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European Flexibility Roadmap

D10.5

EU-SysFlex

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ABBREVIATIONS AND ACRONYMS

AMR	Automatic Meter Reading
BC	Balancing Capacity
BESS	Battery Energy Storage System
BMC	Business Model Canvas
CBCM	Cross-Border Coordination Module
CEP	Clean Energy Package
CIM	Common Information Model
CM	Congestion Management
CNN	Convolutional Neural Network
DBA	Data Bridge Alliance
DEP	Data Exchange Platform
DER	Distributed Energy Resource
DPIA	Data Protection Impact Assessment
DPO	Data Platform Operator
DRR	Dynamic Reactive Response
DSM	Demand Side Management
DSO	Distribution System Operator
DST	Decision Support Tool
DT	Delivery Time
DTS	Dispatcher Training Simulator
EMS	Energy Management Systems
ER	Exploitable Result
ESCO	Energy Service Company
ESIC	Electricity System Improvement Canvas
EV	Electric Vehicle
FCR	Frequency Containment Reserve

FCR-N	Frequency Containment Reserve for Normal Operation
FFR	Fast Frequency Response
FPFAPR	Fast Post-Fault Active Power Recovery
FRR	Frequency Restoration Reserve
FSP	Flexibility Service Provider
GCP	Grid Connection Point
GDPR	General Data Protection Regulation
HEMRM	Harmonised Electricity Market Role Model
HV	High Voltage
ICT	Information & Communication Technology
IPR	Intellectual Property Right
KPI	Key Performance Indicator
LSTM	Long-Short Term Memory
LV	Low Voltage
MOPF	Multi-Temporal Optimal Power Flow
MV	Medium Voltage
NCAS	Network Calculation Algorithm System
PoC	Point of Connection
POR	Primary Operating Reserve
PSS	Power System Stabiliser
PST	Phase-Shifting Transformer
PV	Photovoltaic
QTP	Qualification Trial Process
RES-E	Renewable Energy Sources of Electricity
RoCoF	Rate of Change of Frequency
RPCD	Reserve Procurement Contract Duration
RPF	Reserve Procurement Frequency
RR	Replacement Reserve

RSF	Reserve Sizing Frequency
RSR	Reserve Sizing Resolution
RTDS	Real-Time Digital Simulator
SCOPF	Security-Constrained Optimal Power Flow
SE	State Estimation
SGAM	Smart Grid Architecture Model
SIR	Synchronous Inertial Response
SNSP	System Non-Synchronous Penetration
SO	System Operator
SOC	State of Charge
SOR	Secondary Operating Reserve
SRA	Scalability and Replicability Analysis
SSRP	Steady-State Reactive Power Support
STATCOM	Static Compensator
SUC	System Use Case
SVC	Static Var Compensator
TLQ	Traffic Light Qualification
TOR	Tertiary Operating Reserve
TSO	Transmission System Operator
UC	Unit Commitment
UXP	Unified Exchange Platform
VCE	Value Creation Ecosystem
VPP	Virtual Power Plant
VRES	Variable Renewable Energy Sources
VRG	Variable Renewable Generation

EXECUTIVE SUMMARY

Policymakers have set Europe on an ambitious renewable energy journey to deliver Net-Zero carbon emissions by 2050. This pioneering journey has far-reaching implications for many sectors, most notably energy and, by inference, electricity.

Along this journey, by 2030, over 50% of electricity demand in the pan European power system will be met by Renewable Energy Sources of Electricity (RES-E), much of which must come from variable renewable sources, namely wind and solar. It is estimated that across Europe, 350 GW of wind and 285 GW of solar are required to meet 2030 targets.

At present, electricity is mainly produced centrally by very large conventional power stations and transmitted across national and transnational power grids, down to distribution systems, and to where energy is consumed in our homes, factories and so on. While electricity will continue to be produced centrally at transmission level by renewable and other large generating facilities (both on and offshore), we are beginning to see the proliferation of decentralised and smaller sources of renewable electricity generation at the distribution level, right down to our homes, for example, in the form of rooftop solar photovoltaic (PV). This changes not only the dynamics but also the power flows in the energy system.

Moreover, demand for electricity is set to dramatically increase by 2050, from 20% of overall European energy use today to more than 40% of energy needs. A significant factor associated with this increase in demand is the electrification of our cars and other transport, along with industrial and domestic heating. It has significant implications for electricity systems, increasing demand, changing energy use patterns, potentially resulting in additional system constraints. At scale, this potentially presents significant challenges for power system operation both at transmission and distribution level.

On the other hand, if changing energy use patterns are managed correctly, the aggregation of generation and demand sources with storage capability can offer solutions and services to grid operators, an opportunity that also exists with grid-scale storage and networks assets.

One of the overriding challenges for grid operators through this transformational change is to continue to ensure balancing, stability, reliability and resilience of the power system, ensuring not only generation meets demand at all times, but also that the electrical characteristics of the power system are maintained within adequate operational parameters.

Considering the displacement of current fossil generation and its replacement with variable renewable technology such as wind and solar:

- Firstly, wind and solar are variable in nature and subject to weather conditions.
- Secondly, they are non-synchronous, as they are not by nature electromechanically synchronised to the system, i.e., they interface through power electronics to the power grid.
- Thirdly, conventional generation has inherent performance characteristics and capability which provide much of the grid services (traditionally called ancillary services) required to maintain system parameters.

As this form of power generation is displaced by variable sources of renewable generational this inherent capability diminishes and must be replaced.

Given the changing dynamics on the power system, it is imperative that power system operation becomes more flexible, adaptable and capable. This can only happen with the right technological, system and process changes, along with market enhancements to incentivise investment in the flexibility needed.

EU-SysFlex, a Horizon 2020-funded project on "System operation and flexibility solutions for integrating 50% renewables by 2030" aimed to address these challenges by identifying and demonstrating new types of system and flexibility services.

This flexibility roadmap incorporates the findings and results of the EU-SysFlex project to provide a pathway that facilitates large-scale renewable energy integration across Europe. It is built on the SRA (scalability and replicability analysis) of solutions from the project demonstrations, the analysis and investigations on technical scarcities, system services and market designs, system operator procedures, and data management.

Overall, the eight key messages and recommendations extracted and refined by the EU-SysFlex studies and trials, which serve as the fundamental core of this roadmap, are as follows:

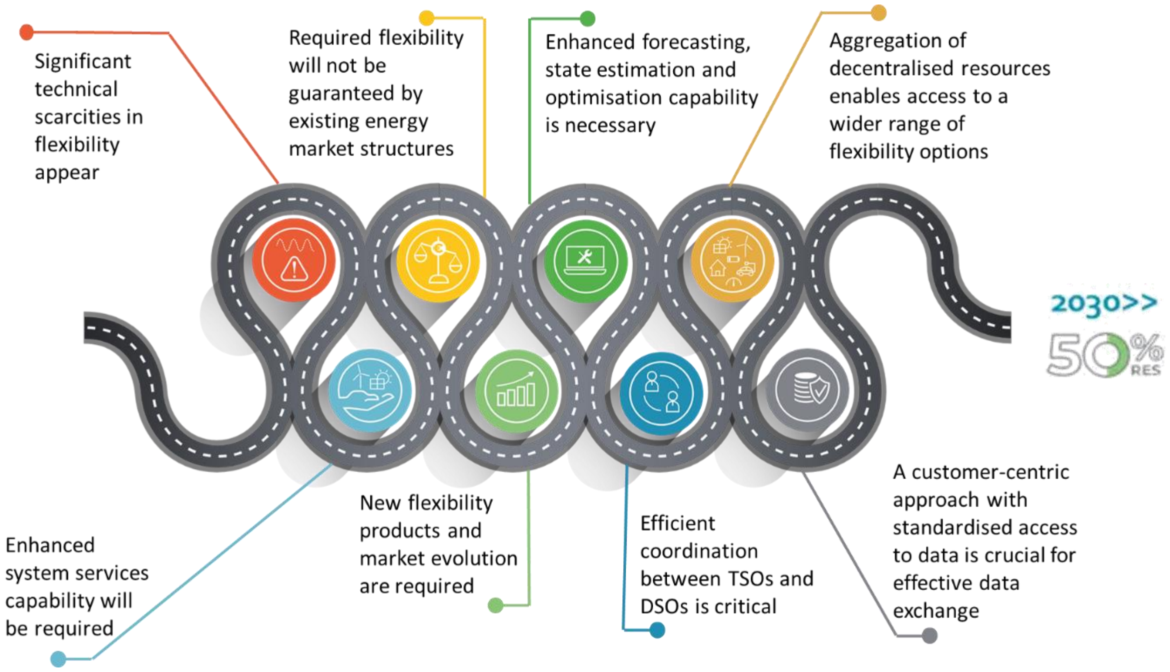
1. As we transition to a European power system with a high share of variable renewables significant technical scarcities in flexibility appear.
   Some technical scarcities represent emerging areas of concern, while others are well-known, but are exacerbated by the transition to high levels of renewables. The non-synchronous nature of wind and solar resources represents a particular challenge. All scarcities require mitigation measures to ensure continued safe, secure and efficient power system operation to support Europe's renewable and net-zero ambition.

2. Enhanced services will be required from a wide range of technologies in order to mitigate the identified technical scarcities and ensure the required system flexibility.
   In addition to enhancing the system services provided by existing resources, new resources, such as variable renewable technologies, energy storage, and demand-side response, can offer the required system flexibility. Active participation from all technologies, new and existing, is required.

3. Existing energy market structures will not guarantee the required flexibility and volume of system services to address the identified technical scarcities and support investment in low carbon generation.
   Relying on existing energy market structures will result in future financial shortfalls for all generating technologies, due to reduced energy revenues in the long-term horizon.

4. New flexibility products and market evolution are required to ensure the provision of sufficient system services capability to mitigate the identified technical scarcities.
   In addition to creating new flexibility products, unnecessary entry barriers to flexibility markets must be removed, to embrace new and emerging technologies, based on reviewing existing specifications for flexibility products and their incorporation in electricity markets.

5. New operator decision support tools with enhanced forecasting, state estimation and optimisation capabilities are required for the future power system to activate new flexibilities.
   Demonstrations were successful in showcasing the potential of a range of emerging technologies. However, rollout trials are required to fully understand their reliability and their ability to provide all of the flexibility required for an environment with high shares of wind and solar generation.
6. Efficient coordination between transmission system operators (TSOs) and distribution system operators (DSOs) is critical given the significant share of future resources connecting to the distribution network.
   Extensive trials and demonstrations, supplemented by scalability and replicability analyses, provide validation that a dedicated coordination approach is required, so that all assets connected at any layer of the power system can be utilised to the mutual benefit of both TSO and DSO.
7. 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.
8. A customer-centric approach including standardised access to data and data-driven services is crucial to guarantee stakeholder and information system interoperability for effective data exchanges at the European level.
   Interoperability is a key requirement for the future power system in which new and numerous players will handle and share large volumes of energy-related data. Data platforms based on standardisation can progressively achieve secure and privacy-respecting cross-border and cross-sector data exchanges.



THE EU-SYSFLEX KEY MESSAGES

1. INTRODUCTION

Over a four-year period from 2017, the EU-SysFlex project consortium has analysed different dimensions of future power system complexities. From a top-down perspective, ambitious renewable scenarios were explored and studied to identify which challenges arise, given the changing energy landscape by 2030 and beyond, what new capabilities and system services will be required and what mitigation measures can be put in place to address them. It is clear from this analysis that significant technical scarcities in flexibility appear as we transition to a European power system with a high share of variable renewable energy sources (VRES). In response, innovative system services capability will be required from a wide range of technologies, as well as enhanced flexibilities across all voltage levels at European scale. This will require significant market design and regulation changes to ensure investment in the flexibility required by system operators.

Through demonstration projects and trials conducted across Europe, technological capability to provide services to the grid at Distribution System Operator (DSO) level, Transmission System Operation (TSO) level, coordination across DSO/TSO as well as cross border data management and exchange were explored. Efficient coordination between TSO and DSO is critical to ensure more effective and efficient use of distributed flexible capability and to maximise the benefit to the overall power system. Aggregation of decentralised resources through Virtual Power Plant demonstrated access to a wider and more reliable range of flexibility options, including the participation of residential customers and a range of distribution connected assets. Efficient access, activation and optimisation of services from a larger number of smaller and decentralised sources requires not only coordination and market enhancements but also interoperability, secure management and exchange, and standardisation of data.

Finally, renewable integration and operation at high levels of variable renewable technology, such as wind and solar, require new operator decision support tools with enhanced forecasting, state estimation and optimisation capability.

Work Package 10 of the EU-SysFlex project has several main objectives: definition of key performance indicators (KPIs) for the industrial-scale demonstrations, performing scalability and replicability analysis (SRA) of the results from the demonstrations, and also integrating results from market studies and data management solutions, and, finally, providing a roadmap for development and deployment of innovative services needed to support the integration of variable renewable sources, storage and flexible demand technologies.

Utilising the results and outcomes of the EU-SysFlex project, the flexibility roadmap described in the following report outlines a pathway to help facilitate the integration of large-scale variable renewable energy sources across Europe, as well as the optimisation and maximisation of their use.

1.1 WHAT IS POWER SYSTEM FLEXIBILITY?

EU-SysFlex considers a broad definition of flexibility as the power system's ability to deploy its resources to respond to changes and uncertainties in demand and generation in the short, medium, and long term to ensure system stability and robustness. Additional flexibility considerations include voltage control, congestion management, system restoration, and system adequacy. Potential flexibility resources include (but are not limited to) conventional and renewable generation, demand-side management, and supporting technologies such as storage, SVCs (static var compensators), and STATCOMs (static compensators).

System services represent a set of services which are required to ensure that the system will have sufficient resources to meet its flexibility needs, while a system product defines the required supplier response, in order to fully or partly satisfy a given system service.

1.2 THE EU-SYSFLEX PROJECT

The EU-SysFlex project is a Horizon 2020 funded project which aims at addressing system operation and flexibility challenges associated with the integration of 50% renewables on the European power system by 2030. EU-SysFlex is a unique consortium comprised of 34 members, including transmission and distribution power system operators, aggregators of distributed energy resources, technology providers, research and academic institutions, and consultancies spread across 15 European countries. The project figures and the distribution of the partners are shown in Figure 1-1.

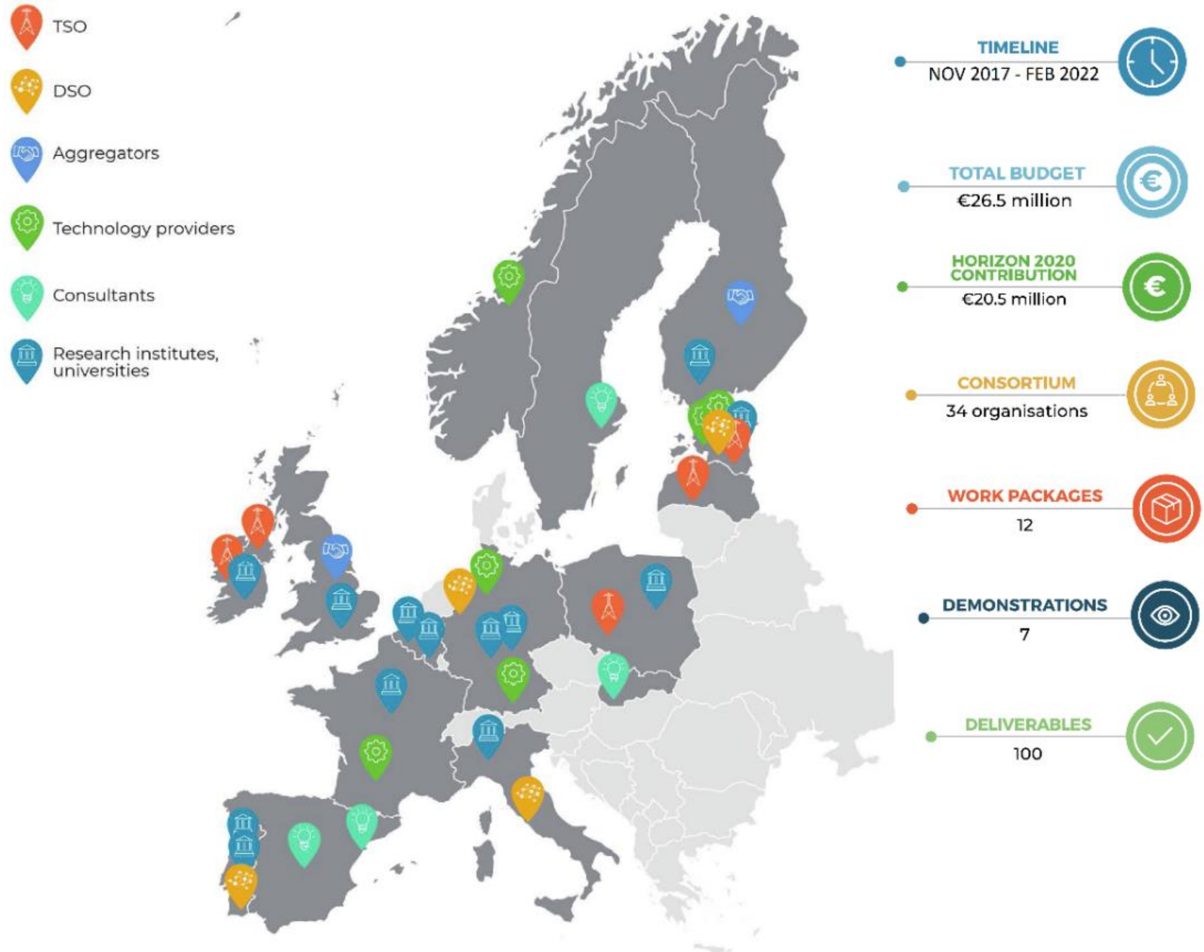


FIGURE 1-1: EU-SYSFLEX IN FIGURES

The EU-SysFlex project tests a high level of integration of renewable energy sources in the pan-European electricity system. It has identified flexibility issues and solutions associated with integrating large-scale renewable energy and creates a plan to provide practical assistance to power system operators across Europe. The overall concept of EU-SysFlex is that the transformation of the European system to incorporate a high share of RES can be better realised by integrating three elements: 1) a deep understanding of high-RES system technical shortfalls, 2) demonstrating the capability of technologies and innovative approaches to address these shortfalls and 3) responding to these shortfalls with an approach based on the provision of services incentivised by well-designed markets, rather than promoting specific technology for the provision of these services. The general approach of the project is shown in Figure 1-2.

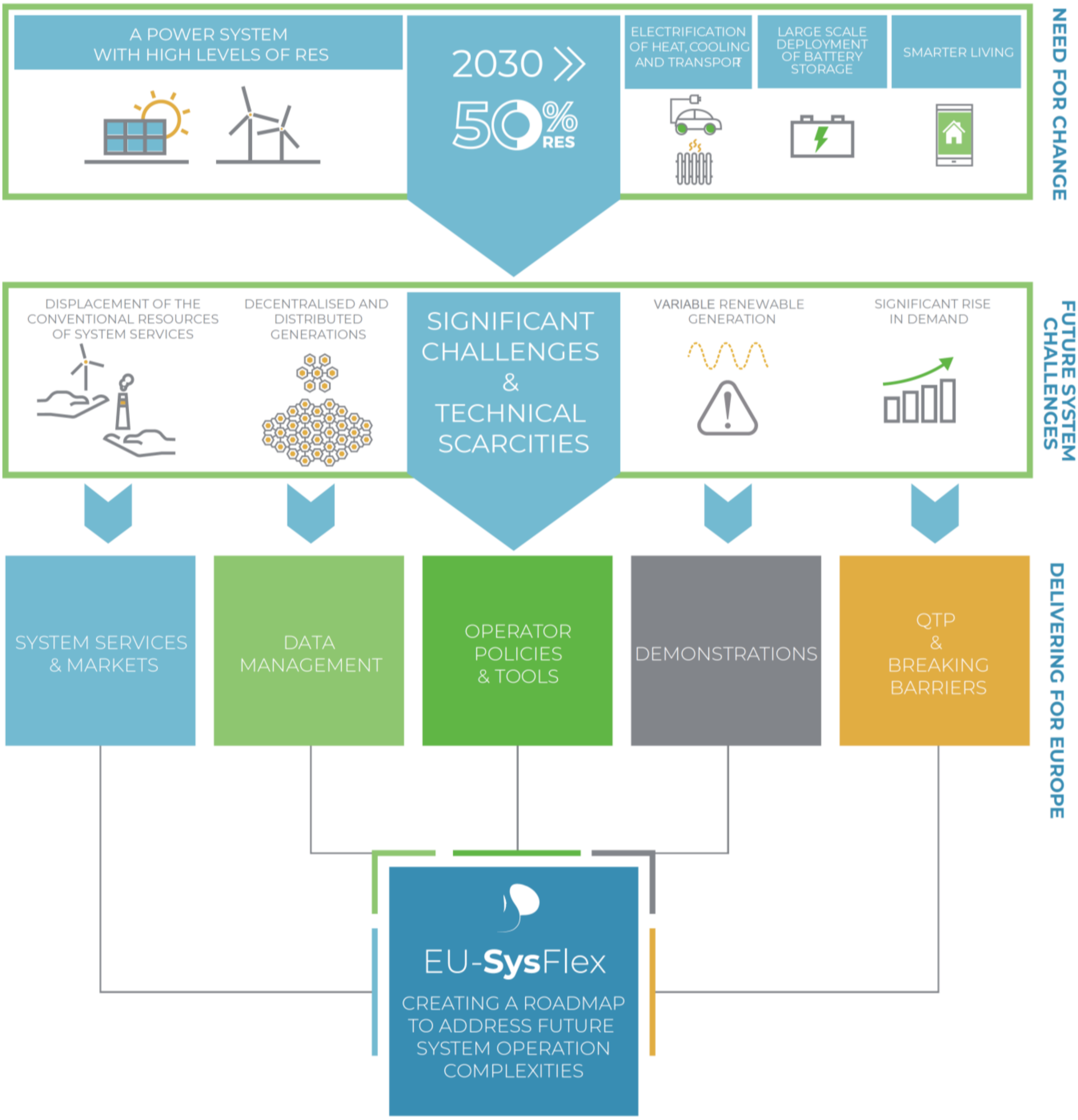


FIGURE 1-2: GENERAL APPROACH OF THE EU-SYSFLEX PROJECT

EU-SysFlex develops several high-RES scenarios and network sensitivities to assess the technical scarcities of the European power system from different points of view (frequency stability, voltage stability, congestion management, etc.). As previously mentioned, these technical scarcities are triggered by challenges that the power system will face to satisfy decarbonisation targets, such as for variable renewable generation, the significant rise and changes in demand due to electrification, displacement of thermal conventional sources of system services, and the increase in decentralised and distributed generation. By performing economic analysis, the project assesses the gap in revenues needed to incentivise the investment in renewable generations and required flexibility for the future European power system. The goal here is to demonstrate whether there are sufficient revenues under EU policies to support the investments required for delivering a higher level of system services to address the identified technical scarcities. Developing innovations for existing and new system services goes hand in hand with analysing the required flexibility products and market evolution. Advanced modelling techniques are used to assess product characteristics and corresponding market designs. EU-SysFlex also provides recommendations for data management in flexibility services and develops a customer-centric data exchange approach for standardised access to data and data-driven (flexibility) services, aimed at all stakeholders (transmission and distribution system operators, suppliers, flexibility providers, energy service companies, etc.) and enables cross-border data exchange.

