment decisions change strongly in the presence/absence of requirements for different system services. The magnitude of the investment signals driven by system services markets will require more attention.

News from demonstrations and trial

Enabling provision of system flexibility from the distribution grid

Three EU-SysFlex demonstrators in Germany, Italy and Finland are analysing and testing opportunities arising from decentralised flexibility resources to serve TSOs' and DSOs' needs. The three demonstrators complement each other in reaching the joint objectives of improving the TSO-DSO coordination, providing ancillary services to TSOs from distribution system flexibilities and investigating how these flexibilities could meet the needs of both TSOs and DSOs.

The **German Demonstrator** is enabling the provision of flexibilities from the meshed high voltage distribution grid. The demonstrator has set up a new coordination process between TSO and DSO to manage increasing congestions in the transmission and distribution grids that arise due to the growing decentralized renewable resources and changing flows. Furthermore, the demonstrator has developed a new automated tool for voltage control and reactive power management. Field tests are currently starting in order to:

- prove the more **efficient voltage control and congestion management,**
- validate the new **processes including data exchange,**
- test the **function of tools** under **online grid operating circumstances,**
- validate the **accuracy of forecasting,**
- analyse the advantages of **combined optimization of active and reactive power**
- and demonstrate the feasibility of a **fully-automated process** for grid optimization.

The **Italian Demonstrator** focusses on providing flexibilities from the medium voltage level has completed its development of automated tools for Network State Analysis, Network Optimization and Reactive Power Management. Among the developed solutions, we should highlight the upgrade of forecasting for RES-E generation as well as load and grid optimization. Offline simulations, including the use of RES-E, Storage, On Load Tap Changer (OLTC) and Static Compensator (STATCOM) in congestion management, balancing and voltage support all demonstrated the effectiveness of the new coordinated process for the provision of ancillary services to the TSO.
Overcoming the challenge of specifying the STATCOM with its innovative functions at the distribution level, the set-up for the field tests is being completed to validate the tools and simulations' results. This will pave the way to RES-E integration thanks to an advanced Smart Grid infrastructure and improved Distribution Network Observability and to introduce a new concept of resilient network.

In the **Finnish Demonstrator,** the concept of aggregation of flexibilities at the low voltage level is validated in several pilots. One is dedicated to the coupling of e-car charging stations and smaller-scale batteries while the other provides a system software to aggregate small-scale batteries. Field tests of a large-scale battery energy storage system show satisfactory results on frequency control (FCR-N) and reactive power compensation that will be further improved. Preliminary tests of management of electric heating loads with a high number of loads showed that the communication channel is too slow for the services targeted. However, the flexible potential of the loads will be evaluated in the next steps. For all pilots, defining the economic profitability in the flexibility market and acceptance by customers will be key to industrialization.

Distribution grid as a key flexibility provider

The Flexibility Hub (FlexHub) in **Portugal** is a platform for DSO-TSO coordination that aims to exploit the potential flexibility of assets (RES-E, storage, etc.) connected to the distribution grid. The FlexHub includes a reactive power market simulator that clears local reactive power flexibility to balance the DSO and TSO reactive power needs, a DSO software tool for the Traffic Light Qualification of bids for secure provision of active power to the TSO (in an enhanced restoration reserve market),

and also an equivalent dynamic model that represents an aggregated response of the distribution grid (at the power substation level) in case of large frequency or voltage disturbances on the transmission network. The demonstration results and KPI assessment will be completed in the next steps which will feature both a set of offline tests and online demonstration of the FlexHub in full operation.

The Virtual Power Plant as a flexible enabler of renewables

The other **Portuguese demonstration** develops a utility-scale Virtual Power Plant (VPP) aggregating large hydro and wind farms, in order to optimize RES-E participation in energy markets. The VPP's different modules and components have been fully developed – both the VPP Core and the VPP Controller. The IT architecture and specifications are complete, and the offline and online field tests will soon be launched in Portugal with different assets. The objective is to validate the operation of the VPP as well as its replicability and scalability.

Virtual Power Plant based on the "multiple-service and multiple-resource" approach

The **French demonstration** has developed an operational version of the innovative Energy Management System (EMS), comprising both a day-ahead and intraday scheduler to optimize the allocation of planning and services and a short-term controller to manage the continuous operation of the Virtual Power Plant (VPP). This ensures optimal use of the distributed resources and allows the VPP to participate into system services as a full-scale stakeholder.
In addition, an advanced offline simulation platform has been developed, allowing to simulate precisely the behaviour of the whole system (EMS + VPP) in realistic conditions from a few days to several months. It has been proved useful to jointly tune the different software parts and improve the global performance of the EMS with respect to forecast errors and contingencies.
Moreover, testing has started bringing satisfactory results in the simultaneous multi-service provision (fast frequency response, frequency reserves, renewable generation smoothing, etc.) to the power system from the 2 MW storage as well as the FCR provision from a 12 MW wind farm.