Increasing the flexibility of the pan-European electricity system requires a comprehensive and all-encompassing vision that extends across a broad portfolio of new approaches, solutions and technologies. EU-SysFlex demonstrates different business use cases in eight field tests at various voltage levels and across Europe: Germany, Italy, Finland, Portugal (two demos), France, Ireland and Northern Ireland, and Estonia. The demonstrations and trials provide evidence of how the timely provision of these services will be achieved using new approaches to coordinate the resources, actors and new technology mixes that will be present in the future European system. They also highlight the need for new operating tools, effective and efficient coordination between the transmission system operators and distribution system operators, and aggregation of decentralised resources in order to facilitate their access to a wider range of flexibility options within flexibility markets.

1.3 THE FLEXIBILITY ROADMAP

This roadmap acts like a "compass", guiding all relevant parties in aligned directions towards the main objective. It also serves as a guide for individual power system operators along their journey towards decarbonisation, allowing them to recognise obstacles and collaborate with other parties, even if a dramatic shift in direction is necessary. Overall, the EU-SysFlex flexibility roadmap aims to communicate proposed strategic recommendations to a wide range of stakeholders: decision-makers, regulators, system operators, utilities, technology developers, ..., as depicted in Figure 1-3.

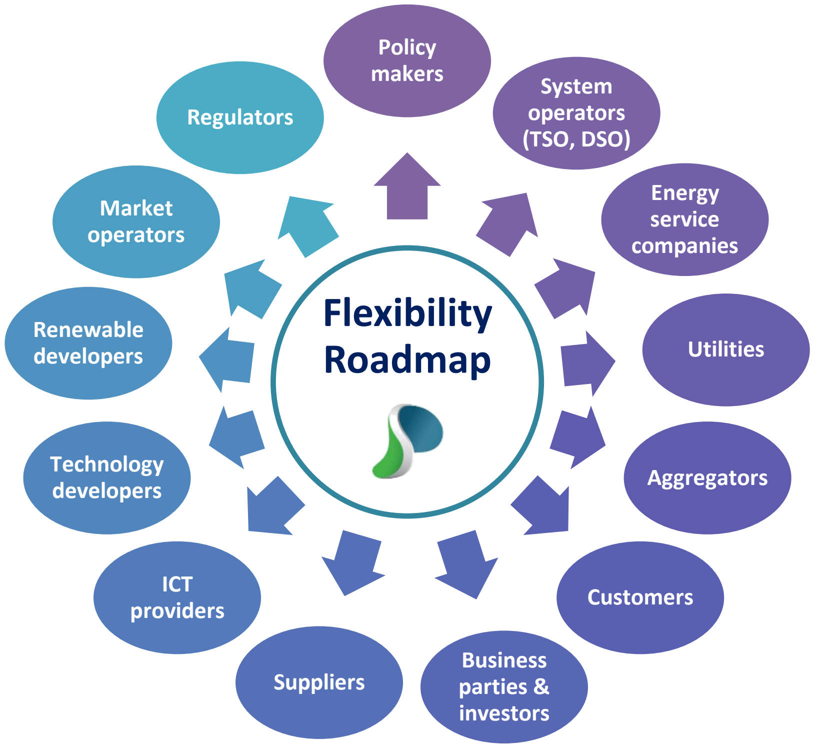


FIGURE 1-3: THE FLEXIBILITY ROADMAP'S TARGET AUDIENCES

The EU-SysFlex flexibility roadmap for European Power Systems incorporates the findings and results of the EU-SysFlex project. It provides a pathway that facilitates a high share of renewable energy integration across Europe. It relies on scalability and replicability of solutions from the project demonstrations, the analysis carried out on system scarcities, required mitigations and enhancement in services, market design, system operator procedures, and data management, as described before. The scalability and replicability analysis aim to assess how, and whether, those solutions tested in the field are scalable to large power system areas and replicable from one country/area to another. An additional factor which must be considered in a European context is the individual system and market dynamics within each state and synchronous area. Each power system, at a national and regional level, has its own unique characteristics and environment, for example the level of interconnection, the nature of the existing generation portfolio, system services market development, rules and regulations, etc. Implementation of common approaches and solutions at European level to maximise effectiveness and efficiency, while recognising the needs of individual states, is required. The approach taken by EU-SysFlex in developing this roadmap was to focus on key pan-European challenges which must be addressed to achieve our renewable ambition. These findings can assist in policy recommendations and in the development of detailed national and regional action plans.

The flexibility roadmap addresses some high-level questions that must be answered for the European power system to progress toward 2030 decarbonisation targets:

- What issues and scarcities will the EU power system face in 2030?
- Which solutions can be deployed to mitigate the technical scarcities identified?

- How do we support an appropriate mix of technologies to provide the needed technical solutions and system services?
- How do we enable the utilisation of technical solutions and system services?

The heart of this roadmap are key messages and recommendations extracted and refined by EU-SysFlex investigations and trials, organised into eight sections:

1. Technical scarcities,
2. Required flexibility,
3. Financial gaps,
4. Market evolution,
5. New operating tools,
6. TSO-DSO coordination,
7. Aggregation of decentralised resources,
8. Data management.

The roadmap also provides an overview of the EU-SysFlex demonstration projects and qualification trials, describing their objectives, features, methodologies, findings, achievements, and lessons learned. As mentioned before, these demonstrations and qualification trials have been conducted in Estonia, Finland, France, Germany, Ireland and Northern Ireland, Italy, and Portugal (two demos).

2. KEY MESSAGES FOR THE FUTURE EU POWER SYSTEM

FIGURE 2-1:EU-SYSFLEX KEY MESSAGES TITLES

2.1 TECHNICAL SCARCITIES

As we transition to a European power system with a high share of variable renewables significant technical scarcities in flexibility appear.

Some technical scarcities represent emerging areas of concern, while others are well-known, but are exacerbated by the transition to high levels of renewables. The non-synchronous nature of wind and solar resources represents a particular challenge. All scarcities require mitigation measures to ensure continued safe, secure and efficient power system operation to support Europe's renewable and net-zero ambition.

The technical characteristics of the power system are changing with the transition to high levels of variable non-synchronous (i.e. wind and solar generation), which is leading to technical issues and scarcities in essential capabilities of the power system for secure and stable operation.

With the decommissioning of conventional power generation, that traditionally provide reserves and system flexibility, technical scarcities begin to appear, not only in inertia and frequency control, but also in voltage and rotor angle stability as well as in congestion management and energy balancing. Amongst other levers, these scarcities provide evidence of the need for system services to come from a wider pool of resources, including both new and existing technologies. While some issues are well-known and mechanisms already exist for addressing them (such as frequency and voltage control), the transition to higher levels of non-synchronous renewables, and, therefore, the displacement of conventional generation, requires solutions and capabilities from newer and a wider range of resources, including renewable generation itself. These issues are emerging at both transmission and distribution system level and will require mitigation actions.

The EU-SysFlex Renewable Ambition Scenario, is built with 66% RES at a European level, over half of which are variable (wind and solar). Scarcities are evident even at “only” 34% VRES and need be solved to pursue the journey to net-zero. The severity and likelihood of the emergence of technical scarcities are system-dependent, and are strongly linked to the share of system demand that is met by variable and non-synchronous generation. Indeed, the more variable generation utilised to meet the demand, the more scarcities that are likely to appear and the greater the challenge in dealing with them. Technical scarcities are particularly evident for more isolated systems, such as Ireland and Northern Ireland power system, or the Iberian Peninsula, as the EU-SysFlex studies have shown. However, even a large synchronous system with strong interconnection, such as Continental Europe, experience scarcities in stability control, for example, during system split situations. Scarcities in congestion management are already present in some areas in Continental Europe such as Germany and spreading with higher shares of variable decentralised generation. Balancing also proves more and more challenging as variable generation increases, especially in the winter when demand increases and solar produces less, raising questions about seasonal storage and keeping flexible thermal plants.

Evidence from the EU-SysFlex project suggests that the Continental European system will experience more issues of concern and technical scarcities in key system support capabilities as it evolves with higher levels of variable non-synchronous generation.

A description of the EU-SysFlex project's studies on the technical scarcities and challenges of the future European power system is provided in Chapter 3.

2.2 REQUIRED FLEXIBILITY

Enhanced services will be required from a wide range of technologies in order to mitigate the identified technical scarcities and ensure the required system flexibility.

In addition to enhancing the system services provided by existing resources, new resources, such as variable renewable technologies, energy storage, and demand-side response, can offer the required system flexibility. Active participation from all technologies, new and existing, is required.

Power system simulations and analysis have shown that utilising a range of different technologies to provide system services capability effectively mitigates, or at least supports the mitigation of, the technical scarcities identified in stability control. Network technologies, such as synchronous condensers, STATCOMS, Static VAr Compensators, as well as renewable generation technologies, such as wind and solar generation, plus batteries and demand-side management, are found to be suitable technologies for mitigating a range of scarcities that will manifest themselves at high levels of renewables. This is a critical result, as these are the technologies that will inherently be online and operating at times of high renewables, while at the same time displacing conventional synchronous technology, such as thermal generation.

The project has also shown the value of cross-border and cross-voltage levels pooling of resources to enhance the flexibility potential to address scarcities in balancing and congestion management. Additional aspects such as the increasing share of energy storage in batteries and Electric Vehicles at national and pan-European scales showed that more variable energy could be integrated in the power mix while addressing other scarcities.

The required mix of solutions will need to be assessed holistically in order to consider trade-offs and synergies. The reason is that some scarcities can be mitigated by a range of different technologies and strategies, while some technologies can be more effective in mitigating a selection of different issues.

The key will be to identify the mix of technologies needed to ensure the reliability, stability and resilience of the power system while delivering value to consumers. One way to deliver this is to develop regulation and electricity market designs that incentivise investment in suitable technologies, providing choice, and treating all relevant technologies on a level playing field.

More comprehensive operational measures, such as redispatch, for mitigation of scarcities will still be essential for supporting the transition or evolution of the power system towards decarbonisation, in conjunction with the arrival of system services provision from non-synchronous technologies.

The EU-SysFlex demonstration projects and trials have proven that decentralised technologies can provide some of the required system services capability. These technologies include, but are not limited to, batteries, electric vehicles, demand response, wind generation, static var compensators, and virtual power plants. While many flexible resources are connected to the Distribution Grid, their capability to provide services to both Transmission and Distribution Operators has been determined. Demonstrations in this project have shown that their capabilities can be enabled through enhanced TSO-DSO coordination and platforms.

In Chapter 4, more details are provided about potential options for mitigating the identified technical scarcities.

2.3 FINANCIAL GAPS

Existing energy market structures will not guarantee the required flexibility and volume of system services to address the identified technical scarcities and support investment in low carbon generation.

Relying on existing energy market structures will result in future financial shortfalls for all generating technologies, due to reduced energy revenues in the long-term horizon.

In an energy-only market, and as the power system transitions to higher levels of variable generation, the number of hours with zero system marginal prices increases. This is a situation where additional generation can be obtained without increasing the market price, as is the case with wind and solar generation, since their marginal cost of production are almost zero due to their "free" energy sources. As a result, energy market revenues are falling for all generating technologies, and, in particular, revenues for the variable renewable resources themselves decline more rapidly. In the case of conventional technologies, revenues will fall due to the market price but also to the reduction in running hours and the increase in start-ups and shut-downs expected.

Analysis has shown that with decreasing market prices, existing energy markets will not provide adequate revenues to fund future sustainable generation portfolios. Additional and adequate revenue streams are needed in order to ensure that the required flexible and low-carbon technologies and capabilities are present in the system.

One way to do so is to maintain specific incentives to develop renewable energy sources. The carbon content of energy sources should also be reflected in the costs to favour low-carbon technologies.

Using Ireland and Northern Ireland as a case study, the analysis has demonstrated that enhanced System Services can provide a revenue stream to improve the financial viability of both VRES and conventional technologies.

A market-based rather than a regulated approach for the acquisition of flexibility for new and existing system services is the preferred solution. However, flexibility markets need to send clear long-term signals to investors and incentivise the participation of new actors and resources. In the absence of such markets, sub-optimal portfolios will be obtained, which can increase operating costs and CO2 emissions with increased renewable energy curtailment, due to insufficient flexibility and system services capability at certain times.

A regulated approach may be required where challenges exist for implementing market-based solutions for the required system services in the short to medium-term, in order to facilitate the integration of higher levels of VRES, and/or when the current availability of assets in the market does not guarantee sufficient availability of system services to facilitate the establishment of a competitive liquid market. However, even with a regulated approach, relevant early-stage markets should be developed (e.g. secondary trading of certificates) with a view to moving gradually towards a fully market-based approach.

The financial challenges that the European power system faces in providing sufficient flexibility for the transition to a higher share of renewable energy are discussed at the end of Chapter 3.

2.4 MARKET EVOLUTION

New flexibility products and market evolution are required to ensure the provision of sufficient system services capability to mitigate the identified technical scarcities.

In addition to creating new flexibility products, unnecessary entry barriers to flexibility markets must be removed, to embrace new and emerging technologies, based on reviewing existing specifications for flexibility products and their incorporation in electricity markets.

As the system transitions to increasing levels of VRES, system scarcities arise, and system services help mitigate them. The design of flexibility products to provide system services and the development of their associated markets is a dynamic process. As a result, regular assessment and revision to ensure "fit for purpose" solutions from a system operation and investment perspective are required. Furthermore, partial design improvements are worthwhile and not all changes to products, services and markets need to be introduced at the same time. A step-by-step approach to adapt markets should be considered. However, whenever possible, the speed of change must be implemented in a transparent and planned manner to facilitate appropriate investment considerations by potential market participants.

Currently, there is a large variety of flexibility products across different member states. These products were grouped in this project according to the system services they are designed to provide, which allowed EU-SysFlex to identify some potential gaps in the products required to ensure that all future system needs are addressed. Based on this, new innovative products were proposed including synchronous inertial response, fast post fault active power recovery, dynamic reactive response, ramping products and congestion management products.

When considering the design of flexibility markets, EU-SysFlex identified important recommendations:

- There is no one-size-fits-all approach across Europe. The technical characteristics of each system should be considered, and the design adapted accordingly.
- Close to real-time markets have advantages – as better information and data become available, the need to reserve upfront flexibility by system operators to address uncertainty decreases. Furthermore, close to real-time markets facilitate Flexibility Service Providers (FSPs) to develop more accurate forecasts of their available capacity and, as a result, they can take part in the market in a more efficient manner. However, new and more complex tools are required to deal with the volume and frequency of data to process. In addition, some FSPs (e.g., industrial consumers) could find it more difficult to operate in these markets as they require longer preparation times.

The following challenges should be considered when designing flexibility markets:

- ✓ Methodologies to share cost and benefits between TSOs and between TSOs and DSOs–methodologies will include both market and system operational costs (e.g. cost of coordinating SO-SO operations) and common investment costs.

- ✓ Approach to incorporate grid limitations into market models – Grid constraints should be captured in the relevant phases of the flexibility market process.
- ✓ Effect on prices of demand response and energy storage - The introduction of demand response and energy storage drives a flattening effect on potential price increments
- ✓ Providing sufficient stable investment signals to ensure appropriate level of investments in generation and other flexibility sources.

For certain services, both TSOs and DSOs may want to use the same flexibility at the same moment in time. Therefore, it should be defined how such flexibility is allocated. An important feature of this flexibility optimisation is whether it is performed using a centralised or decentralised approach. Both options are found to be feasible. While a centralised approach is more likely to provide a system-optimal result, a decentralised optimisation can deliver similar results provided appropriate grid information is shared between the parties.

For joint products (products that could cover more than one system service), the project found that this could raise barriers for some flexibility providers. A joint product would have additional technical requirements, which could mean that some FSPs could not deliver the product, while they are still able to deliver one of the separated products. However, without quantitative analyses, it is difficult to undertake a final assessment of whether joint procurement of any selected services is more beneficial for system efficiency than separate procurement. The trade-off between potentially decreased costs (due to synergies between products, services and processes) and increased complexity will depend on the national situation. In general, joint procurement of system services could reduce transaction costs, increase liquidity, decrease the volume of flexibility needed, and decrease strategic behaviour in markets. On the contrary, the timeframe for service optimisation, including the coordination of SOs, might not be sufficiently aligned, and a joint algorithm to select flexibility and/or coordination between SOs would probably be more complex.

Chapter 5 explores market evolution and how it supports the required system services.

2.5 NEW OPERATING TOOLS

New operator decision support tools with enhanced forecasting, state estimation and optimisation capabilities are required for the future power system to activate new flexibilities.

> Demonstrations were successful in showcasing the potential of a range of emerging technologies. However, rollout trials are required to fully understand their reliability and their ability to provide all of the flexibility required for an environment with high shares of wind and solar generation.

Enhanced forecasting capability of demand and renewable generation, along with the inclusion of advanced optimisation and estimation approaches will be essential tools in system operation environments with a high share of variable RES. Such tools and capability can provide an accurate estimation of the production from renewable generation for inclusion in scheduling/unit commitment calculations, and thus should result in more reliable estimation of the flexibility capability, and more accurate service market bids. It also plays a key role for aggregators; since forecasting and optimising the availability of distributed energy resources (DERs) are vital to ensuring successful market operation (to define optimal bidding sizes and times, and to define the available potential in current and future scenarios). Thus, developing high-performance tools for forecasting, estimation, and optimisation is essential for both system operators and service providers.

Implementation of testing platforms, or trial processes, could effectively help system operators to assess the "real world" performance of new technology types (or existing technology types providing new services). The result of such assessments can serve as a baseline for benchmarking future performance and qualification of new participants via a more streamlined, standardised process. The information of different technology features and limitations could also help to identify barriers to participation in capacity, energy and services markets by sustainable technologies, which could be assessed and eventually circumvented.

Today's qualification and performance verification methods applied by TSOs to assess the quality and compliance of services provided are primarily designed for conventional generation units. These methods need to be revised by SOs, while considering renewable generation specificities (e.g. reserve provided by a generator based on variable baseline power instead of constant baseline power).

System operator Energy Management Systems (EMS) need to evolve, and control centre engineers should be regularly trained, to be prepared for extreme scenarios that may manifest themselves on the future European power systems. Robust, modular, vendor-agnostic solutions are required to facilitate interoperability among EMS components between control centres.

Data requirements, in terms of the volume of data to be collected, stored, analysed and communicated for prediction and monitoring of flexibilities, are likely to increase significantly due to increased demand for flexibility services and the trend towards provision by smaller units. Therefore, more advanced models, based on machine learning, are needed for baseline calculation and forecasting. Furthermore, novel privacy-enhancing technologies may be needed for transferring private data, such as baselines.

New flexibility resources, primarily from distributed small-scale devices, do not (individually) have the same reliability as traditional solutions. However, ignoring lower-reliability resources will trigger investment in traditional solutions that provide reliable grid services, but in a less favourable way from a decarbonisation point of view or at a higher cost, due to overinvestment in capacities, to back-up variable energy sources and small-scale solutions. The reliability performance of new resources should be assessed and monitored at high granularity considering their temporal characteristics, and risk analysis should be integrated with techno-economic optimisation processes to support system operators using system services from these new resources.

The possibility of distributed resources offering services to the transmission grid represents a challenge and opportunity for both DSOs, who must manage distribution networks where resources behave in new and unexpected ways, and TSOs, who previously could rely upon well-understood conventional solutions to meet system needs. Both TSOs and DSOs must study innovative methods and improve their decision support tools, to solve network congestion, voltage violations and maintain system stability at high system non-synchronous penetration levels, while also maximising the hosting capacity of both networks, while facilitating the provision of system flexibility. In order to better integrate VRES, we firstly need improved distribution network observability.

The EU-SysFlex demonstration projects 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. These tools have been implemented in field tests, and their performance has been evaluated by off-line simulation and real-time tests. Furthermore, scalability and replicability analysis has been used to validate the practicality of these solutions.

Section 6.1 delves more into the role of operating decision support tools for system operators in future power systems with a higher share of RES. In addition, the methodologies and capabilities that have been implemented and tested in the EU-SysFlex demonstration projects will be introduced in section 6.2.

2.6 TSO-DSO COORDINATION

Efficient coordination between transmission system operators (TSOs) and distribution system operators (DSOs) is critical given the significant share of future resources connecting to the distribution network.

> Extensive trials and demonstrations, supplemented by scalability and replicability analyses, provide validation that a dedicated coordination approach is required, so that all assets connected at any layer of the power system can be utilised to the mutual benefit of both TSO and DSO.

With an increasing share of generation connecting to distribution grids, voltage violations, congestion and back-feed phenomena are becoming challenging. At the same time, increasing flexible capability is being connected to the distribution system. There is, therefore, an increasing need for TSO-DSO coordination to utilise all solutions for congestion management and voltage control to ensure that operational security limits are not violated on both the TSO and DSO networks. Observability and availability of active and reactive power increasingly connected to Distributed Networks is key for TSO to continue operating with optimal efficiency. The required system flexibility needs to be achieved with increased cost-efficiency by avoiding countermeasures and exploiting synergies between system operators, through collaboration and innovative approaches which ensure the provision of system services.

Significant opportunities exist to support even closer cooperation of distribution and transmission system operators, including the definition of common flexibility products, joint prequalification and procurement of system services, coordinated grid impact assessment to identify restrictions for system service activation, activation of the same flexibility for both TSO and DSO needs, and settlement of system services with costs sharing strategies.

For certain services, both TSOs and DSOs may want to use the same flexibility at the same time and the flexibility optimisation can be performed using a centralised or decentralised approach. A centralised approach is more likely to provide a system-optimal result. However, it is very challenging from computational and control points of view, since it requires centralised electricity markets for all power generation plant (including DERs) and centralised system operation. It requires a central entity that integrates TSO and DSO system operation to optimise the whole system. Therefore, it may not be compatible with existing operational structures whereby a TSO focuses on national transmission system operation, while DSOs operate distribution networks. The performance difference between incremental coordination and simultaneous coordination can be facilitated if the appropriate information is shared between the parties, market operation is close to real-time (e.g. 15 - 30 mins ahead) and distribution network operation is quite flexible (e.g. using smart grid technologies).

To enhance coordination between TSO and DSO, and improve grid observability, data exchange enabling access to necessary data from resources connected to the distribution network is vital. A 'flexibility platform' concept has been demonstrated in EU-SysFlex, enabling easy access to the market for distributed and aggregated resources, as well as efficient implicit TSO-DSO coordination. To ensure interoperability of flexibility services, one needs to focus on data interoperability next to harmonising regulatory/business processes. Therefore, several system use cases were designed for flexibility prequalification, bidding, activation and verification to address issues of homogeneous and secure data management through the concept of Data Exchange Platform. Proper data management contributes to the participation of stakeholders across geographical borders and for any asset.

In addition to the required coordination between TSO and DSOs, cross-border coordination between system operators (mainly TSOs) is vital in improving system efficiency, as it enables pooling flexibilities across countries and increased generation from less flexible capacity, both "slow" conventional and renewable technologies, which is often cheaper. This happens because balancing capacity exchange allows importing flexibility from other control areas, thus reducing the technical constraints on online capacity within a control area (freeing up low-marginal cost capacity). Cross-border coordination allows reducing the overall need for balancing capacity (and, therefore, reduces the need for "back-up capacity"). The benefits of a coordinated approach are more significant as the share of renewables increases.

Section 6.3 presents the techniques and measures offered by the demonstration projects for enhanced coordination between the TSO and DSO.

2.7 AGGREGATION OF DECENTRALISED RESOURCES

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 pooling of different types of variable and less predictable resources through aggregation can enhance forecasting capability, reduce imbalances, and increase overall commercial viability. So-called virtual power plants represent one solution to prevent shortfalls of individual assets through optimal use of multiple resources, which would increase the availability and enhance the performance of system services by aggregating and coordinating diverse assets. This has been demonstrated in the multi-services provision of the VPP in this project. Energy storage facilities such as BESS and pumped storage are essential assets for VPPs as they increase the flexible capability and availability of the services, allow them to provide power up and down or to consume or generate energy, perform price arbitrage on markets and handle VPP renewable generation deviations. Even within current market structures, VPPs offer a solution to support the participation of renewables in existing market products while preventing shortfalls of individual assets.

Smaller distributed resources could also provide system services. Aggregation, including storage assets, improves efficiency in reliability (delivering services when needed), range of services capability, as well as, cost-efficiency. This increases system operator confidence in using the resources and enables better risk management at the aggregator and system levels. Aggregation also simplifies system operator management of service providers by reducing the number of parties to interact with.

The activation of aggregated DSO flexibility resources for TSO needs should appropriately consider distribution grid operational needs. As a result, the strong link between aggregation and coordination shall not be overlooked; activation of the aggregated flexibility must not compromise grid security.

Aggregation could also enable a significant volume of system services from small, and very numerous, demand-response resources down to residential level. In this sense, low entry barriers and empowerment of consumers to choose between different aggregators are key elements to encourage smaller customers to actively participate in system services markets through aggregation. The characteristics of aggregation platforms (easy connection of assets, standardised interfaces and communication) also play a key role in promoting replicability and scalability. A reliable and agile platform is essential to integrate different services. Even though the main participants in the flexibility market are system operators, aggregators, large generation and demand-side units, there are also some interactions with end-customers, i.e. prosumers. The 'Affordable Tool' developed by EU-SysFlex for aggregators can provide easy access to the market.

In order to remotely operate and control a VPP, or an aggregated solution composed of distributed resources that are not necessarily geographically close, the ICT (Information & Communication Technologies) challenges are significant, not only concerning stable and robust data exchange capability requirement, but also the cyber security aspects.

In three of the demonstration projects, EU-SysFlex designed and tested VPPs, in the field (Finnish, and Portuguese VPP demonstrators), and in a dedicated concept grid (French VPP demonstrator). In these demonstration projects, the required optimisation and forecasting tools, control and communication units, as well as the energy management system, were developed for the efficient performance of VPPs in real-time operation. In addition, EU-SysFlex successfully developed and tested the aggregation of small, so far untapped, flexible assets on the medium and low voltage grid to provide system services to the TSO and meet the needs of the DSO in Finnish demonstrator.

A summary of the findings of the demonstration projects on the aggregate requirements and frameworks will be provided in Section 6.4.

2.8 DATA MANAGEMENT

A customer-centric approach including standardised access to data and data-driven services is crucial to guarantee stakeholder and information system interoperability for effective data exchanges at the European level.

> Interoperability is a key requirement for the future power system in which new and numerous players will handle and share large volumes of energy-related data. Data platforms based on standardisation can progressively achieve secure and privacy-respecting cross-border and cross-sector data exchanges.

A customer-centric conceptual data exchange model for an energy flexibility market serving all stakeholders (TSOs, DSOs, suppliers, flexibility providers, ESCOs, etc.) should enable cross-border and cross-sector data exchange. The approach further includes a data role model, with new roles illustrating the increasing importance of data exchange in the energy sector. The focus is on data platforms, but the model should enable a mix of different data management models (centralised, decentralised, distributed) and governance models (standards-based, open-source).

The European electricity sector has put in place a robust methodology based on a system-approach, which promotes interoperability by using standards (Use Case definition, HEMRM, CIM, SGAM). It would be valuable to extend this approach to other energy vectors, and to cross-sector domains through "CIMification", as proposed by EU-SysFlex. CIM (Common Information Model) profiles are recommended for flexibility data exchange and private data exchange.

Existing data protection and cyber security legislation and standards provide generally sufficient guidelines on how to ensure data protection through technology design. However, sufficient resources need to be invested into the privacy domain by system operators and other stakeholders to enable privacy by design. There is a lack of communication to exchange data about cyber incidents, both in the energy sector in general, but also in the energy data exchange domain specifically.

A data framework can be designed to match all the identified big data requirements, whereas the framework relies on a combination of various open-source components, and not just one unique multi-purpose component.

Based on interviews performed with European data platform operators, there is a focus on increasing the value provided by platforms, e.g. increasing the volume and type of available data, as well as allowing third-party applications to connect to the platform. A business model analysis highlighted that the challenge mainly relates to the use of private data based on customer consent, including smart-meter and sub-meter data. However, application owners exist who can transform data to value, and the data market could also contribute to increase data value, incentivising customers to share their data in exchange for services and/or additional revenues.

Several demonstrators within EU-SysFlex proved the usability of the approach based on the Data Exchange Platform to exchange different types of data (e.g. meter data, flexibility data) between any stakeholders (e.g. system operators, flexibility providers, data hubs, other data platforms), including across country borders and across sectors. Adopting this distributed data exchange approach, a single API is provided, and multiple, different connections can be avoided, while ensuring secure and privacy-respecting data exchange. Empowering customers can be further strengthened by providing single points for data access. Furthermore, such customer portals can facilitate access to services based on the supplied data to choose between different applications and energy efficiency services provided by ESCOs, flexibility services provided by aggregators and any other services provided by other emerging stakeholders.

Section 6.5 outlines the project's data exchange concepts, as well as the findings and recommendations for various aspects of data management.

3. WHAT ISSUES AND SCARCITIES WILL THE EU POWER SYSTEM FACE IN 2030?

In order to identify the challenges associated with the pan-European power system transitioning to high shares of variable renewable energy sources, it was first necessary to develop a) a set of comprehensive high renewable scenarios, and b) detailed models of the power system. The combination of scenarios and power system models allowed detailed simulations and analyses to be conducted.

3.1 SCENARIOS

A set of coherent and transparent scenarios for the pan-European power system, which are consistent with the aims and objectives of the EU-SysFlex project, were developed. The scenarios in EU-SysFlex are a crucial starting point for the technical and market modelling analysis, which is central to the project. All scenarios and network sensitivities developed have a least 50% of the annual electricity demand met by renewable sources by 2030 (50% RES-E) to align with European Climate Policy.

Two core scenarios were developed for the pan-European system (Energy Transition with 52% RES-E and Renewable Ambition with 66% RES-E). The 52% and 66% RES-E figures are the average figures across the pan-European power system for each of the scenarios. These values can be higher or lower for individual member states. These scenarios define the installed generation capacities by fuel type, demand, interconnection and storage portfolios to be used. They also include consideration of demand electrification based on increased adoption of electric vehicles and electric heating, as well as consideration of interconnection capacity between countries. The specifics of the scenario development process and the details of each of the scenarios are available [D2.2][1].

In addition to the percentage of RES-E in the scenarios, the percentage of variable non-synchronous renewable resources is of particular interest to the EU-SysFlex project. This interest stems from the fact that the majority of development in renewables over the coming years will be in wind and solar generation, which are variable in nature, and also due to the results of a literature review [D2.1], which found that the challenges of integrating high levels of renewable generation are primarily seen at times of high variable non-synchronous generation penetration. In EU-SysFlex, VRES is typically considered to be wind generation and solar PV. Overall, the share of VRES in 2030 reaches 24% in Energy Transition and 35% in Renewable Ambition for the whole pan-European power system. The share of variable renewables varies from member state to member state and is reflective of individual generation portfolios and national renewable policies, reaching as high as 71% for some member states.

While Spain, Portugal, Denmark and the island of Ireland all have high VRES levels in the scenarios (see Figure 3-1), there is one major difference: Spain, Portugal, and Denmark are all well interconnected with neighbouring countries, to a much greater extent than the island of Ireland. Consequently, it was deemed vital to assess the different synchronous areas and other parts of the European system separately. This led to the development of

[1] The references are listed at the end of the document in the section titled "Project Deliverables".

network sensitivities. These network sensitivities were developed to stress particular parts of the European network in order to examine further technical scarcities in greater detail. They reflect more ambitious national policies, e.g. the Low Carbon Living scenario for the Ireland and Northern Ireland power system (70% RES-E), or to analyse the impact of some technology choices on the power system, e.g. High Solar for the Nordic system, or Distributed Renewables for the power system in Poland, and enabled analysis of unique or specific areas of the European power system.

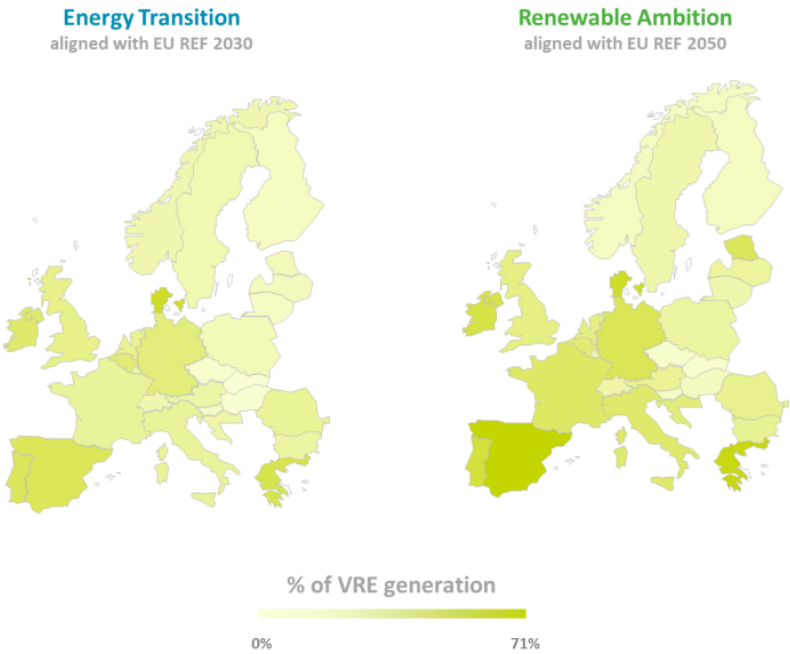


FIGURE 3-1: SHARE OF VARIABLE NON-SYNCHRONOUS RENEWABLE GENERATION (WIND AND SOLAR) FOR POWER GENERATION FOR ENERGY TRANSITION (LEFT) AND RENEWABLE AMBITION (RIGHT)

While it has been mentioned above that it is crucial to consider the share of VRES in conjunction with the share of RES, it is important to note that these are annual average figures. Perhaps of greater importance in this project is the consideration of the instantaneous share of variable non-synchronous renewable resources, such as wind and solar generation. As non-synchronous generating technologies are connected via power electronic control-based interfaces, they are inherently different to conventional generation. Thus, the concept of SNSP (System Non-Synchronous Penetration) becomes relevant. SNSP measures the amount of non-synchronous generation, such as wind and solar**,** on the system, as a percentage of demand at each instant in time. In some member states and synchronous areas, the instantaneous penetration of renewables could approach 100% for some hours of the year (see Figure 3-2). It is therefore worth paying particular attention to these hours, since they are deemed the most challenging from a system operational point of view.

With such high instantaneous renewable penetration levels, there would be very few conventional plants online and operating, which represents a significant paradigm shift from the traditional view of power system operation. Traditionally, large conventional power plants provided the bulk of the energy required to meet the system demand. These plants also inherently provide most system services to support and enable the safe, secure and reliable operation of the system. Consequently, it is not difficult to anticipate that significant technical challenges and technical scarcities could emerge in the transition away from large conventional fossil fuel power plants towards variable renewable generation sources, such as wind and solar. The literature review identified that the main technical scarcities are likely to appear in the domains of frequency and voltage control, rotor angle stability, congestion management and system restoration [D2.1]. For clarity, a technical scarcity can be loosely defined as a shortage of something that the power system has traditionally had in good supply, which is needed for its safe and reliable operation.

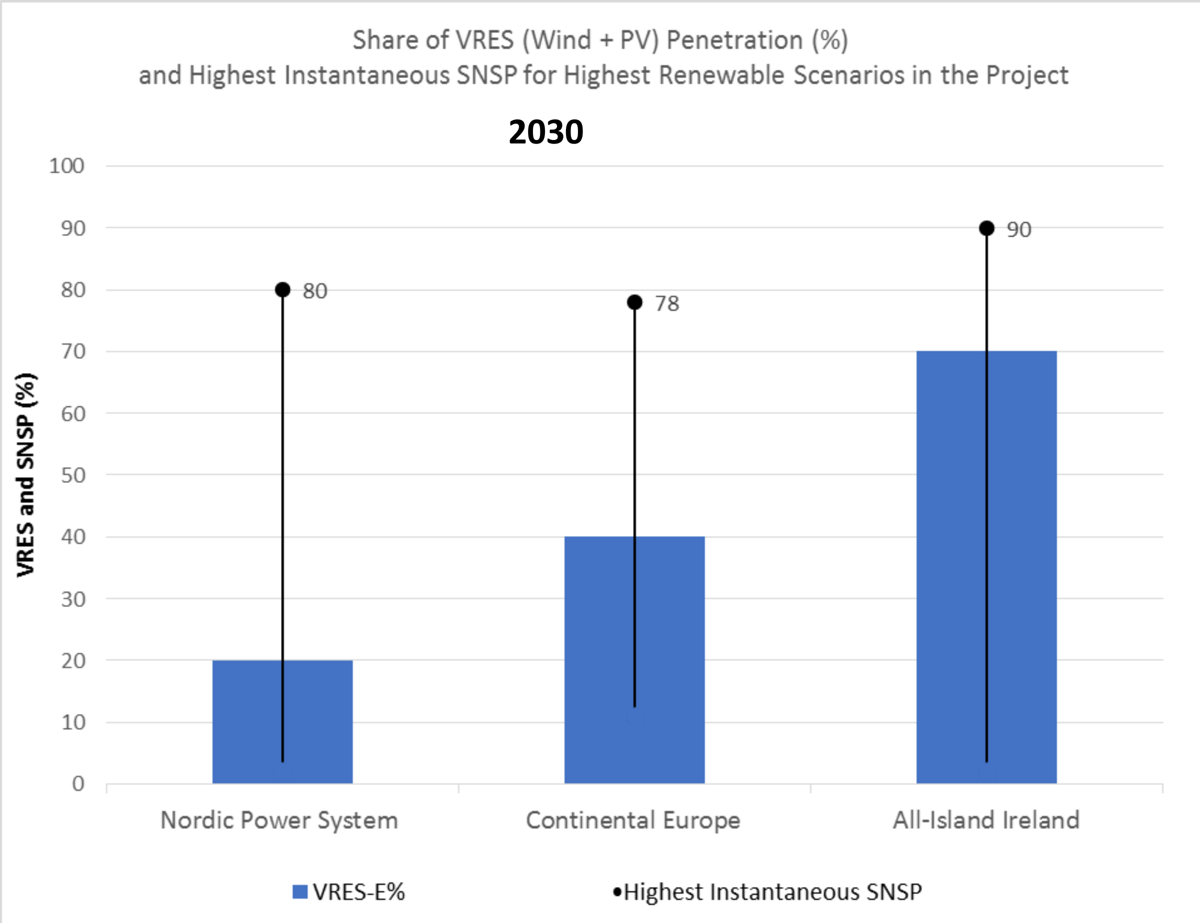


FIGURE 3-2: SHARE OF VARIABLE NON-SYNCHRONOUS RENEWABLE GENERATION (WIND AND SOLAR) FOR THE SYNCHRONOUS AREAS STUDIED IN THE PROJECT AND THE HIGHEST INSTANTANEOUS LEVELS OF NON-SYNCHRONOUS PENETRATION

3.2 MODELS AND SIMULATIONS

Due to the unique nature of each of the synchronous systems considered within EU-SysFlex (Ireland and Northern Ireland, the Nordic system, and the synchronised Continental European system) and the different generation portfolios being considered, it was identified that the full range of scarcities would not arise in all three synchronous areas. Thus, not all systems needed to be studied for all scarcities. Instead, focus and attention were placed on the relevant scarcities for each synchronous area. The assessment of scarcities is power system-specific. To this end, specific models have been developed for the simulations, and detailed analysis has been performed for the following combinations of system and scarcity: a detailed model of the Ireland and Northern

Ireland power system (all scarcities), a detailed model of the Polish transmission system that is connected to an approximate model of neighbouring countries (voltage and rotor angle), a reduced six node model of Continental Europe (frequency), a simplified frequency stability model of the Nordic system (frequency), and a subset of the Continental European system (congestion). To assess the scarcities, various stimuli were applied, and thousands of simulations were conducted. Full detail on the models and methodologies can be found in [D2.3].

3.3 TECHNICAL SCARCITIES

In EU-SysFlex, by examining three different synchronous areas with increasing levels of non-synchronous generation penetration (Nordic, Continental and All-Island), it was clearly found that increasing levels of non-synchronous generation, and consequently reduced numbers of synchronous machines on the system, leads to scarcities in system capability and technical challenges that must be resolved. Details of the analysis and findings are available in [D2.4].

3.3.1 FREQUENCY CONTROL

A direct consequence of increasing non-synchronously connected generation (PV and Wind RES technologies) is a decline in power system rotational energy or system inertia, due to a reduction in the number of synchronous machines, i.e. conventional power plant, on the system, leading to higher Rate of Change of Frequency (RoCoF) values following a disturbance. Inertia scarcity has therefore been investigated across the various systems under consideration. It has been observed that increased RES levels result in an overall trend towards reducing system inertia, increasing RoCoF and, generally, higher frequency deviations following the sudden loss of an infeed/export, across all the examined systems:

- Different operating conditions for the Continental power system were explored, including interconnected system operation and system split conditions. It has been shown for the Continental system that with higher SNSP and lower inertial response, there is a tendency towards higher local RoCoF values. There is an indication that RoCoF values as high as 1.3 Hz/s[2] could be reached in the Iberian Peninsula, after a reference incident (i.e. the tripping of two of the largest generating facilities connected to the same busbar, which is 3 GW in the Continental European System).
- System inertia levels, for the Ireland and Northern Ireland system exhibit a similar, albeit a more serious, inertia problem. It was found that for a 2030 power system with SNSP levels approaching 90%, RoCoF values can be sufficiently excessive, so as to prohibit any meaningful analysis of frequency deviations in time-domain simulations. Therefore, reducing inertia levels has clearly been identified as a scarcity for the

[2]For existing power plant capabilities and system protection devices in the Continental European System, a range of 0.5-1 Hz/s is the maximum range that can be operated successfully.

ENTSO-E, "Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe – Requirements and impacting factors", March 2016. Available: https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/RGCE_SPD_frequency_stability_criteria_v10.pdf

Ireland & Northern Ireland system, which, if left unmitigated, is likely to severely impact future system operation at high RES levels.

- For the Nordic power system, it was observed that upon increasing the operational levels of RES in the system, the minimum system inertia shows a declining trend. However, the RoCoF was deemed not to be a serious issue for this system in 2030 for the considered scenarios, for which a high share of synchronous machines are still connected, with RoCoF values never rising above 0.4 Hz/s. This is due to a large number of synchronous hydro generating machines in the Nordic system. Thus, while the Nordic system has a high RES level, the level of VRES generation, on an annual basis, is actually much lower than the other two systems examined (see Figure 3-1) due to the high share of hydro generation.