Data management for flexibility solutions

In order to test the opportunities and challenges linked to data management in the development of a flexible digital power system, several software applications are being developed. They are currently tested for the potential of free data flow, easy market access for small demand side units, cross-border and cross-sector exchanges and TSO/DSO exchanges on the flexibility market. All these tools will be integrated in the Data Exchange Platform to demonstrate a solution for conceptual European data exchange model. These demonstrations will support the studies and recommendations on role models, use cases, big data management, as well as security, privacy and interoperability of various energy data.

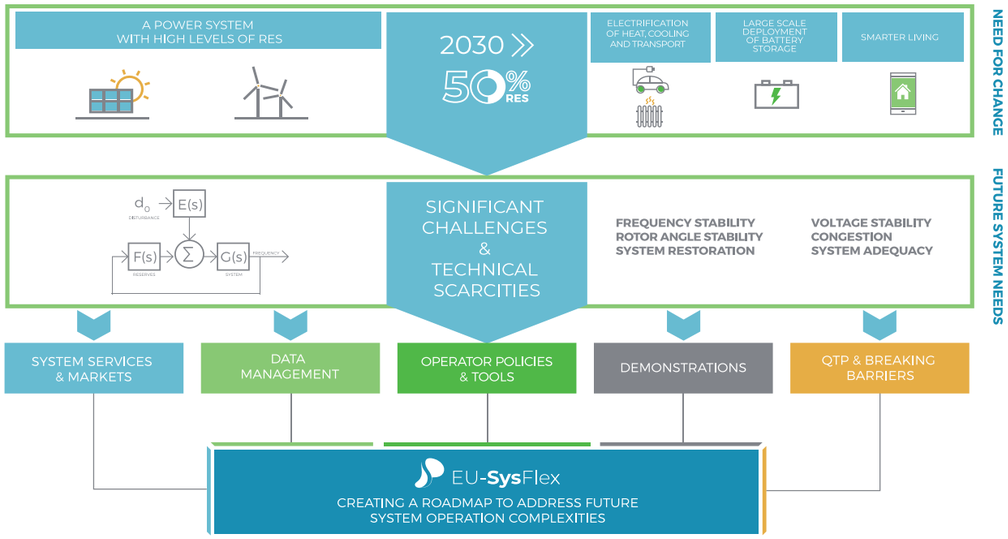
Qualification Trial Process and control centre integration

A Decision Support Tool is developed to optimize cross-border flows at the day-ahead planning stage, and to provide preventive and corrective suggestions across multiple periods in intraday planning. It will integrate the Real Time Dispatcher Training Simulator adding new services and flexibilities for TSOs. The other part of the work focuses on the Qualification Trial Process (QTP) by the TSO in **Ireland and Northern Ireland**. It includes five new trials qualifying new providers of System Services such as solar PV and new communication protocols for control and data acquisition, and trials demonstrating provision of System Services by aggregations of residential devices such as domestic batteries and EVs capable of discharging to the grid.

Next steps

The first years of the project underlined the technical and financial challenges arising from increasing share of renewables in the European power-generation portfolio, especially from variable non-synchronous resources. To tackle the financial challenges, market enhancements were studied and simulated, providing interesting potential mitigations such as increasing volume of reserves, designing smaller-granularity products closer to real-time, etc. To accompany the energy transition, these changes in market design, as well as ensuring revenues for providers of flexibility and capability, need to be deployed now.

Several industrial-scale demonstrations are currently running to test various processes to provide some viable solutions that help tackle the technical challenges. Some are addressing the observability and provision of flexibilities embedded in the distributed grids, at various voltage levels, and improve the TSO/DSO coordination to operate a more flexible power system. Others are developing advanced control and optimization approaches for distributed resources management to address the optimized capability of providing adequate energy and system services from RES-E, when aggregated with other resources and storage. The results and learnings are expected in the upcoming months. The field tests will prove the accuracy and advantages of the various tools and functions developed for the grid and VPP optimizations, leading the path to fully automated processes. The digital challenge represents the management of huge volumes of data, including increasing amounts of private data which benefit from interoperable and cybersecure solutions connected to the Data Exchange Platform.



Through the QTP learnings in Ireland, the integration of new and renewable technologies includes market and grid code arrangements, measurement standards, performance monitoring, forecasting and real-time control tools for the system operation. Furthermore, scaled up and tested in the Dispatcher Training Simulator, these experiences will be leveraged as operator protocols are devised, summarizing TSO and DSO concerns for high-RES-E system operation with service provision from non-conventional technologies.

The next step is to carry out a scalability and replicability analysis to understand how the innovations can be enlarged and deployed at a large scale in the European Power System. Together with a reliability analysis of the services provided and business-model studies, they will feed the roadmap to a low-carbon, secure and flexible power system.

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The EU-SysFlex project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.