In addition to RoCoF, system frequency deviations following a sudden energy imbalance (infeed or export loss or system split event) are a key measure of system frequency stability. In addition to increased RoCoF values, reducing system inertia contributes to large frequency deviations following a sudden energy imbalance. Another key contributing factor determining the largest frequency deviations following a sudden energy imbalance (frequency nadirs & zeniths[3]) is the nature, magnitude and speed of contingency reserve response required to contain the system frequency within normal operating limits. Thus, low nadirs and high zeniths indicate a decline or scarcity in frequency reserves:

- For an intact Continental power system, it has been shown that frequency nadirs following the loss of a large generating unit in each jurisdiction decline as non-synchronous renewable levels increase. However, frequency nadirs in the Iberian Peninsula are the worst affected, where, for the highest renewable scenario, the loss of 2 GW of generation in the peninsula has been shown to lead to nadirs of around 49.35 Hz. It was observed that for the Continental power system split events examined, the frequency stability of the system is endangered, and nadirs could fall as low as 46 Hz, well under the load shedding level (i.e. 49 Hz), in the Iberian Peninsula. However, the probability of such extreme system split events is low but should be assessed in future work.
- The majority of cases examined for the Ireland & Northern Ireland system experience nadirs above the load shedding threshold. While it was found in the Ireland and Northern Ireland analysis that there are some frequency nadirs below load shedding levels, there is mitigation currently available, such as carrying sufficient fast acting reserve. Results indicate that the higher the volume of fast reserve available, the higher (better) the resulting frequency nadirs.
- For the Nordic system, reducing inertia levels at certain operating conditions led to lower frequency nadirs, similar to the other systems examined. That being said, even in the highest variable renewable scenario

[3] Frequency nadir is the lowest point that the system frequency reaches after a system event, such as the loss of a large unit/infeed. Frequency zenith is the highest point that the system frequency reaches after a system event, such as the loss of a large outfeed/demand.

EIRGRID & SONI, “Shaping our electricity future – Technical report”, 2021.

Available: http://www.eirgridgroup.com/site-files/library/EirGrid/Full-Technical-Report-on-Shaping-Our-Electricity-Future.pdf tested here, these nadir levels are never below the load shedding threshold due, in part, to the large number of synchronous hydro generators operating.

It has been observed that increased RES levels, or more specifically, VRES levels, result in a trend towards reduced system inertia, increasing RoCoF and, generally, high frequency deviations following the sudden loss of an infeed/export, across all the examined systems.

3.3.2 VOLTAGE CONTROL

Both steady-state voltage control and dynamic voltage regulation have been investigated so as to reveal any potential scarcities regarding steady-state reactive capacity and dynamic reactive regulation capability:

- The analysis shows that the low voltage network in the Polish system exhibits a lack of steady-state reactive power capacity, as demonstrated by deteriorating steady-state voltage regulation. Reactive power scarcity becomes most apparent under high load and minimum inertia conditions. Within the sub-networks of the Polish system, regions with a higher magnitude of installed renewable capacity show a trend towards diminishing stability margins. Steady-state short circuit levels for the Polish system across the considered scenarios remain within operational requirements, pointing to the absence of potential issues regarding dynamic voltage regulation.
- For the Ireland & Northern Ireland system, it has been observed that there is a significant correlation between increasing renewable generation levels and the deterioration of voltage regulation, as evidenced by steady-state voltage deviation magnitudes. A general trend towards dynamic reactive injection scarcity across the system is observed, particularly in weaker parts of the system[4], with the scarcity being more pronounced in the highest renewable scenario.

The Polish and Ireland & Northern Ireland power systems exhibit a steady-state voltage regulation scarcity as the system evolves towards higher levels of renewable generation. The Ireland & Northern Ireland system exhibits a clear deterioration of fault levels and a dynamic voltage regulation scarcity, issues not observed for the Polish system. However, it is to be noted that the cases analysed for the Polish system have been pre-selected using specific criteria, as opposed to analysing all potential system configurations. Therefore, the lack of potential scarcity in Poland could be due to the selected scenarios and more investigations may be required in the future.

3.3.3 ROTOR ANGLE STABILITY

Rotor angle stability analysis has been carried out for the Continental European and Ireland & Northern Ireland power systems. Critical clearing time was used to assess the existence of a stability margin scarcity:

- The studies performed for the Continental System focused upon the detailed model of the Polish system and showed no scarcity in stability margin, when assessed through critical clearing times for a range of

[4] These areas typically have little or no stronger transmission network (220 kV and above), have high RES capacities, low local demand and are electrically distant from conventional generation.

busbar and single and double circuit faults that are cleared by primary protection operation. However, a localised scarcity is observed when close end line faults, or busbar faults, are cleared by backup protection.

- The studies performed for Ireland and Northern Ireland found no global scarcity of stability margin. However, a localised scarcity does emerge for several cases when assessed according to the absolute worst-case backup protection clearing time, and for a very small set of cases. These cases are driven by specific combinations of contingencies, unit commitments and generator pre-fault conditions, and not the overall SNSP level.

Therefore, a localised scarcity of stability margin (measured through critical clearing time) is emerging for any situation where backup protection is required to operate (e.g. due to protection failures), and, therefore, a longer time for fault clearance, in both the Continental system studies and the Ireland and Northern Ireland studies. However, there is no scarcity of stability margin if primary protection clears the faults within its designed operation time.

Rotor angle margin was used to determine if a scarcity of synchronising torque was present in the Ireland and Northern Ireland system. This scarcity was not studied for the Continental system.

- In general, there were no angular stability issues identified in the Ireland and Northern Ireland system. However, a small subset of contingencies exhibited angular instability that caused a generator to slip a pole. This revealed a clear localised scarcity in synchronising torque and occurred regardless of the scenario, being manifested through angular instability of certain generators for certain N-1 contingencies. No global scarcity was observed in the Ireland and Northern Ireland studies. This scarcity indicates a need for more detailed study and more specific, localised metrics for assessing the relative security of a case in the future, as the system level measures applied during these studies failed to indicate the presence of this localised scarcity.

Oscillation damping is another metric that was assessed:

- Oscillation damping in the Continental European system was studied for the detailed model of the Polish system. This study indicated that oscillation damping presents a global scarcity with poor settling and halving times for almost all cases and scenarios. It should be noted that this conclusion is only applicable to the Polish system, and not to the wider Continental system, due to the models that were employed. Consequently, this is an area that warrants further work.
- Oscillation damping studies for the Ireland and Northern Ireland system indicated a localised scarcity of oscillation damping, and a global scarcity of oscillation damping depending on the scenario considered. This scarcity can primarily be observed as a local oscillation in one or two units when a contingency occurs close to their point of connection.

Oscillation damping presents a scarcity in both the Ireland and Northern Ireland studies and the Pan-European system studies. However, it is far more acute in the Continental Europe system results, and all cases studied exhibit unacceptable damping for most contingencies and all scenarios. In the Ireland and Northern Ireland studies, damping was significantly reduced for all cases and, at times, was outside of acceptable limits. This makes it a local scarcity compared to the global scarcity observed for the Continental system.

3.3.4 SYSTEM CONGESTION

The type of congestion investigated across the systems analysed is not comparable, and hence the methods used to carry out the analysis also differed substantially. However, both elements of this work revealed the emergence of global scarcities as renewable shares increase.

- For the Continental European system, congestion was studied from the perspective of unscheduled flows at the transmission system level, where unscheduled power flows are a concern as they will displace scheduled market flows and, through this, manifest a scarcity. This scarcity is driven by the tendency for renewable energy sources to be localised in particular parts of the system, which increases the likelihood of loop flows occurring when these localised resources serve remote domestic demand. The results highlight that an increase in RES installations in the Continental European system will increase the severity of this congestion scarcity, and this will likely cause unscheduled flows to exceed the acceptable level of 30% of capacity (as allowed under the Clean Energy Package), which will require mitigating actions. This scarcity occurs because, unlike conventional technologies, RES tend to be localised in very particular regions of Europe.
- The scarcity observed in the Ireland and Northern Ireland power system is a global scarcity that is also driven by the location of new VRES. VRES are installed in parts of the transmission system where there was traditionally little generation or demand. Therefore, sufficient transmission infrastructure is not in place to transfer this power to the load centres, and the infrastructure that is in place can become heavily overloaded. Overloads are observed at low SNSP, and the occurrence and magnitude of thermal overloads increase with SNSP, indicating a lack of transmission network capacity.

3.3.5 OTHER TECHNICAL AREAS OF CONCERN

- *System Restoration:* System restoration was only studied for the Ireland and Northern Ireland power system. It was found that as the transition is made to a power system with higher levels of variable renewables resources by 2030, there is likely to be
  - a) a decrease in the number of self-starting generating units,
  - b) an increased likelihood that a self-starting synchronous generator will be offline, which could impede timely system restoration.
  - In addition, higher levels of renewables will result in an increase in the geographical dispersion of the generation resources, which can fundamentally change the system restoration paths to target generators or loads. While not identified as an area of scarcity in EU-SysFlex, it will be crucial to be cognisant that changes to the portfolio can result in issues surrounding system restoration, and thus this is an area that warrants further investigation.
- *Generation Adequacy*: In addition to the suite of technical challenges and instabilities associated with the transition to high levels of renewables, an area of concern is the potential reduction in system adequacy associated with the displacement of conventional generation. As power systems transition towards portfolios with higher levels of VRES, the capacity of VRES that is required to displace conventional capacity,

and still maintain the same level of generation adequacy, increases dramatically. This is a result of the variable nature of these resources and the fact that renewable generation availability may not coincide with peak demand times. It should be noted that although a portfolio may be sufficient from the point of view of generation adequacy (and the scenarios developed in EU-SysFlex are), and having sufficient capacity to meet peak demand, there is no guarantee that the portfolio also has the requisite capabilities to mitigate the technical scarcities. Indeed, as shown above, despite the scenarios being generation adequate, there were still other significant scarcities materialising with high shares of VRES.

3.3.6 TECHNICAL SCARCITY SUMMARY

The key findings are summarised in Figure 3-3. Referring back to Figure 3-1, it can be noted that the scarcities are more evident at higher VRES levels (i.e. systems with higher VRES levels and higher SNSP levels will experience more challenges). In summary, analysis of the Continental European and Nordic systems for the year 2030 clearly demonstrated technical scarcities associated with certain domains of system stability (e.g. voltage control), while also highlighting emerging scarcities for others (e.g. frequency control and congestion management). These scarcities are indicators of the evolution of system capability needs, due to changes in the system generation portfolio, increasing VRES levels, and the stress placed upon existing operational practices and policies. These scarcities are more evident for the Ireland and Northern Ireland system for the year 2030, which has the highest VRES level and instantaneous SNSP level of the three systems studied, which manifest technical scarcities across multiple categories of system stability for the scenarios analysed. Reflective of this trend, there is evidence that as higher and higher levels of non-synchronous RES generation are added, the Continental European system will experience more issues of concern, and will generally evolve towards experiencing technical scarcities in key system support capabilities.

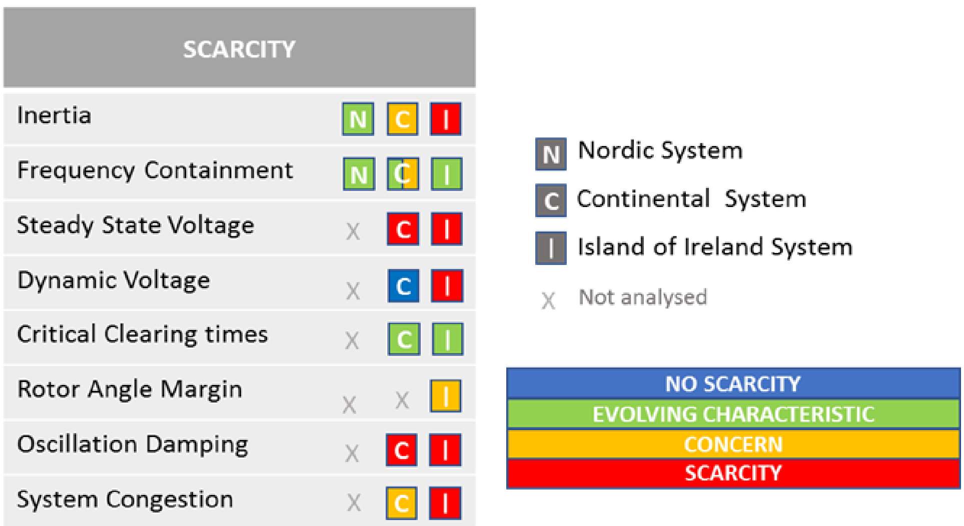


FIGURE 3-3: SUMMARY OF THE TECHNICAL SCARCITIES IDENTIFIED FOR THE THREE SYNCHRONOUS AREAS

3.4 FINANCIAL CHALLENGES

In conjunction with the technical challenges that have been outlined in previous sections, there are also economic and financial challenges to be contended with in the transition towards a power system with high levels of renewables. The existing energy market structure was developed for conventional, centralised and high availability plants, and it employs marginal cost-based electricity pricing. As discussed at the start of this chapter, the generation portfolios will evolve over the coming decade. Thus, the energy market will no longer be dominated by conventional plants, and renewables, with their low marginal costs, will play a greater role.

Analysis of this project [D2.5] for the Continental, Nordic and Ireland and Northern Ireland power systems demonstrated that, as the level of renewables increases, there is a general decrease in average energy prices (cannibalisation effect) since, for many hours, renewable generation becomes the marginal generation. The extent of the decrease is dependent on the specific system and the underlying generation portfolio. As a result of these falling energy prices, energy revenues are also decreasing, which results in a financial gap for many generation technologies, if assumed to be reliant on the energy market alone. At very high shares of renewables, it was even found that conventional generators may not earn sufficient revenue, due to low utilisation, and the increase in start-ups and shutdowns. This brings into question the appropriateness of relying on energy market designs that are predicated on marginal cost-based pricing as we transition to power systems with high shares of renewables. It is recommended that the potential of employing a value-based pricing framework in electricity markets should be considered in earnest in future work. Furthermore, even with higher carbon prices, energy-only market revenues do not cover the investment costs for many renewable technologies. This suggests that a carbon price alone is an insufficient mechanism for driving the decarbonisation agenda. Consequently, it is recommended that alternative mechanisms to carbon pricing alone are explored in future work.

The outcomes from this analysis indicate that there will be substantial financial gaps for all generation technologies in the examined power systems in 2030 and beyond. Consequently, there are concerns regarding the ability of the energy market alone to compensate producers adequately and promote investments in the capability needed by the European power system to meet the technical scarcities discussed earlier. System services markets could be an effective mechanism to tackle not only the technical scarcities discussed above, but also the financial challenges associated with reliance on an energy-only market. The analysis of system services capability from a range of technologies is presented in the next chapter, while the market evolutions and new system products are discussed in Chapter 5.

4. WHICH SOLUTIONS CAN BE DEPLOYED TO MITIGATE THE TECHNICAL SCARCITIES IDENTIFIED?

In order to enable a safe transition to a decarbonised power system, it is crucial that the scarcities and technical challenges presented in Chapter 3 are mitigated. Failure to successfully mitigate the issues will ultimately lead to an inability to reach the renewables targets. Consequently, this project specifically seeks to propose mitigation measures and solutions which ensure that the European power system can continue to be operated safely, securely, reliably and efficiently, whilst meeting renewable targets. These solutions can include technical options, procurement of system services (both new and existing), operational strategies and new market designs. Tackling the identified system scarcities will require a holistic approach with system-level thinking in order to deliver solutions. Market evolution will be discussed in Chapter 5.

This chapter outlines the key findings of analysis conducted on potential mitigation measures and some technology options that could be utilised to solve the technical scarcities and challenges. It is important to note from the outset that the measures and options discussed in this chapter are not exhaustive; they are representative of the technical characteristics needed to mitigate these scarcities. Details of the analysis and findings can be found in [D2.6].

Similar to the scarcities discussed in Chapter 3, mitigation of scarcities is power system specific. Analysis to investigate the performance of various measures were carried out based on the same detailed models discussed in Chapter 3, namely:

- models of the Ireland and Northern Ireland power system for all scarcities,
- detailed model of the Polish transmission system, connected to an approximate model of neighbouring countries observing voltage and rotor angle scarcities,
- reduced six node model of Continental Europe for frequency scarcities, in conjunction with a detailed dispatch model.

Network devices, as well as renewable technologies, such as wind and solar generation, plus battery storage and demand-side management, are found to be appropriate for providing the necessary capabilities, and thus mitigate some of the scarcities that will manifest at high levels of renewables. Critically, these are the technologies and resources that will become increasingly available as the system shifts towards high renewables with reduced (online) conventional plants.

Utilising market-based mechanisms to incentivise investment and deployment of such technologies and resources is essential. Without such market mechanisms, it is challenging to see how mitigation of the identified scarcities can be addressed, which implies the development of comprehensive system services markets and the procurement of associated products.

4.1 TECHNICAL CAPABILITIES AND SYSTEM SERVICES FOR MITIGATION OF SCARCITIES

4.1.1 MITIGATIONS FOR FREQUENCY CONTROL SCARCITIES

A number of different mitigation measures and technologies have been demonstrated through simulation for both the Continental European power system and the Ireland and Northern Ireland power system to support the significant frequency stability issues identified. Many of the technologies modelled are comparatively new options, and thus, represent mitigation measures available at times of high renewable generation. Recall from Chapter 3 that increased RES levels will tend to reduce system inertia, and thus increase the RoCoF, and frequency deviations resulting from unexpected frequency events.

The importance of the provision of inertia, or, Synchronous inertial response (SIR) capability, from synchronous condensers and conventional synchronous generators, was demonstrated for both the Continental European system, and the Ireland and Northern Ireland power system. Additionally, the benefits of including an inertial constraint in dispatching considerations is noted in both cases, which ensures that sufficient levels of inertia are maintained. Synchronous condensers are shown to be good alternatives to conventional synchronous generation for inertia provision, and for satisfying the inertial constraint in the Continental European power system, allowing more renewables to be accommodated, but maintaining the inertia levels. In the Ireland and Northern Ireland power system, synchronous condensers are found to be effective in slowing the RoCoF (see changing slopes of the frequency declines between 1 second and 2 seconds in Figure 4-1), resulting in a delayed frequency nadir (see Figure 4-1 and how the nadir occurs almost 2 seconds later in the case with mitigation); thereby facilitating frequency response (reserves) from other resources, including fast frequency response.

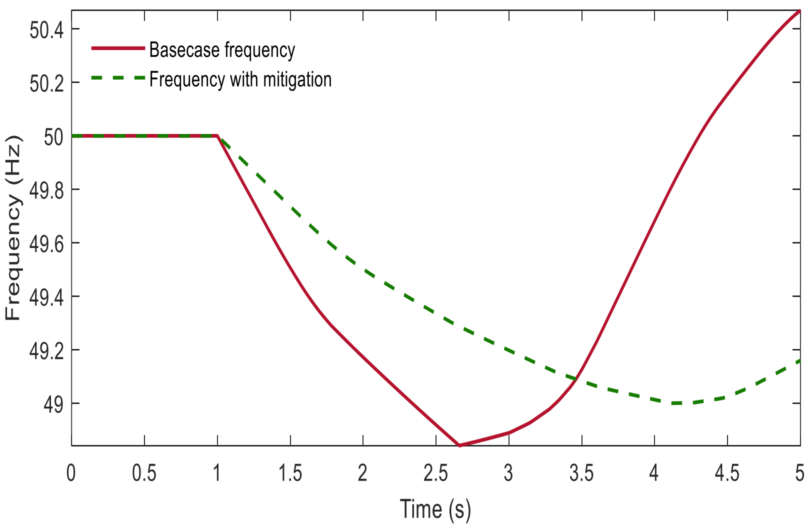


FIGURE 4-1: ILLUSTRATION OF THE ABILITY OF SYNCHRONOUS CONDENSERS TO DECREASE THE SYSTEM ROCOF ON THE IRELAND AND NORTHERN IRELAND POWER SYSTEM FOLLOWING AN EVENT AND THE SUBSEQUENT DELAY IN THE FREQUENCY NADIR BEING REACHED

Fast frequency response (FFR), for example, is defined (in Ireland and Northern Ireland) as the additional increase in active power output from a unit, or a reduction in demand, following a frequency event that is available within two seconds of the start of the frequency event. FFR capabilities from Battery Energy Storage Systems (BESS) and wind turbines were demonstrated through simulations for the Ireland and Northern Ireland power system.

Analysis shows the significance of FFR provision in terms of frequency stability, especially during times of high variable renewable penetration levels, whereby the active power injection delays the frequency nadir, thus enabling the contribution of slower reserves from other resources to counterbalance the frequency decline.

Studies also indicated that the frequency response capability from wind farms can be beneficial in supporting frequency stability, particularly at times of high renewables levels, through the provision of Primary Operating Reserve (POR)/Frequency Containment Reserve (FCR), which is on a slower time frame than FFR.

An increased need for reserve resources, in general, was identified for the Continental European power system with the transition to higher shares of variable renewables, which could be mitigated if new types of resources are able to provide reserve. To this end, significant field trials were undertaken during the project to demonstrate the ability of novel technologies, such as EVs, PV and storage, VPP and batteries, to provide the full range of reserve services.

The obtained results from the French demonstration project show that wind farms can efficiently provide frequency support services [D8.3]. Once a minimum level of generation is available (typically above ~15% of rated power), wind farms can provide FFR, FCR & FRR[5] frequency services based on active power modulation. This demonstration has performed tens of hours of experiments on the 12-MW Anglure wind farm in order to verify the quality of FCR provision. An example of the experimental results from one of the completed tests is shown in Figure 4-2, which demonstrates the ability of the tested wind farm to deliver downward and upward power reserve around its baseline operating point (which can be defined while knowing the estimated available wind power without reserve provision) when the grid frequency goes respectively above and below the reference value of 50 Hz. An overview of the French demonstration is provided in Appendix VI.

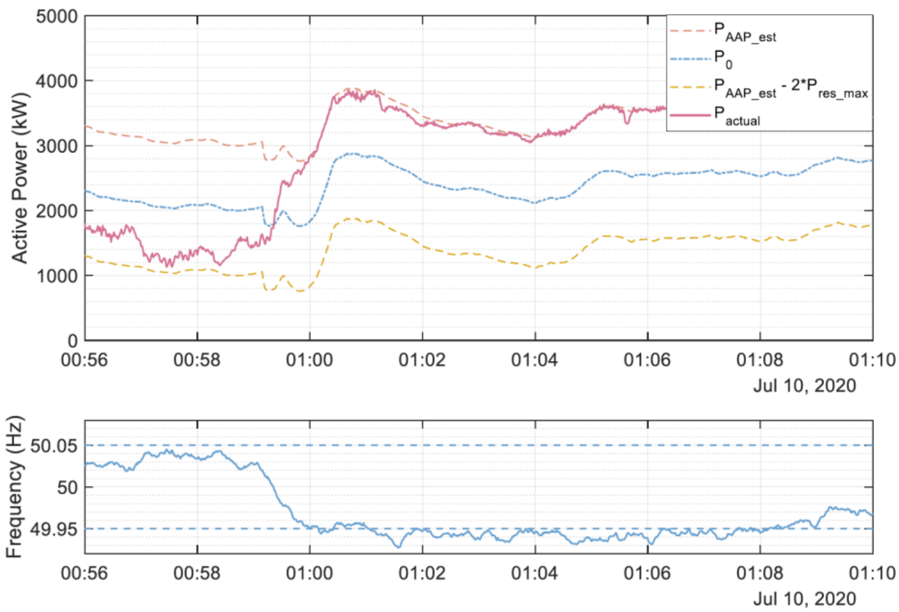


FIGURE 4-2: WIND FARMS PERFORMANCE FOR PROVIDING FCR SERVICE – TESTED BY FRENCH DEMO [D8.3]

[5] Frequency Restoration Reserve

The Finnish demonstration studies have shown that BESS units represent a novel solution for fast and reliable flexibility services at all scales [D6.9]. Two different BESS units were demonstrated: a 1.2 MW/0.56 MWh industrial scale BESS, and a 0.1 MW medium (office) scale BESS. The office-scale BESS was not actually bidding on the FCR-N (Frequency Containment Reserve for normal operation [D2.6]) market during the demonstrations[6]. However, it was controlled according to the FCR-N rules for a test period of two weeks during non-peak power tariff hours. When the frequency is above 50 Hz, the BESS charges, when the frequency is below 50 Hz, it discharges, while when the frequency is between 50±0.01 Hz, it idles. Figure 4-3 shows a short period of normal operation of the office-scale BESS under FCR-N control. As the frequency changes, the control of the BESS is fast and accurate. An overview of the Finnish demonstration is presented in Appendix III.

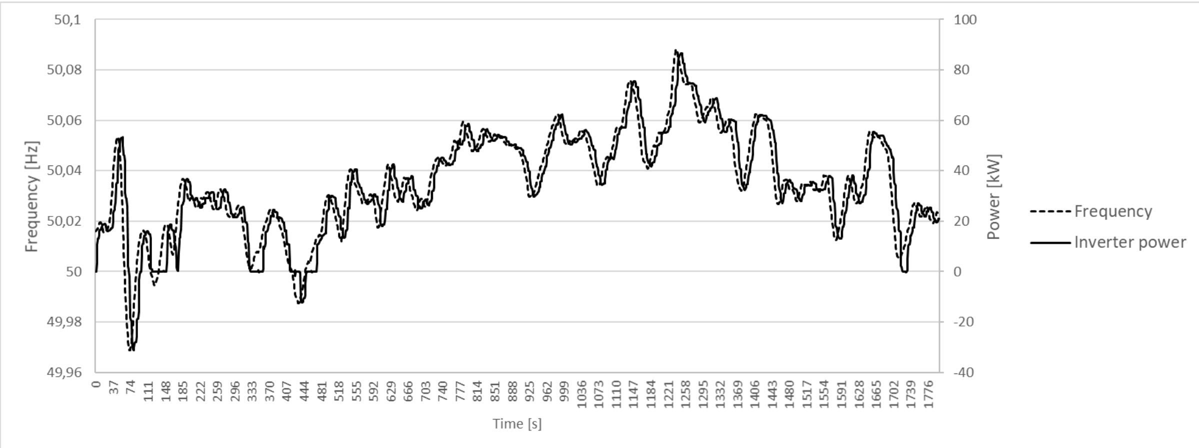


FIGURE 4-3: OFFICE-SCALE BESS UNDER FCR-N OPERATION– TESTED BY FINNISH DEMO [D6.9]

The overarching conclusion from the analysis on frequency stability is the need for a range of mitigation measures from a broader set of technology types, particularly those that will be available at times of high renewable generation, to provide the required system services. In this context, the Qualification Trial Process (QTP) was launched in March 2017 in the Ireland and Northern Ireland power system to provide a technical framework to trial resilience services from new technology providers. The QTP is a multi-year programme to understand the range of challenges for new, or existing, technologies to provide current, or future, System Services. With the help of service providers and participants, the TSOs in Ireland and Northern Ireland have demonstrated the use of reserve services, including fast frequency response. The QTP, in particular, supports demonstration of the ability to use a range of services to assist in resolving frequency stability scarcities [D4.4, D4.5, D4.6]. An overview of the QTP demonstration in the Ireland and Northern Ireland power systems is provided in Appendix VIII.

4.1.2 MITIGATIONS FOR VOLTAGE CONTROL SCARCITIES

Recall from Chapter 3 that the Polish power system and the Ireland and Northern Ireland power system exhibit a steady-state voltage regulation scarcity as the system evolves towards higher levels of renewable generation.

[6] Began operating in the market at the end of 2021.

Also, a general trend towards dynamic reactive injection scarcity across the Ireland and Northern Ireland system was observed, particularly in the weaker parts of the system at high levels of renewables.

Mitigation of the steady-state voltage scarcity will require provision of Steady-State Reactive Power support (SSRP) capabilities from new types of technologies deployed in specific geographical locations**.** Reactive power reserve activation from wind generation, capacitors and shunts were shown through simulations of the Polish system to be good alternatives to conventional synchronous generation for reactive power provision, and for reducing over and under voltages. In Figure 4-4, the images on the left show the case without mitigation measures, while the images on the right show the same cases when including reactive power provision from wind generators).

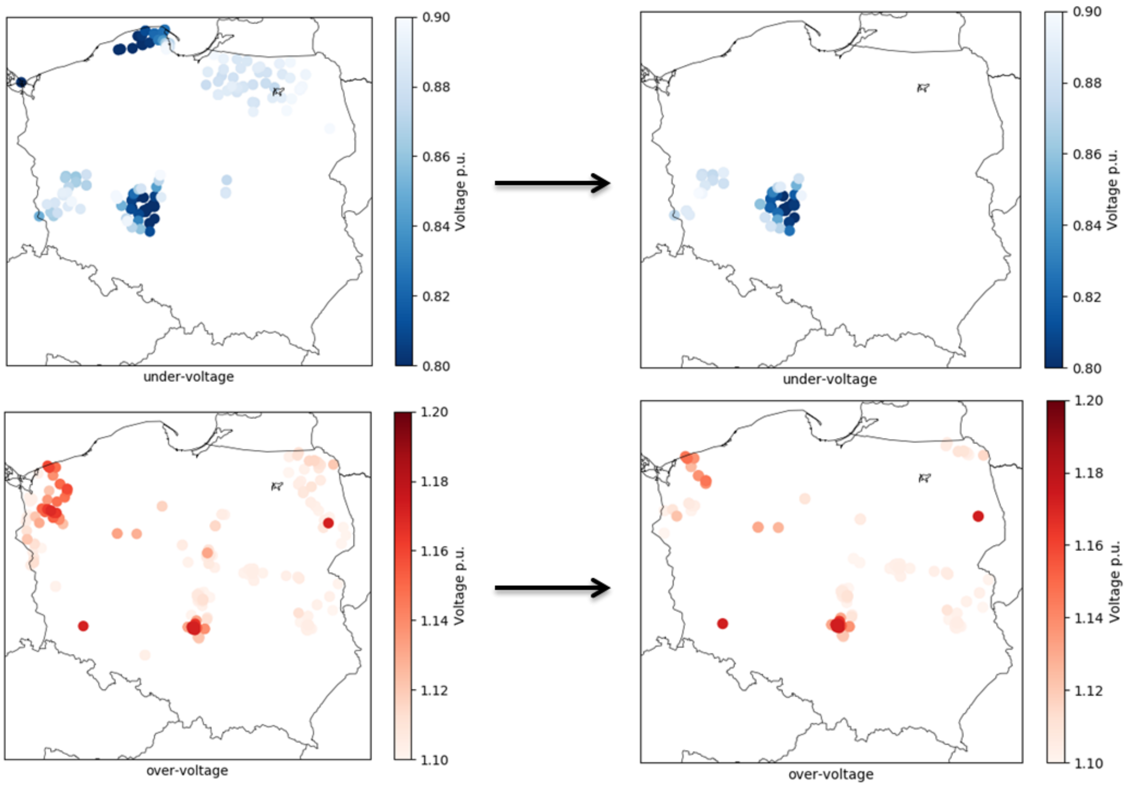


FIGURE4-4: ILLUSTRATIVE IMPROVEMENT IN UNDER AND OVER STEADY-STATE VOLTAGES FOR THE POLAND SYSTEM FOLLOWING THE INTRODUCTION OF REACTIVE POWER RESERVES FROM NON-SYNCHRONOUS ENERGY RESOURCES

For the Ireland and Northern Ireland power system, mitigation of the steady-state reactive power scarcity was found to be possible through increased reactive power provision under normal operating conditions, and following a system disturbance. Static and dynamic reactive resources were found to be effective in this regard. These additional resources include, but are not limited to, capacitor banks, STATCOMs, SVCs, synchronous condensers, and, potentially, the reactive capability from some DSO connected wind farms to complement the existing reactive capability from TSO connected wind farms.

Dynamic Reactive Response (DRR) capability from synchronous condensers, STATCOMs and SVCs was demonstrated for the Ireland and Northern Ireland power system to help mitigate the dynamic voltage scarcity. Analysis showed that the fast provision of DRR is vital in mitigating a dynamic voltage scarcity, and also reveals that the location of a DRR provision resource is key in mitigating the scarcity identified. Additional future studies would be required in determining the optimal placement of DRR resources.

Importantly, many of these reactive power (both static and dynamic) providing technologies will be available at times of high variable renewable generation, and, apart from the renewable technologies themselves, they typically do not provide active power and so utilising these technologies to provide reactive support would not displace renewable generation. Thus, they would support the overall objective of reaching high renewable shares and ultimately decarbonisation of the power system.

Several project demonstrations have evaluated the provision of reactive power services from a range of new technologies, including wind turbines and solar PV, STATCOMs and capacitor banks.

Results from the Italian demonstration project show the high capability of distribution resources for reactive power support. This demonstration includes one 1 MVA / 1 MWh BESS, two 1.2 MVAr STATCOMs modules, and four remote-controlled PV generators. Figure 4.5 presents the reactive capability areas versus the set-ups of the different case scenarios in this demonstration (shown in Table 4-1) [D6.3].

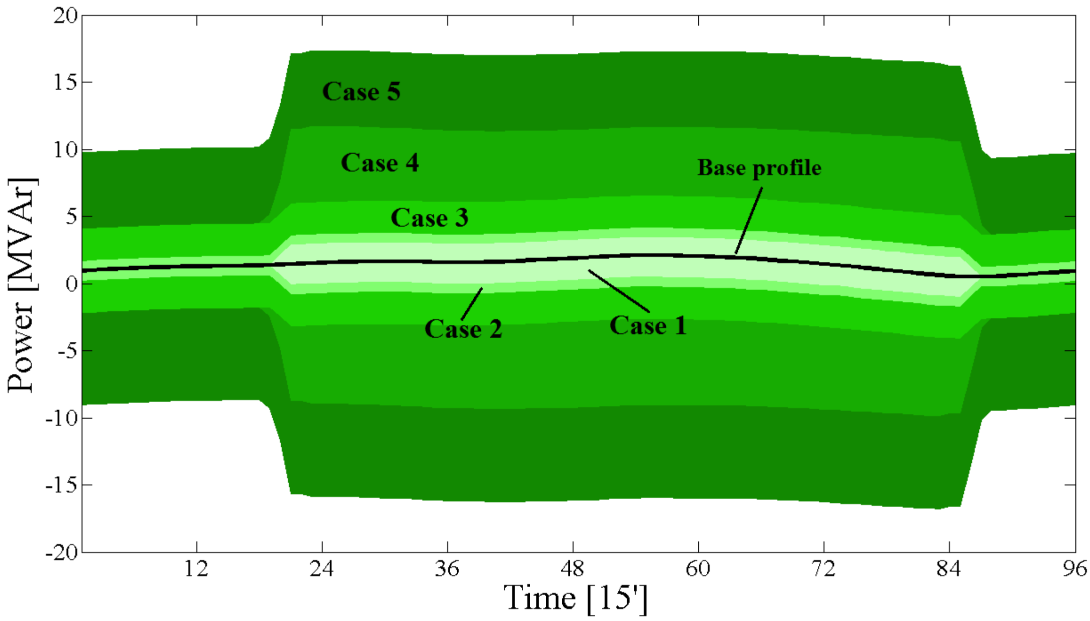


FIGURE 4-5: AGGREGATED REACTIVE POWER CAPABILITY FOR DIFFERENT CASE SCENARIOS CONSIDERED IN ITALIAN DEMONSTRATION [D6.3]

TABLE 4-1: FLEXIBLE RESOURCES SET-UPS FOR THE SIMULATED CASES – ITALIAN DEMONSTRATION [D6.3]

	Case 1	Case 2	Case 3	Case 4	Case 5
Resources	4 PV generators	Case 1 + BESS	Case 2 + STATCOMs	All PV gens + BESS + STATCOMs	All gens + BESS + STATCOMs

It is very noticeable that there is a considerable boost to the capability area given by the exploitation of all the resources and generators connected to the demonstration network, and also for the PV plants themselves (Case 5 and 4, respectively). Both STATCOMs and battery storage complement the lack of reactive power flexibility in the night/evening hours when PV plants are not producing energy (Case 3). In addition, the contribution to the capability area achievable from dispatchable generators (conventional, biomass and hydro plants, in this network) becomes evident, as they can add more than twice the reactive power flexibility already provided by the STATCOMs and battery storage (clearly visible from the comparison of Case 5 and Case 3).

Even if full exploitation of the theoretical reactive capability requires specific management of the OLTCs (which may be quite demanding in terms of tap shifting, compared to a limited gain in capability area), the results of the offline simulations demonstrate that suitable management of the STATCOMs may relieve OLTC operation, allowing better voltage and losses control by means of reactive power modulation.

One of the Flexibility Hub (FlexHub) demonstration project objectives in Portugal involved the control of resources on the DSO grid for reactive power provision (voltage control and congestion management) acting within a local reactive power market. This demonstration includes two wind parks (Barroso II – 12.3 MW and Barroso III – 23.1 MW) and two 3.43 MVar capacitor banks as the available resources to provide reactive power services. Figure 4.6 depicts the reactive power setpoint, for the TSO, before the market session (red dots), the TSO reactive power needs (orange column border) and the volume obtained from the market (orange column shading) by selecting flexibility bids for 28 delivery times (DTs) in a simulated market session [D7.6]. As can be seen, the needs of the TSO are entirely met for all DTs by these resources from the distribution network (wind farms and DSO capacitor banks).

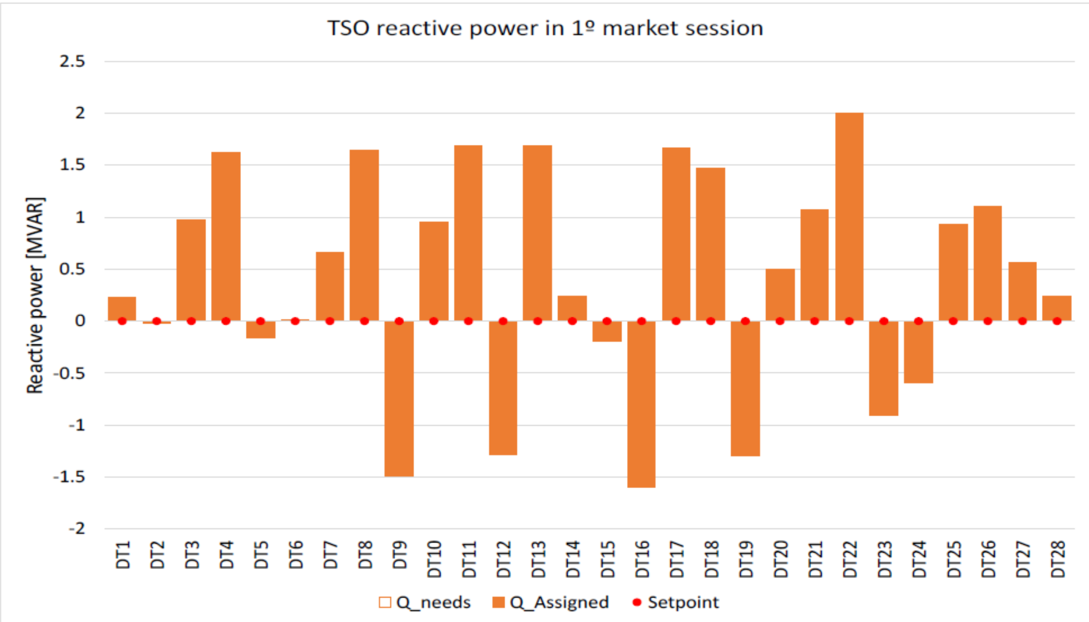


FIGURE 4-6: TSO NEEDS AND ASSIGNED REACTIVE POWER IN A MARKET SESSION WITH DSO RESOURCES - FLEXHUB DEMONSTRATION [D7.6]

The Qualification Trial Process, as described before, has also investigated the use of Reactive Power services in order to provide greater voltage controllability. In this analysis, the TSO, along with the trial participants and providers, specifically investigated utilisation of the Steady State Reactive Power service [D4.4, D4.5, D4.6].

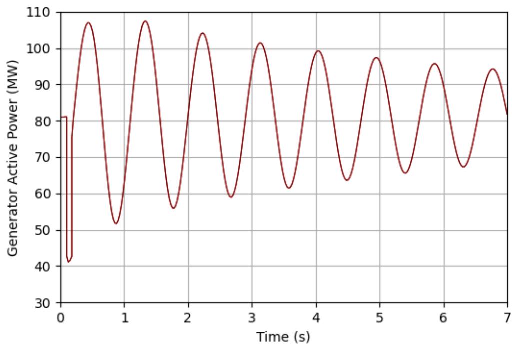
4.1.3 MITIGATIONS FOR ROTOR ANGLE STABILITY SCARCITIES

A number of different mitigation measures and technologies have been demonstrated for alleviating some of the rotor angle stability issues observed in both the Continental European power system, and the Ireland and Northern Ireland power system. Recall from Chapter 3 that some metrics were utilised to assess rotor angle stability issues, including oscillation damping and rotor angle margin.

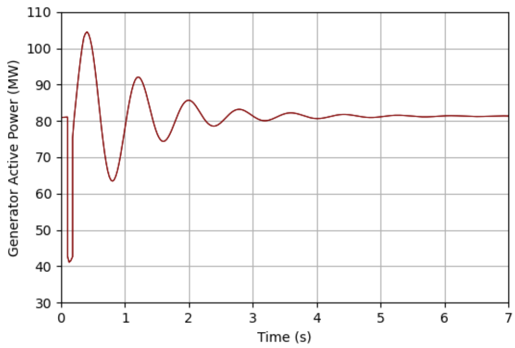
In terms of oscillation damping, tuning of power system stabilisers (PSS) for relevant conventional synchronous generators was demonstrated for the Continental Europe power system in order to mitigate associated scarcities. Results indicate that optimal tuning of power system stabilisers, alongside automatic voltage regulators, for conventional synchronous machines may augment the oscillation damping capability. This is important, as conventional plants still have a crucial role to play over the coming years in the transition to a more decarbonised system, and it is critical that all technologies can work in harmony to deliver upon the end goal. Several options were investigated in the Ireland and Northern Ireland power system, focusing on potential technical solutions and their capabilities, including the addition of power system stabilisers to specific oscillating units, and the addition of synchronous condensers and STATCOMS to provide the needed capabilities. Study of the Ireland and Northern Ireland power system demonstrates that the addition of PSSs or STATCOMs provides significant damping, while a slightly more limited mitigation effect is observed from synchronous condensers.

Dynamic Reactive Response capability from synchronous condensers, STATCOMS and SVCs is demonstrated in the Ireland and Northern Ireland power system for mitigating synchronising torque scarcities, which manifest as rotor angle margin issues. Analysis shows that large quantities of these technologies would be required to alleviate this localised issue. Studies reveal that the most appropriate mitigation option appears to be an operational policy, under specific circumstances and system conditions, that would modify the considered unit commitment by dispatching down the unit that loses synchronism and increasing the output of another generator to accommodate the shortfall in generation from the dispatch down process.

Development of a new damping product may be necessary in order to incentivise sufficient capabilities and performance to deal with this specific scarcity. System services have already proven that they can incentivise investment in new technologies that can provide a needed capability.



(a)



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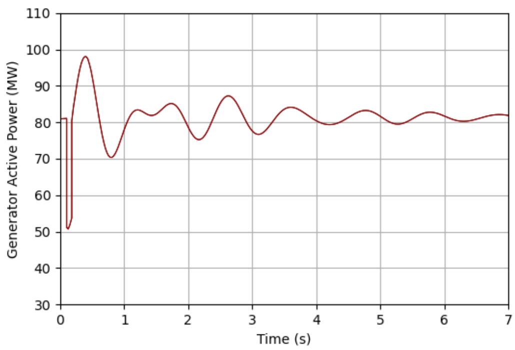

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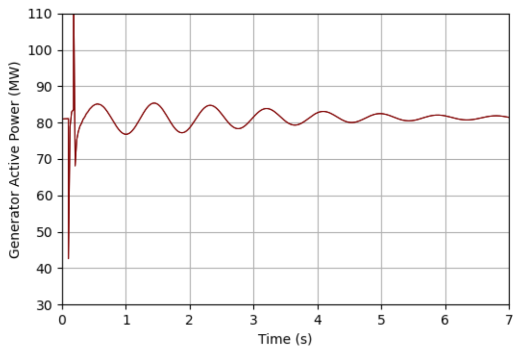


(d)

FIGURE 4-7: ACTIVE POWER OUTPUT OF OSCILLATING UNITS WITH MITIGATION MEASURES EXAMPLE FOR THE IRELAND AND NORTHERN IRELAND POWER SYSTEM
(A) BASE CASE, (B) ADDING PSS, (C) ADDING SYNCHRONOUS CONDENSER (D) ADDING STATCOM

4.1.4 MITIGATION MEASURES FOR SYSTEM CONGESTION

Indications across Europe suggest that network congestion may become one of the most difficult challenges in dealing with high levels of renewables integration. Societal and environmental pressures may indicate that it is not economically viable to develop transmission networks that would guarantee compliance based on traditional security and planning criteria under all conditions and scenarios. Thus, alternatives to the traditional solution of building new transmission lines, as well as other complementary mechanisms, need to be considered.

Although the strategy applied by many TSOs across Europe in relation to system congestion is to maximise the use of the existing transmission networks and to minimise new build, results from this project indicate that in some areas, there may be no alternative but to invest in new infrastructure. Uprating existing lines could be seen as an alternative to investing in completely new lines or circuits. Additionally, it should be noted that if no new network can be built for social and/or environmental reasons, novel alternative mitigation measures would need to be considered for managing congestion.

Results from the Ireland and Northern Ireland power system showed that a number of low and medium voltage network reinforcements are required in terms of mitigating congestion for some critical hours; however, further reinforcements, or operational mitigation measures, are required for less critical hours. While it is evident that these reinforcements have a positive impact on network congestion, the planning process must have cognisance of the potential risks associated with relying on network reinforcements (cost, societal and environmental pressures and build times).

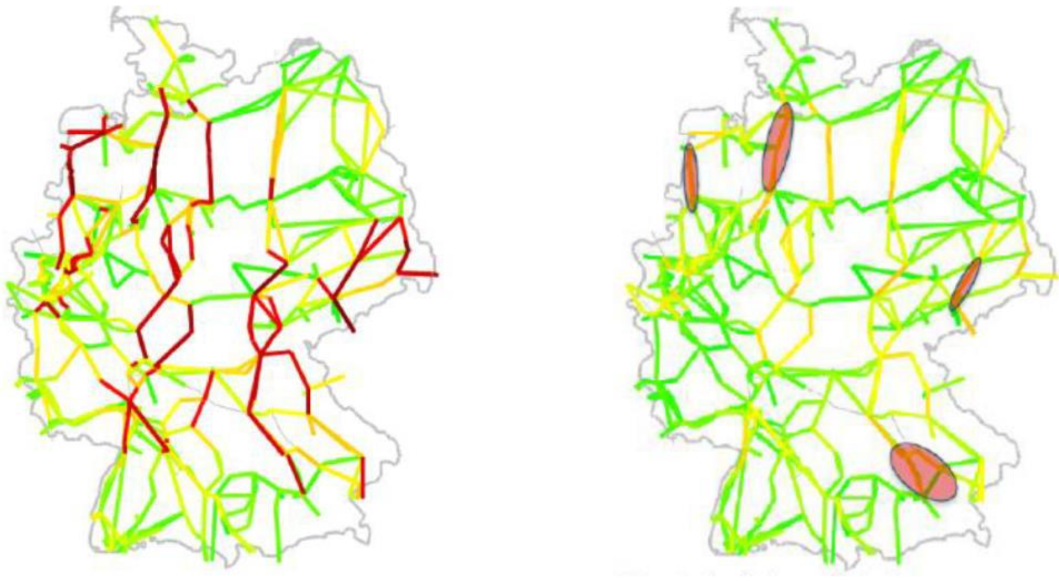
Results also demonstrate that congestion cannot be addressed by reinforcement alone, and alternative mitigation mechanisms also need to be considered. Optimal combinations of operational mechanisms, including load shifting, generation adjustments, phase shifter angle adjustments and transformer tap changes, were demonstrated as potential mitigation measures for eliminating congestion in less critical hours, without the need for significant additional reinforcement.

In addition, smart power flow controllers were studied. Such devices can provide a modest reduction in the degree of overloads, and they can be used as an option for modestly overloaded lines. However, power flow control devices alone are not sufficient to completely remove overloading violations for lines. They need to be used in conjunction with other mitigation options.

Demand side management (DSM) was also considered as a potential option for alleviating congestion. A key benefit is that at high levels of renewables, demand will be available, and also since loads are dispersed throughout the system, it is a viable mitigation alternative in any place where it is needed. For the Ireland and Northern Ireland system, in some areas where congestion management is most needed, there are limited load centres (i.e. North-West region of the island), and thus, the ability of DSM to provide congestion mitigation is limited. However, the proof-of-concept study demonstrated that there is potential for DSM to reduce overall system costs and network loading on certain lines, showing its potential contribution to congestion mitigation.

The overarching conclusion from work on congestion management is that, while reinforcements and network build are required, reinforcements alone cannot solve all congestion issues. Therefore, a range of different measures and options will be required to support a reduction in network congestion. In order to optimise utilisation of all the solutions required, coordination at a system level, between all system players, would be necessary, especially between the TSO and the DSO. This increasing share of distributed RES leads to higher requirements in congestion management for both the TSO and DSO. Already today, events occur that cause congestion both in the TSO and DSO grids. An exemplary situation is when conventional power plants located in the distribution grid provide reserve requirements (frequency control or frequency restoration) for the TSO cause congestion in the distribution grid. In this case, there is a risk that if the TSO and DSO do not coordinate their actions, the DSO solves this congestion, e.g. by reducing RES production in the distribution grid, counteracting the reserve activation measure taken by the TSO [D6.6].

Increasing RES shares can also reduce the potential for generation redispatch. If units feed in as traded by commercial aggregators (who set the schedule), without the TSO performing redispatch, many lines would show congestion (see, for example, red transmission lines in Figure 4-8 (a) from the German demonstration project) [D6.6].



(a) (b)

FIGURE 4-8: GERMAN TRANSMISSION GRID; (A) BEFORE REDISPATCH, (B) AFTER REDISPATCH (SOURCE: BNETZA, GERMAN REGULATORY AUTHORITY, 2017) [D6.6]

As seen in Figure 4-8 (b), after performing redispatch at the transmission level, some lines remain above the 100% capacity loading for the (n-0)-case (red bubbles). In congestion management, the goal is always to achieve line loadings of less than 100% in the (n-1)-scenario to fulfil the (n-1)-criterion. Including RES connected to the distribution grids in the redispatch process increases the redispatch potential to achieve transmission line loadings below 100% for the (n-1)-scenario [D6.6].

4.1.5 MITIGATION MEASURES FOR OTHER AREAS OF CONCERN

- ***System restoration:*** As previously discussed, achieving EU renewables targets will require the deployment of high levels of VRES resources in a more distributed and decentralised manner. This has the potential to fundamentally change system restoration paths to target generators, or loads, and is an area of concern that requires consideration and review of system restoration paths. It will be crucial, in the future, to have black start capability coming not only from conventional power plants, but also from a wider range of technologies. These technologies could include, but are not limited to, wind, solar, batteries and interconnectors. In conjunction with a review of system restoration plans, it is recommended that the development of a market-based black-start system service product be put in place to address future black start needs. This will incentivise investment in a broader set of technologies to provide black start capabilities.
- ***Maintaining Generation Adequacy and Supporting Renewables Integration:*** As discussed in Chapter 3, a potential reduction in system adequacy was also identified as a challenge associated with the displacement of conventional generation. Traditionally, adequacy contribution has largely come from conventional thermal power plants. However, with the transition to a more decarbonised power system, there is a need to avail of the adequacy contribution provided by other resources, such as renewable

technologies, battery storage technologies and demand-side response. Interconnections can also contribute to pool and share across borders variable generation and reserves, which can support balancing and avoid curtailments in renewable generation. Additionally, studies for Continental Europe showed that integration of electric technologies in the demand-side such as batteries and electric vehicles can contribute to energy balancing and system services, and have a positive effect on the integration of renewable generation in the system, limiting its curtailment. However, it must be remembered that a generation adequate portfolio may not result in a portfolio with the same level of capability to mitigate technical scarcities (especially those that manifest at high levels of variable renewables) as today's generation portfolio, which includes a significant share of conventional power plants. Therefore, it is recommended that not only the adequacy of the generation portfolio and the system services capability of the generation portfolio need to be considered in parallel in the planning stages, but also the additional flexibility that can be provided by new assets in the demand side (batteries, EVs, …).

4.1.6 FUTURE WORKS IN THIS AREA

It is recommended that future work be conducted to determine the optimal suite of technologies and operational mechanisms to ensure the required mix of capabilities. The EU-SysFlex project has demonstrated the individual capability of different resources and technologies, in conjunction with new operational policies and other mechanisms, to support the mitigation of a range of technical scarcities. In reality, however, no mitigation measure will be implemented in isolation, but instead there would be complementarities and interactions between measures. It is thus recommended that, in future works, these interactions are assessed holistically at a system level, as opposed to solely on an individual scarcity basis, to ensure that any complementarities are appropriately exploited. It is anticipated that the most efficient way to deliver the needed capabilities is to develop appropriate markets, and to incentivise investment in the needed technological capability. There may be a need to develop new system services to incentivise investment in technologies with the required capabilities to tackle the technical scarcities. Potential recommended areas of future work include investigation of the benefits of new system services, such as an oscillation damping service and a network congestion service. These would require detailed technical analysis, in conjunction with market design considerations, which will be discussed in Chapter 5.

4.2 OTHER CONSIDERATIONS

4.2.1 VALUE OF SYSTEM SERVICES

As discussed in Chapter 3, the impact of the growing dominance of low and zero marginal cost generation can have a detrimental impact on the revenues of generating technologies, such as gas turbines, that are needed to provide vital system services, but also for the renewable resources themselves, as a result of the cannibalisation effect. This, in conjunction with the analysis of mitigation options, provides evidence that incentives are needed to encourage investment and to develop a future generation portfolio that has the required capabilities to provide those system services that are necessary to address the technical scarcities and meet renewables targets.

For the analysis detailed in [D2.5], the Ireland and Northern Ireland power system is used as a case study to outline the potential value of system services. One benefit of adopting system services is the ability to accommodate higher levels of renewables while maintaining secure operation of the power system. Therefore, the primary monetary value of system services could be argued to simply be the reduction in total system operational costs as a result of accommodating higher levels of renewables and displacing carbon-intensive conventional generation. Analysis suggests that the value of system services for Ireland and Northern Ireland by the year 2030 would be of €700 million per annum, a value that matches or exceeds the typical financial gap experienced by the generation portfolio as a result of the cannibalisation effect.

Future work should investigate the potential value of system services for the pan-European power system. It is recommended that this work be incorporated into market designs. Utilising market-based mechanisms to incentivise investments in the required capability is vitally important. Without such market mechanisms, it is challenging to see how mitigation of the identified scarcities can be addressed and, ultimately, how renewables targets can be achieved. Discussions on the development of comprehensive system services markets, and the procurement of associated products, are provided in Chapter 5.

4.2.2 RELIABILITY OF NEW RESOURCES

New flexibility resources, primarily from distributed small-scale devices, are likely not to have the same (individual) reliability as traditional solutions. Small-scale resources, such as demand response from electric vehicles or electric heating loads, are not dedicated to providing grid services; therefore, their availability will be temporal [D10.3]. The reliability of some other technologies, such as storage, to provide grid services, also depends on their energy storage capacity. In addition, many of the flexibility solutions for future power systems are from devices connected to the distribution grid. Therefore, the delivery of their services to transmission level depends on the strength of the local distribution networks and on the existence of good coordination and interfaces between the Transmission and Distribution System Operators.

Ignoring lower-reliability resources will trigger investment in traditional solutions that provide reliable grid services in a less favourable way (from a decarbonisation point of view) or at a higher cost (due to the low cost of renewable energy sources or small-scale solutions). The system operator needs to recognise the equivalent capacity from new resources against traditional capacity as a reference to adopt new resources. Studies conducted by the EU-SysFlex project clearly show that, even if the reliability of (individual) new resources may be low, additional capacity can be procured to maintain the same reliability levels if needed [D10.3]. By understanding the individual or aggregated reliability performance of DER, the system operator can, therefore, manage the risk and determine the optimal portfolio of resources considering both conventional and DER [D10.3].

4.2.3 OTHER ENABLERS

In conjunction with appropriate market designs for system services, aggregation of distributed resources and coordination between TSO and DSO will be crucial for enabling and incentivising technical solutions, and achieving the required mix of technologies. Sections 6.3 and 6.4 offer an overview of the overall contextual environment, as well as work performed within the EU-SysFlex demonstration projects on these critical subjects.

5. HOW DO WE SUPPORT AN APPROPRIATE MIX OF TECHNOLOGIES TO PROVIDE THE NEEDED TECHNICAL SOLUTIONS AND SYSTEM SERVICES?

The main findings in relation to the identification of system services, and the markets that will be used for the acquisition of the flexibility products aimed at addressing these system services, are now considered.

5.1 SERVICES AND PRODUCTS

To address those scarcities generated by the introduction of VRES (discussed in section 3.3), system operators need to activate system services (i.e. physical actions, be it the provision of active or reactive power, and/or energy, to mitigate a particular technical scarcity or scarcities). To deliver these services, system operators need to define products, or "options", that will be procured and remunerated. The products will depend on the technical scarcities being mitigated.

The state-of-the-art assessment undertaken in EU-SysFlex ([D3.1]) found more than one hundred and twenty different products or product concepts. Analysis showed that the existing suite of products predominately address current challenges, rather than the future technical scarcities identified in EU-SysFlex [D2.1]. These products and product concepts were subsequently grouped into a number of generic system services, which varied from legacy services to new and innovative services and concepts at varying stages of development. These system services are summarised in Table 5.1:

TABLE 5-1: GENERIC SYSTEM SERVICES IDENTIFIED IN EU-SYSFLEX

High-level System Service	Generic System Service	Aim
Frequency control	Inertial response	Minimising RoCoF
	Fast Frequency Responses (FFR)	Extend time to reach nadir/zenith
	Frequency Containment Reserve (FCR)	Contain the frequency within bounds
	Frequency Restoration Reserves (FRR)	Return frequency to nominal
	Replacement Reserves (RR)	Replace reserves utilised to provide faster products
Congestion management (CM)	Fast Product	Emergency congestion management product
	Slow Product	Congestion product for dealing with predictable/forecastable congestion
	Long Term Product	Congestion product with long lead time for dealing with frequent or permanent congestion
Voltage control	Steady State Reactive Power	Voltage control during normal system operations
	Dynamic Reactive Power	Voltage control during a system disturbance.

It was found that, when considering products, there appear to be two large groups: those designed to solve frequency scarcities and those designed to solve other scarcities. Those products aimed at facilitating frequency management are relatively standardised, and integration at a European level is ongoing (for instance, the PICASSO, MARI and TERRE initiatives for aFRR[7], mFRR[8] and RR, respectively). This standardisation has resulted in these products having similar specifications in most European countries.

On the contrary, products aimed at addressing other scarcities present some significant differences between countries, and there are low levels of harmonisation of such products between European markets. Furthermore, some of those products were only available in fewer countries. Even if heterogeneously defined, eight steady-state voltage products (being used in 7 different jurisdictions) were identified, while only one product (being used in 2 jurisdictions) was identified to address dynamic reactive power scarcities.

As for congestion management, a very limited number of explicit congestion management products were identified. Based on the analysis undertaken in EU-SysFlex, resources earmarked for frequency control or voltage control are also being used for congestion management. Examples of products that could be utilised to mitigate or manage congestion include tertiary reserves (e.g. Belgium market) as well as products being developed in the EU-SysFlex demos. However, it was identified that additional analysis could be required for these services, with a special emphasis on the amendment of existing products for frequency control, incorporating, by necessity, locational aspects or in designing congestion management products that are bespoken and uniquely different from frequency control products to address different needs for the process of congestion management.

As part of evaluating existing products, EU-SysFlex also identified some potential gaps in the current range of products that need to be addressed to ensure that all future system needs are addressed. To cover these gaps, new innovative products were then proposed. Such products include synchronous inertial response, fast post fault active power recovery, dynamic reactive response, ramping products and congestion management products.

Developing and implementing these innovative products could represent a first step but, since the scarcities will continue to evolve as more VRES are connected, it is important to remember that designing services and products is a dynamic process that may require regular revisions to ensure that they remain fit for purpose, from both network and investment perspectives.

When considering the performance (and potential need for change) of a product, it will be important to consider two factors (in addition to the ability to deliver the relevant service). The first of these factors is the ability of the product to affect investment decisions. Remuneration of these services generates new revenue streams for potential flexibility providers, which could affect incentives to invest in new assets by facilitating the closure of the financial gap discussed before.

The second factor is that, when considering a product, it is important to evaluate whether all technologies (that can deliver those services) are allowed access to those revenue streams. A lack of technology neutrality could generate biases that affect the efficient development of new energy sources and the functioning of energy

[7] Automatic Frequency Restoration Reserves

[8] Manual Frequency Restoration Reserves

markets. To support technology neutrality, the product designer should avoid product attributes that could result in certain sources of flexibility being excluded. In this project, we discovered that currently, there are a number of requirements, or product parameters, that may exclude technologies, and, therefore, may hinder technology neutrality. Therefore, a first stage, going forward, would be to identify those attributes and modify them (without compromising the system operator's ability to obtain the service that the product would be addressing) to facilitate the integration of as many (different) flexibility providers as possible.

5.2 MARKET DESIGN

Markets refer to mechanisms that match buyers and sellers of flexibility.[9] As services and products evolve, markets also need to change. Therefore, it is important that the processes and roles in these markets are kept under review, to adapt to new scarcities (or evolution of old scarcities). However, as much as possible, these changes should form part of a clear trajectory, such that investors make the best decisions for current and future system needs [D3.2].

When considering the processes that compose the market, four phases are identified:

- **Prequalification**: The prequalification phase deals with the certification and registration of all assets applying to provide the flexibility service. This phase includes the prequalification for the provision of the product, for the participation in the market and for the provision of the product given the grid conditions. The outcome of this phase is a qualified volume per product per unit or aggregated unit.

- **Procurement of capacity and energy products**: This phase covers the acquisition of flexibility capacity (when relevant) and energy, i.e., bidding of flexibility offers and the clearing of the market (or selection of resources if there is no market). For this phase, EU-SysFlex identified four main potential procurement approaches depending on how and whether the optimisation of the system takes place:
    - <u>Centralised optimisation</u>: Buyer(s) of the product submit its/their requirements. These bids are then used to clear a market using one single algorithm that optimises the selection at both transmission and distribution levels, considering all grid constraints. The results are sent to system operators and market operator(s).
    - <u>Decentralised optimisation</u>: FSPs send their bids to one or several market operators. These bids are then matched with the SOs requirements using a number of algorithms that optimise the selection at different levels. These selections require coordination to ensure that bid selection does not create additional grid constraints and that flexibilities are scheduled only once.

[9] It should be noted that market design is not the only option for procuring the required capabilities. Tariffs, grid codes, and dynamic contracts can also allow/require some assets in the grids, renewable generation or on the demand side to provide flexibility. But these options have not been in the scope of this project and need further studies. Also, future studies need to develop methodologies to combine explicit and implicit flexibility mechanisms (e.g. tariffs) (where necessitate) to optimize a cost-efficient use of flexibility resources.

  - Distributed market approach: A distributed market is characterised by a high number of potential buyers and providers of flexibility (often referred to as peers). The distributed market acts as a secondary market. Within the organisation, there is no optimisation of transactions, but one or several marketplaces can be defined to increase visibility to flexibility providers and buyers. Possibly, marketplaces can play the role of clearing houses for bilateral transactions among peers.
  - Regulated approach: Under a regulated approach, no market organisation exists.
- **Activation of flexibility**: This phase covers the interactions between roles covering the activation of flexibility when required. The activation of flexibility can be done automatically (i.e. through either a self-activation triggered by network state or automatic signal sent by the SO) or manual (i.e., when the activation order is sent either by the SO or the market operator and executed by the flexibility provider).
- **Settlement**: Measurements and data exchange for verification and financial flows for the financial settlement between the buyer and the seller. This phase includes the measurement of the amount of active or reactive power delivered by the flexibility, comparison with the amount expected following the activation order and, if necessary, the adjustment for balancing perimeters of the flexibility provider's Balance Responsible Party.

When considering these phases, EU-SysFlex identified that the characteristics of the products would need to be considered in the design of each of these phases, i.e., there is no single approach for all products.

When considering the potential evolution of different phases of the markets, this project has identified the following questions:

- How to create synergies between multiple system services?
- How to adapt market processes to optimise procurement of system services, including coordination between TSO and DSO?
- How shall potential grid restrictions be integrated into the flexibility selection process?

Insight into each of these questions is discussed in the following sections.

5.2.1 HOW TO CREATE SYNERGIES BETWEEN MULTIPLE SYSTEM SERVICES?

New scarcities mean that SOs need to acquire new system services. However, one important point to consider is whether there needs to be a linear relationship between products and services (i.e. whether one product is only used to deliver one service).

In the scientific literature, definitions and studies of joint procurement are provided in ([D.3.2]), mainly focused on energy and reserve procurement. The major characteristic of joint procurement is that FSP may provide only one bid for solving one or several scarcities of one or several system operators. Therefore, the necessity for them to choose between several separated markets is limited or completely avoided, causing higher liquidity on the combined market. Joint procurement can also lead to lower volumes of flexibility needed, where one bid can solve different problems. This includes solving different problems on the same scarcity (e.g., congestion at DSO and TSO level) or even different scarcities. Therefore, "joint" can relate to:

- the buyers, i.e. the coordination of DSOs and TSOs
- the scarcities and products, i.e. that one product can be used to solve several scarcities or vice versa
- the optimisation across scarcities, i.e. that scarcities can be solved in a joint process (based on centralised or decentralised optimisation).

The table below describes the different forms of joint procurement in more detail.

TABLE 5-2: OPTIONS FOR JOINT AND SEPARATE PROCUREMENT

Number of products	Number of scarcities	Number of buyers	Centralised/ Decentralised optimisation	Joint Procurement	Optimisation across scarcities	Example
1	1	1	No (missing coordination across SOs)	No	No (separate optimisation of scarcities)	Separate procurement of mFRR and CM by TSOs; procurement of CM by DSOs
1	1	2	Yes	Yes	No (separate optimisation of scarcities)	Coordinated procurement of CM by TSOs and DSOs (see Chapter 5)
1	2	1	Yes	Yes	Yes (joint or coordinated)	Procurement of mFRR type of product for CM and imbalances by TSOs; Procurement of CM product for CM and voltage control by DSOs
1	2	2	Yes	Yes	Yes (joint or coordinated)	Procurement of mFRR type of product for CM and imbalances by DSOs and TSOs
2	1	1	Yes	Yes	No (separate optimisation of scarcities)	Procurement of reactive power and active power for voltage control by TSOs or DSOs
2	2	1	Yes	Yes	Yes (joint or coordinated)	Procurement of reactive power and active power for CM and voltage control by TSOs or DSOs
2	2	2	Yes	Yes	Yes (joint or coordinated)	Procurement of reactive power and active power for CM and voltage control by DSOs and TSOs

Among the cases of joint procurement where one product was used to address different scarcities, EU-SysFlex considered the effects of joint procurement of congestion management and mFRR products, i.e., one product was designed to facilitate the delivery of more than one system service. This has some advantages, as it reduces market costs by avoiding duplication (i.e. allows profiting of potential economies of scope in the provision of services). If the only option is joint procurement (i.e. creation of a so-called "super product"), however, the combination of requirements for different services leads to a more restrictive product definition, which can exclude certain FSPs, and lead to lower market liquidity. This is especially relevant for congestion management, since the requirement for a faster mFRR product can exclude certain types of generation, or demand response and storage, whose preparation time exceeds the activation time of the mFRR product (even if they could still provide the congestion management service).

The introduction of such a combined product, however, can come at a cost as the activation process for these products could end up being more complex, as the SO needs to identify whether each bid is aimed at one or multiple system services.

There is no “one option fits all” in this analysis, but the decision should be taken on a market by market basis. Therefore, when considering combined products, additional complexity should be balanced against potential increases in efficiency, but lower liquidity is also possible.

An extreme case of combined products, also considered in our analysis, is the creation of a market where there are no set products, but flexibility providers would publish their available flexibility (and associated conditions), and network operators would make their preferred choices (supermarket approach). This option has the advantage that it facilitates the inclusion of all flexibility providers into a single market. However, it could require significant computational capabilities when the SO decides to choose between different flexibility sources. Therefore, this option would not be implementable in the short term, but it could be a long term solution once the market is more mature.

Balancing and wholesale markets can be organised separately or via a joint market, taking into account the technical constraints of the balancing providers. The European Integrated Energy Market is based upon separated (sequential) market clearing. These markets have higher costs when additional VRES are introduced. In Europe, however, a shift to a joint clearing market is unlikely in the near future, given the significant changes it would require.

To mitigate these higher costs, however, EU-SysFlex analysis derives three implications for sequential energy and reserve markets in Europe:

- The additional costs of sequential reserve scheduling are driven by the technical inflexibilities and limitations of conventional power plants (e.g. minimum up/down time). Load response and renewables are more flexible in providing reserves in some senses (e.g. they don’t impose minimum up/down requirements), at least from a purely technical perspective. Therefore, reserve market design should be opened up for reserve provision by renewables and flexible loads. This could entail a broad set of actions, such as allowing load aggregators to bid in reserve markets, or reducing contract durations to enable reserve provision by variable generation.

- As the required level of reserves is assumed here to increase with the wind and solar PV share, the additional cost of sequential market design increases as well. This effect can be partially offset by improving the dimensioning of reserves by, for instance, dynamic reserves and more short-term reserve sizing. As such, the need for reserves can be determined more accurately, and less reserves need be scheduled.

- It is illustrated in this project ([D3.4]) that the additional cost of sequential clearing has a more than linear relation with the level of wind and solar PV. In other words, the cost difference becomes larger with increasing wind and solar PV, and at an increasing rate.

Therefore, a recommendation based on this analysis is that mitigating measures must be introduced sooner rather than later.

5.2.2 HOW TO ADAPT MARKET PROCESSES TO OPTIMISE PROCUREMENT OF SYSTEM SERVICES, INCLUDING COORDINATION BETWEEN TSO AND DSO?

This section discusses the main decisions needed to design a flexibility market that this project has considered.

5.2.2.1 SHOULD THERE BE A MARKET?

The first decision to be made is whether using markets is the optimal solution. The Clean Energy Package states that flexibilities should be procured by SOs via market-based processes (i.e. not regulated), but some exceptions are nevertheless allowed based on the nature of the service, the forecasted liquidity, the bidding behaviour and the transition costs.

However, EU-SysFlex analysis finds that a market-based rather than a regulated organisation should be the preferred solution, if the necessary conditions are in place to allow for the introduction of a market. Such conditions include sufficient competition, liquidity, transparency and clear market rules, limited strategic behaviour such as increase/decrease gaming, regulatory oversight so that prices are determined by competition rather than being arbitrarily regulated. Nevertheless, a regulated organisation could still be preferred in some cases, provided it complies with the terms of the Clean Energy Package[10] (CEP), but even those cases could benefit from some potential market mechanisms. In some cases, a mix of market-based and regulated organisations (mandatory participation with or without compensation) can be used to minimise transition and system costs.

In those cases where markets are chosen, the approach to optimisation (as discussed above) and what actors should take each role are other decisions to be taken. For flexibility products, it is possible to implement a single centralised optimisation (i.e., one single algorithm selecting from all flexibility bids those that minimise costs and keep the system within its operational limits), or a decentralised optimisation (i.e. separated optimisation algorithm exist for the distribution and transmission grid, so that at least two consecutive steps are required). When choosing the optimisation structure, the decision-maker needs to balance two different effects. On the one hand, higher degrees of market integration, when associated with a single optimisation of the network, would facilitate efficient allocation of flexibility products. On the other hand, decentralised optimisation might be easier in terms of computation.

[10] See articles 6 and 13 in the REGULATION (EU) 2019/943 on the internal market for electricity and articles 31.7 and 40.5 in the DIRECTIVE (EU) 2019/944 on common rules for the internal market for electricity

In terms of the roles, the role of MO could also be theoretically allocated to different actors, such as existing market place operators or system operators. The question also depends on the number of marketplaces and whether there shall be competition between marketplaces. Moreover, the decision for centralised or decentralised optimisation and the allocation of the optimisation responsibilities to actors influences the allocation of the MO role to actors.

To allocate these roles, it is necessary to conduct a cost-benefit analysis, considering all chances and risks, but specifically also addressing national specificities (e.g., regulation, number of DSOs and TSOs within the bidding zone, existing processes of optimisation, historical organisation, etc.) as well as the choice for centralised or decentralised optimisation.

5.2.2.2 SHOULD THE MARKET BE INTEGRATED WITH OTHER NATIONAL BALANCING MARKETS?

One potential type of market interaction that received special attention in this project is cross-border balancing. The importance of extending market integration to realise cross-border balancing is growing, driven by concerns regarding market concentration in balancing markets, and the expected increase of less predictable generation from VRES.

When speaking about market integration, it is important to remember that different levels of integration are possible. EU-SysFlex identified the following levels of market integration [D3.4]:

- Coordination of the real-time activation of balancing energy through:
    - Imbalance netting: TSOs exchange opposing imbalances before using balancing energy.
    - Using a common merit order list: TSOs use a common merit order list of balance energy bids, such that balance energy is provided at the lowest cost.
- Coordination of the procurement/contracting/allocation of balancing capacity through the exchange of balancing capacity implies the contracting of balancing capacity located in different control zones.
- Coordination of the sizing of balancing capacity requirements through the sizing of balancing capacity for a certain region (spanning multiple control zones) and the sharing of balancing capacity within that region.

Coordinating the procurement and sizing of balancing capacity is more complex than the coordination of the activation of balancing energy. Since coordination of the activation of balancing energy happens in real-time, the status of the network is known, and the remaining cross-zonal capacity can be used for the exchange of balancing energy. In contrast, as procuring balancing capacity happens before real-time, the exact state of the network is not known. Hence, to ensure the real-time deliverability of balancing capacity located in a different zone, it must be guaranteed that the required cross-zonal capacity will be effectively available.

This requirement of reserving cross-zonal capacity for balancing capacity invites investigation of the potential benefits of using cross-zonal capacity for exchanging or sharing balancing capacity. These benefits were assessed for case studies based on the Central-Western European system, with power system portfolios based on the EU-

SysFlex Scenarios: Energy Transition and Renewable Ambition. A model was developed with detailed technical constraints to simulate the co-optimised allocation process of cross-zonal capacity for balancing capacity exchange, and sharing in joint day-ahead energy and balancing capacity market clearing. Activation of balancing energy in real-time is assumed to be fully coordinated.

Hourly simulation results for a week-long period illustrate how cross-border coordination of balancing capacity markets can lead to more cost-efficient power system operation for three reasons [D3.4]:

1. **Provision of balancing capacity itself is more efficient**: when cheaper balancing capacity is available in neighbouring control zones, balancing capacity exchange allows for import of that capacity (and vice versa).
2. **Cross-border coordination enables increased generation from less flexible capacity, both "slow" conventional and renewable technologies, which is often cheaper**: balancing capacity exchange allows importing flexibility from other control areas, thus reducing technical constraints on online capacity within a control area. This can free up low-marginal cost capacity initially (partly) allocated to provide balancing capacity, allowing increased contributions from low-marginal cost, low-flexibility capacity, and even reduced curtailment at times of high renewable output. As the stringency of flexibility requirements varies in time and place, different control areas can benefit from these effects at different times. The benefits of a coordinated approach are greater as the share of renewables increases.
3. **Cross-border coordination reduces the overall need for balancing capacity**: offers the potential to drive the most significant cost savings. On the one hand, it allows for a reinforced version of the second effect described here, i.e. lowering technical constraints on the power system portfolios, thus allowing for more low-marginal cost capacity to be used for electricity generation. On the other hand, and probably more significantly, it reduces the need to build "back-up capacity".

5.2.2.3 HOW OFTEN SHOULD PROCUREMENT TAKE PLACE?

Linked to the number of markets, another question considered in the analysis is the mechanism to match supply and demand and, more concretely, the regularity with which this matching takes place. This includes considerations about discrete markets (i.e. taking place at one point in time), continuous markets (where demand and supply take place whenever a bid matches a request) and distributed markets[11].

When considering discrete markets, it is important to understand the effects that market timing can have on the results. The temporal granularity of balancing capacity/reserves markets can be characterised by the frequency of sizing reserve requirements and the corresponding resolution, and the frequency and resolution at which the required reserves are procured, as illustrated in Figure 5-1.

[11] Both centralised and decentralised markets could be run as distributed markets. However, this option received limited attention as the interest of implementing a distributed market for the procurement of flexibility services seems limited. In addition, the complexity is not negligible. A deeper investigation into distributed markets would be necessary to properly assess its potential relevance for the procurement of system services.

Four temporal aspects of reserve markets (and partially illustrated in the figure above) are as follows:

1. Reserve sizing frequency (RSF) specifies how regularly reserves are sized
2. Reserve sizing resolution (RSR) sets the duration of blocks
3. Reserve procurement frequency (RPF) sets how regularly reserves are procured
4. Reserve procurement contract duration (RPCD) specifies the resolution of reserve products, being allocated at the unit level (i.e. duration of the procurement blocks)

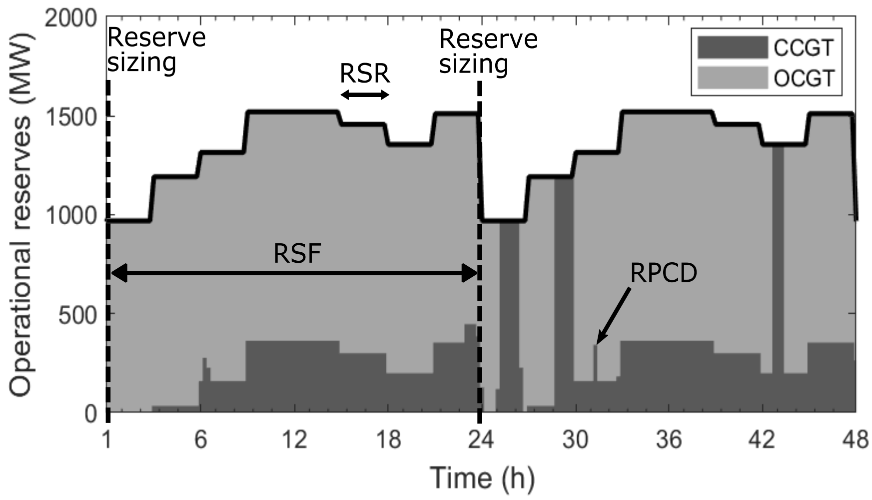


FIGURE 5-1: ILLUSTRATION OF TEMPORAL COMPONENTS OF A MARKET [D3.4]

To evaluate these effects, [3.4] EU-SysFlex quantified the potential benefits to cost-efficiency (and hence welfare) and reserve market liquidity of adopting increasingly more dynamic temporal granularities of reserve markets for case studies combining the Belgium electricity system for the Energy Transition and Renewable Ambition EU-SysFlex scenarios. Quantification was based on a unit commitment and economic dispatch (UC) model, designed to simulate the impact of the temporal granularity of reserve markets.

- A more frequent procurement process has the potential to lower the cost of reserves, as more frequent reserve sizing and procurement will allow improved forecasts to be employed, as well as facilitate the introduction of more cost-efficient dynamic reserve sizing. Results of two case studies revealed that the total operating cost savings reach 1.5% to 1.8% when moving from a very conservative (i.e. sizing well in advance, daily procurement and daily reserve contracts) to a highly dynamic (i.e. sizing and procurement close to real-time with quarter-hourly resolution) joint energy-reserve and balancing market.
- Increasing the temporal resolution of reserve markets allows more cost-efficient, dynamic sizing of reserves. Adopting higher temporal granularities mitigated reserve market scarcity. More frequent reserve sizing with a higher reserve requirement resolution resulted in total cost-savings of 0.75-1.10%.
- A short contract duration allows accounting for the time-dependent availability of reserve providers (particularly important for variable sources, such as wind and solar PV, and certain types of responsive load), as well as the time-dependent opportunity cost of offering capacity in reserve markets (particularly

relevant for thermal generators). Reducing the reserve procurement contract duration and procuring reserve capacity more frequently yielded cost savings of 0.75% and facilitated the integration of variable renewables in reserve markets.

From a practical viewpoint, more frequent reserve sizing and procurement could pose challenges related to market operation. However, it is debatable whether they weigh up to the considerable benefits of the market design changes investigated in this work.

Furthermore, it is also possible that changes to the frequency of the procurement process also affect the capacity of certain technologies to participate in these markets. To illustrate these effects, EU-SysFlex looked at how shortening the mFRR procurement cycle influences wind technology participation, and, consequently, the day-ahead market.

To deliver this analysis, this project investigated twelve scenarios depending on the selection of:

i. two EU-SysFlex scenarios (Energy Transition and Renewable Ambition),
ii. frequency of mFRR procurement (daily, weekly, monthly), and
iii. future need for mFRR, as defined by the Belgian TSO, Elia (low and high need, both for mFRR up and mFRR down).

This impact was then analysed by comparing, amongst others, the aggregated cost and the average offered supply/demand for different markets (i.e. day-ahead, mFRR up and mFRR down). We looked at the simulation results from system and technology perspectives, by developing a sequential market simulation tool. The backbone of the simulation is capturing the market time sequence, and, consequently, mapping the different decisions taken by market participants, as well as market operators.

The main actors are the simulator, market operator and market participant. While the latter two are also actors in the real world, the simulator is virtually in control of the execution of the event calendar and the information flow. Another key element of the market simulator is a blackboard for market information, which controls the information flow among individual market participants and market operators, in order to define specific scenarios linked to sharing information. To make the bidding strategies more realistic, forecasting relevant decision-making information is incorporated in the simulation. At the moment, this is linked to forecasting time series for prices and availability of generation units, including underlying weather data.

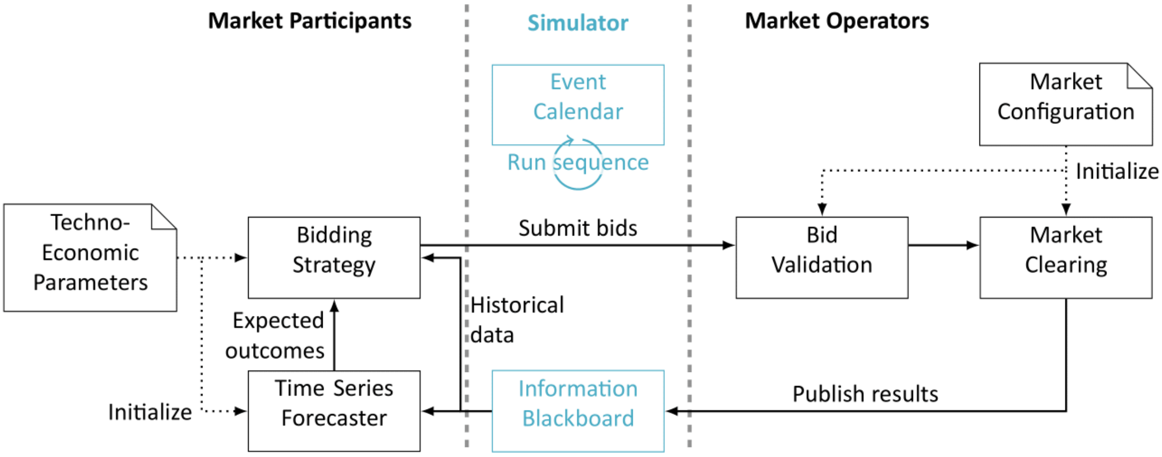


FIGURE 5-2: METHODOLOGY: ENERGYVILLE MARKET SIMULATOR

Results indicate that, from a system perspective, large cost savings can only be achieved by reducing the procurement cycle to daily auctions; changing from monthly to weekly auctions only reduces the cost in a limited way. From a technology perspective, there is a very strong increase in offered capacities from wind and solar towards daily procurement. Offered capacities from solar only appear with daily procurement. There are also seasonal effects, most pronounced for solar and onshore wind. Finally, the procurement cycle also impacts the offered prices. As a consequence of the bidding strategy, and the necessity for reduced capacity available in the day-ahead market (for mFRR up), there are price differences for upwards and downwards reserve. For mFRR down, there is a strong difference in the case of daily procurement, while for mFRR up, there is a shift towards cheaper prices and increased price diversity. The obtained results motivate future work to improve the simulation and gain additional insights.

For all the above reasons, we would propose consideration of more frequent procurement processes for both frequency and non-frequency products.

5.2.3 HOW SHALL POTENTIAL GRID RESTRICTIONS BE INTEGRATED INTO THE FLEXIBILITY SELECTION PROCESS?

As discussed above, when considering the integration of grid restrictions, there are four stages within the procurement process when there is potential to check for grid constraints:

1) Prequalification – The prequalification process may include a check of the impact on grid constraints of activating the flexibility. In the general case, there is too much uncertainty to conclude that activation of a given flexibility will always be secure, but in some special cases, it may be possible.

2) Procurement – In the general case, grid constraints need to be checked during the procurement phase to prevent the procurement of flexibilities that would be unavailable due to grid constraints.

3) Monitoring before activation – After the procurement, there is a need for continuous monitoring to ensure that the flexibility is still available – both due to resource availability and due to grid constraints, to deliver

the required response after activation. In case of the unavailability of flexibility, relevant system operators need to take appropriate action, e.g. procure additional flexibility.

4) Activation – In the case of the activation of slow products (i.e. products with manual activation), activation is the last stage where it is possible to check grid constraints. In normal operation, flexibilities to be activated have been chosen in the procurement phase; thus, checking grid constraints before activation should be needed only in an emergency situation.

The analysis shows that the timing for the review of the grid restrictions varies between products, as is illustrated in Table 5-3:

TABLE 5-3: RELEVANT PHASES OF CHECKING GRID CONSTRAINTS FOR THE DIFFERENT PRODUCTS

Product	Energy/Capacity	Phase during which grid constraints are checked
Inertia	Capacity	Prequalification
FFR	Capacity	Prequalification
FCR	Capacity	Prequalification
aFRR	Capacity	Procurement, monitoring
	Energy	Free bids – grid constraint before procurement Bids due to awarded capacity – no additional check
mFRR	Capacity	Procurement, monitoring
	Energy	Procurement
RR	Capacity	Procurement, monitoring
	Energy	Procurement
Steady-State Voltage Control	Capacity	Procurement, monitoring
Congestion Management	Capacity	Procurement, monitoring
	Energy	Procurement

The table shows that for products with fast-acting delivery timeframe, it would be more appropriate to consider these restrictions in the prequalification phase, i.e., when the relevant agent assesses whether the assets are able to provide the required services. For those products where there is a delay between activation and delivery, it would appear that evaluating this capacity in the procurement phase is possible.

When optimisation takes place in the procurement phase, the options to consider grid constraints depends on the approach used for optimisation. With a centralised optimisation, grid constraints can be integrated in the single algorithm for market clearing and optimisation of the market. However, with decentralised optimisation, it will be important to coordinate the results of the different algorithms to ensure all relevant grid constraints are considered. In these decentralised optimisation cases, EU-SysFlex identified three coordination options:

- **Bottom-up coordination**: optimisation at the distribution level, followed by optimisation at the transmission level.

- **Hybrid coordination**: optimisation at the distribution level, followed by optimisation at the transmission level, and again at the distribution level.
- **Top-down coordination**: optimisation at the transmission level, followed by optimisation at the distribution level.

To carry out the evaluation of grid constraints (centralised or decentralised), the relevant agent receives all necessary data from its allocated SO and (potentially in a consolidated way) from neighbouring networks (representing horizontally and vertically physically connected SOs), which results in coordination between the different areas. To evaluate grid constraints, the amount and type of grid data shared may vary:

- **Comprehensive grid data**, describing the dynamic electrical properties of the grid, such that the optimisation algorithm(s) is(are) able to calculate diverse grid phenomena, select the most efficient combination of flexibilities and perform topology switching.
- **Partial grid data**, using the sensitivities of flexibilities towards critical U/I constraints and U/I margins in the grid, e.g. for one topology.
- **SO only sends bid limitations**, the SO reduces or rejects bids which, if accepted as submitted, would cause grid constraints to be violated. Two sub-options exist, depending on whether bid limitations are sent after a pre-selection step or before the selection.

For both centralised and decentralised approaches, sharing comprehensive grid data appears to be the most promising solution. The relevant agent determines the most efficient solution by using flexibilities and topology switching. Nevertheless, a simplified process, such as placing limitations on bids, may be sufficient in certain instances, in particular for balancing products. Bid limitations can be sent before bid selection or, in the case of grids where the probability of breaching constraints is low, after a pre-selection only in case of breaching grid constraints, requiring an iterative process.

When choosing between the different forms of optimisation, it is important to keep in mind how they would interact with the way that grid constraints are included. For example, Table 5-4 shows the advantages and disadvantages of each type of optimisation under the assumption that comprehensive grid data is exchanged.

Conceptually, in this example, centralised optimisation leads to an optimal allocation of resources at the system level, along with reduced coordination effort and lower interoperability challenges. However, algorithm complexity is increased.

In contrast, decentralised optimisation requires coordination across different levels. Bottom-up coordination is one solution that leads to the optimal selection of bids, where there is separate optimisation of products and radial distribution grids. A hybrid approach can be more efficient where there is joint optimisation of different products, or meshed distribution grids with specific combinations of local grid structures, power flows and characteristics of flexibilities (e.g. location, voltage level and price). Top-down coordination only works for balancing products if there is no need to limit flexibility activation in the operational phase at the distribution level (due to firm connection agreements or prequalification). Therefore, decentralised optimisation appears more relevant for grids where DSOs need locational products to solve voltage and congestion problems. Other advantages of decentralised optimisation include higher resilience, lower complexity of individual algorithms, the possibility to adapt individual optimisation to specific requirements (voltage level, region) and a better fit with current regulatory frameworks. Having decided upon the optimisation approach, it is important then to consider in which phase of the procurement process grid integrity is considered.

TABLE 5-4: ADVANTAGES OF CENTRALISED AND DECENTRALISED OPTIMISATION (OPTION: COMPREHENSIVE GRID DATA)

Advantages of centralised optimisation	Advantages of decentralised optimisation

• Less coordination effort between roles needed (centralised optimisation with comprehensive grid data implies no need for iterations in the operational timeline):
  ○ Reduced coordination time
• Theoretical possibility of (fully) optimal solution:
  ○ More likely to achieve a solution of lowest flexibility costs for all scarcities
• Economy of scale (one vs multiple places for the optimisation algorithm)
  ○ Less investment in buildings and lower hardware maintenance costs
• Interoperability concentrates on the interface to one role:
  ○ One set of rules[12] required (process organisation, IT requirements…)
	• Stepwise optimisation implementation along the voltage levels is possible, considering specific voltage level and regional requirements.
	• Easier to match localised solutions to scarcities, since no new optimisation of the whole system is necessary
	• Simpler individual algorithm, with less data processing:
	  ○ Lower development cost for each algorithm
	  ○ Each algorithm computes an optimum faster
	• Aligns to current SO responsibility framework and regulation framework:
	  ○ The procurement for each SO is optimised separately: responsibilities are clearly allocated for keeping each system secure
	  ○ No adaptation needed for incentive regulation
	• Higher resilience:
	  ○ in case of one agent's failure due to distribution of data processing
	  ○ in case of missing data (only causes calculation interruption in local (and not whole) optimisation, thus lower risk for the whole system)
	  ○ in case of failures, decentralised fall-back procedures must be established (no need for additional IT and telecommunication systems if SO undertakes this role)

[12] Such single sets of rules can also be developed for decentralised optimisation.

5.3 HOW TO BRING EXPLOITABLE SOLUTIONS TO THE MARKET?

Amongst all the EU-SysFlex project results, five key results with potential for exploitation have been identified, here referred to as exploitable results (ERs). A number of selection criteria were considered, including their market potential, type of problem addressed, and geographical, regulatory and political considerations pertinent to the countries in which the ERs are to be deployed (i.e. those represented in EU-SysFlex).

The market opportunity for these ERs was analysed by first providing a high-level overview of the regulatory environment in which they would be deployed, and the roots of the problems which lead to the need for these solutions. These opportunities were evaluated using a number of business modelling tools, including the Business Model Canvas (BMC), the Value Creation Ecosystem (VCE) and the Electricity System Improvement Canvas (ESIC), the latter two of which were developed specifically for EU-SysFlex to better visualise value exchanges occurring between all stakeholders involved in any given solution (i.e. VCE), and the improvements – economic, social and environmental – brought about by the solutions to the business ecosystem as a whole (i.e. ESIC, as shown in Figure 5-3). The procedure employed represents an all-encompassing method to evaluate business opportunities that new solutions for future power systems with a high share of RES could benefit from. For a detailed overview of these tools and their applicability, please refer to [D11.30].

<table>
<tr><td colspan="6">Problem</td></tr>
<tr><td colspan="6">Mission Statement</td></tr>
<tr><td colspan="6">Leader</td></tr>
<tr><td rowspan="2">Key Partners</td><td>Key Activities</td><td rowspan="2" colspan="2">Specific System Benefits</td><td>Buy-in & Regulatory framework</td><td rowspan="2">Beneficiaries</td></tr>
<tr><td>Key Resources & Infrastructure</td><td>Mission Deployment</td></tr>
<tr><td colspan="3">Mission Costs</td><td colspan="3">Economic Benefits</td></tr>
<tr><td colspan="3">Environmental Risks</td><td colspan="3">Environmental Benefits</td></tr>
<tr><td colspan="3">Social Risks</td><td colspan="3">Social Benefits</td></tr>
</table>

FIGURE 5-3: ELECTRICITY SYSTEM IMPROVEMENT CANVAS (ESIC) TEMPLATE [D11.30]

In what follows, the five ERs that have been evaluated are briefly described and the main conclusions from their analyses are presented.

1. In the VPP demonstration, a VPP package (see Appendix IV) has been developed and implemented to reduce imbalance penalties of generation groups, while also offering more, and likely cheaper, ancillary services to the TSO. However, in order for this business opportunity to materialise, certain regulatory changes are needed in the deployment region (i.e. Portugal), particularly to allow different technologies to be aggregated (currently no specific regulatory framework in Portugal exists regarding aggregation) and for market players to be able to balance their own production. See [D11.30] for this opportunity and

implementation analysis, including the VCE, ESIC, stakeholder and market analysis and a BMC. The scalability and replicability of this VPP solution have also been assessed, with a number of European competitors identified.

2. In the Finnish demonstration, aggregation of small-scale distributed energy resources has been analysed to provide grid flexibility in the form of reserves for the TSO (see Appendix III). Here, two asset types were considered: electric vehicle (EV) chargers and BESS. Analysis of these business opportunities showed that aggregating EV chargers under current conditions in Finland (i.e. low reserve market prices and few chargers available) is not yet economically viable, while the economic incentive for residential BESS owners to participate in this ecosystem is still very low due to the low revenue generated by offering flexibility to the grid (partly due to high distribution and tax costs). However, aggregation of industrial-scale BESS could be profitable since the reserve capacity is higher and the costs are lower (i.e. less taxes are paid), but currently, this type of BESS in Finland remains scarce. While technically viable, the demonstrator leader (Helen) may seek to exploit this business opportunity in other Nordic countries which share the same Nord Pool market. However, the competitive landscape is also growing for flexibility service providers across Europe, as shown in the market and competitor analysis (using a Strategy Canvas) of [D11.30], which also contains the VCEs, the ESIC and the BMCs of these businesses.

3. In the Portuguese FlexHub demonstration (see Appendix V), exploitation of a Traffic Light Qualification (TLQ) tool for DSOs to validate replacement reserve bids from DER before their activation by the TSO was analysed. Using the VCE tool, it became clear that a stakeholder – a business developer – was missing in the ecosystem for the solution to become exploitable. This stakeholder should be able to offer the 24/7 software support service that system operators require (that the demonstrator developer, InescTec, as a research centre, would not normally provide). However, as of yet, DERs are not allowed to participate in the Portuguese RR market, and so a regulatory change must occur for this solution to be viable. Pending such a change, the ESIC shows potential for system benefits accrued for a number of beneficiaries, such as (1) the TSO, who would benefit from an increased RR potential, (2) the DSO, for whom grid constraints could be avoided, (3) flexibility aggregators, who would benefit from an additional revenue stream, and (4) grid users, who are expected to benefit from lower grid tariffs due to less curtailment and cheaper reserves contracting. [D11.30] includes the complete ESIC, together with analyses of the stakeholders, market readiness, market potential, competitor and intellectual property rights (IPR).

4. The German demonstrator proposed a solution to the German congestion management problem, using a TSO-DSO redispatch coordination mechanism and a new tool, called BeeDIP (see Appendix I). This solution was enabled by a recent change to the NABEG Law in Germany, which shortened the redispatch anticipation time and allowed renewable generators, which are mostly connected to the distribution network, to participate in redispatch. The ESIC showed many sustainable benefits of this solution for the entire system: economic benefits for all beneficiaries (TSO, DSO, RES, energy traders/aggregators and grid users), environmental benefits (lower CO_2 emissions due to less curtailed RES and lower grid losses) and social benefits (more job creation for flexibility participants, better grid efficiency and a more stable electricity supply). However, before implementing any solution, the most important hypotheses of the

ESIC should be validated (similar to validation of the BMC blocks). This was partly achieved by the demonstration KPIs (technical validation) [D10.1] and partly through stakeholder analysis (business/managerial-related validation), but some points remain which still need validation through in-depth interviews and experimentation. Besides this ESIC and the stakeholder analysis, [D11.30] also contains the VCE, the BMC and IPR analysis of the BeeDIP software sales, and replicability analysis. The latter points to the possibility of using similar congestion management tools in Denmark, although other Nordic countries, Poland and/or the Czech Republic, may also be areas for potential replicability of the proposed solution.

5. Lastly, and different from the four aforementioned ERs, the data exchange demonstrator seeks to address a Europe-wide problem, rather than a national one, with the potential for replicability elsewhere. This problem is due to energy retail and service markets in Europe being highly fragmented due to differences in regulation and data access, which prevents the spread of energy retail, efficiency and flexibility solutions. The proposed solution creates a cross-border Data Exchange Platform (DEP), led by a newly created entity called the Data Bridge Alliance (DBA), which enables interoperability of energy-related data. As shown in the VCE in Figure 5-4, the DBA offers value to (1) regulated data hubs and (2) energy app owners, resulting in value creation for the final grid user. Although the DBA would be a non-profit entity, it will still need to cover its costs. Therefore, a complete financial plan of the DBA was developed, showing net profits after five years of operation and estimating increasing revenue streams from both these stakeholders (regulated data hubs, who would pay a membership fee, and energy app owners, who would pay a subscription fee based on data exchanged). However, a sound strategy for contacting and convincing these two paying stakeholders is needed. Fortunately, European regulation will help, since both the Clean Energy Package and the Data Interoperability Implementing Acts require more cross-border interoperability of data. Besides the VCE and this financial plan, [D11.30] also contains the ESIC, stakeholder analysis, a BMC and IPR analysis.

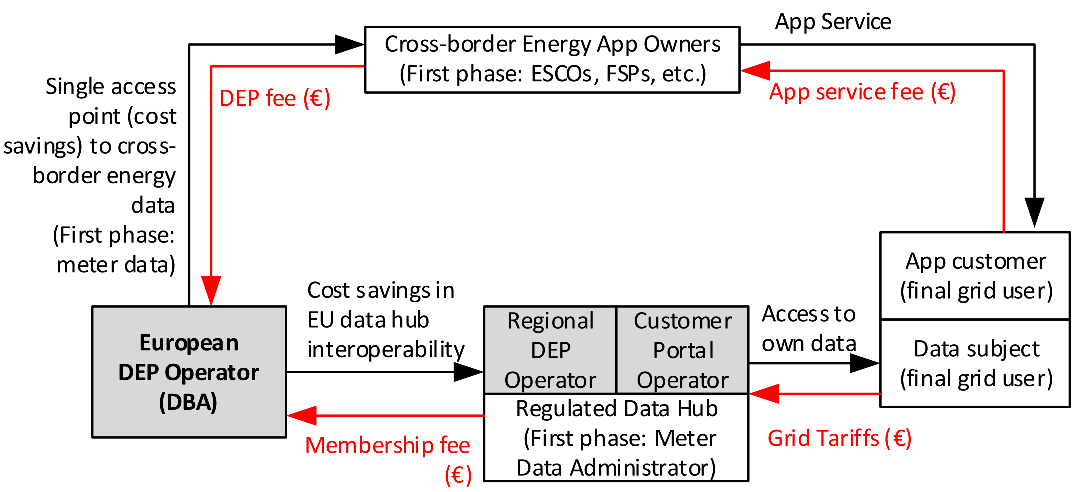


FIGURE 5-4: VALUE CREATION ECOSYSTEM (VCE) OF THE DATA BRIDGE ALLIANCE [D11.30]

Based on the 5 ERs analysed, there are a few emerging trends that can be highlighted as follows:

- The future of EU-power systems will provide promising opportunities for technology/software developers to create value and gain profit, as seen in four of the five ERs analysed (VPP and TLQ in Portugal, BeeDIP software for German congestion problems, and interoperability solution in Europe).
- To promote this participation and facilitate commercial opportunities, it will be necessary to revise and change some existing regulations, as seen in all five ERs analysed.
- Some solutions could be financially viable, even in the current market structures, as found in the case of the aggregation of industrial-scale BESS.
- In some other instances, such as for TLQ in Portugal and congestion management in Germany, it is clear that value is created, but there is a need to find stakeholders willing to orchestrate coordination amongst all stakeholders involved, and implement and provide solutions. In the case of TLQ in Portugal, it was identified that a Business Developer would be most likely to lead this role and solution deployment.

In any case, to explore the likelihood of bringing any of these solutions to market and their potential scalability and replicability, further analyses would be required in collaboration with stakeholders willing to deploy the solution.

6. HOW DO WE ENABLE UTILISATION OF TECHNICAL SOLUTIONS AND SYSTEM SERVICES?

Within the time horizon considered by the EU SysFlex project, regulatory and policy targets, as well as related rules and incentives, will promote ongoing proliferation of RES-E on the European power system.

Traditionally, power system operators have depended on large, centralised, synchronous, and often fossil-fuelled (and hydro where possible) sources of generation for energy and provision of system services. As a result, current energy markets and system services frameworks reflect, to some extent, the historical dominance of large synchronous units, with participants being mostly operators of independent plants, or legacy portfolios tracing their origins to vertically integrated utilities, and non-market mechanisms for securing system services, such as grid codes, that stipulate minimum capability to deliver, e.g. reserve and voltage regulation.

Wind, solar PV and demand-side units are comparatively recent entrants to these structures, but it is nonetheless true that the evolution of generation technologies, as well as the application of sophisticated communications protocols and novel approaches to integrate renewables, have the potential to invert this hierarchy. Indeed, targets for the proportion of electricity demand supplied from renewable sources make it a near-certainty that these participants will become the bulk energy suppliers and, eventually, bulk suppliers of system services.

A potential trajectory towards a more sustainable power system might therefore entail:

- A regulatory environment that includes decarbonisation targets, incentives and favourable rules for RES (such as priority dispatch) will drive continuing displacement of conventional, centralised, synchronous generation by distributed, mostly renewable and non-synchronous generation.
- As a result, technical scarcities will emerge (as outlined in section 3.3), due to the variable output and non-synchronous nature of the increasing share of VRES generators.
- System operators will find that, at some point determined by the characteristics of their respective power systems, it becomes increasingly challenging to continue to progress towards renewable energy targets, while simultaneously relying solely on conventional generators to regulate frequency and voltage. Therefore, they will transition to new system services frameworks to address these scarcities and maintain system security and stability.
- System operators then need to adopt novel approaches to SO-SO coordination, aggregation and data exchange in order to facilitate the integration of renewables into energy and system services markets.
- From a system operation point of view, TSOs and DSOs will face an increasingly complex operational landscape as the volumes of data upon which to base decisions increases, due to the greater number of market participants and services (in different volumes and over different time horizons) they may offer. Moreover, previous procedures and best practices become less relevant in newly evolving scenarios, due to different system behaviour integrated with a high share of RES generation.

The following sections outline the EU-SysFlex project outcomes and findings over operator decision support tools, coordination between TSO and DSO, aggregation of decentralised resources, and data management.

6.1 FUTURE POWER SYSTEM OPERATION

Currently, the majority of system operator decisions are taken by control centre staff based on real-time observations of system representations in Energy Management Systems fed by SCADA[13] data or state estimation. Power flow calculation software tools might be used, e.g. to check that a new network state is n-1 secure. More detailed approaches might consider transient stability using other appropriate software packages.

However, this approach is essentially reactive rather than proactive and does not generally provide the opportunity for optimisation, or for detailed coordination with other system operators. Further, responses to any unforeseen (i.e. not according to day-ahead or intraday scheduling, and not considered by operational planners ahead of real-time) events are based on evolved best practice, or simple criteria, such as merit order.

It is foreseeable that developments outlined above will coalesce and bring about a situation where power system operation is no longer optimal – and may not even be feasible for an unsupported human operator:

- With the proliferation of small, distributed, renewable generators on the power system and their increasing participation in system services markets, the volume of data upon which decisions might be based will increase.
- With increasing variability of generation, uncertainty of demand and increasing interconnection, a greater space of network states emerges, with the optimum harder to identify, particularly when multiple time periods and potential contingencies are considered.
- With emerging scarcities of reserve in various time horizons, steady-state and dynamic voltage regulation, and potentially increasing rotor angle instability, system operation will become more complex and will require monitoring of an increasing number of indices in order to identify and avoid scenarios that pose a greater risk to system stability and security.

The study-case of intraday Q/V management in this project [D4.3] has shown the value of an optimisation-based approach using an analytical Decision Support Tool which indicates a promising avenue of progress. Lower system costs and lower absolute redispatch volumes were achieved compared to evolved best practice and operator experience. This tool includes multiple objective functions and can, therefore, be applied in a number of contexts with the aim of realising similar benefits. Similar approaches, combined with cost-sharing methods, have further been shown to optimise cross border flows to ease congestion and minimise, or mitigate, unscheduled flows [D4.3].

Extrapolating from these findings, it can be stated that advanced EMSs and support systems are needed in operator control rooms, built around high-performance, inherently secure platforms with the functionality of analysing network security and resource optimisation, including the capability to consider multiple time points. They should solve a wide set of optimisation problems which account for;

- Multi-criteria approach and a range of objective functions;

[13] Supervisory control and data acquisition

- Network topology, including the available flexibility of network assets;
- Available market-based active and reactive power flexibility of assets connected to both TSO and DSO networks;
- Special protection scheme logic;
- Risk and uncertainty conditions, including preventive and corrective actions;
- Stability constraints; and
- Inter-TSO/DSO coordination.

Further, EMS systems should enable automated procurement of energy and system services, that is, integration of "market" and "system" information displays and data analytics. Control actions should be pursued such that information is presented to the operator in such a way that bids (or analogous information, such as availability declarations) can be activated for various services and at various locations, where necessary. Also, dispatch instructions should be sent automatically to the assets involved, either directly or via a communications link to an aggregator. A Dispatch Training Simulator has demonstrated this approach via the chosen representation of aggregated generating units and energy storage systems used, e.g. for mFRD/mNRD services [D4.3]. The onward link to, for example, the settlement systems for remuneration of providers has been considered part of the design of tools in the Portuguese FlexHub; a further example of integration of "system" and "market" information [D4.7, D7.2].

Effective decision support tools will also be necessary to support manual interventions from the SO, when needed, affecting large numbers of assets (and their respective market participants) and for the expedient activation of manually dispatched system services products that might be delivered by many distributed providers.

Management of constraints, and curtailment of priority dispatch generation could be undertaken in a similar manner, with assets grouped by type and by location, such that an operator could reduce generation by a desired amount either at a specific location, or globally for a given operator's control area, thus requiring only one control entry from the operator.

Actions that might be required to defend the power system in an emergency state place different demands on system operators; time may not allow for the solution of optimisation problems that can be incorporated into processes for normal operation. Nonetheless, an approach based on minimisation of customer-minutes-lost or energy-not-served type metrics in contingency analysis would be prudent in general, and if cost criteria can be temporarily neglected in favour of an approach that prioritises a technically secure system state in such an emergency, then this will yield faster solution times. This should also facilitate expedient system restoration.

Note that, in most cases, the initial response and subsequent outcomes will often rest upon engineering and policy decisions made far in advance of real-time, namely, in the compilation of scheduling/unit commitment rules and the judgement of operational planners. This will dictate, e.g. how much reserve is held in various timeframes as a proportion of the largest single infeed, or how much reactive capability to maintain. Also critical is the qualification of providers of system services and monitoring of their performance, as this ensures that providers of system services can be relied upon to deliver their capacity on an ongoing basis.

It follows that system operators must build capability to determine the requirements, e.g. for holding reserve or for reactive capability for their own particular system. This requires a high level of competence in the modelling and analysis of power systems, such that dynamic assessments of stability (voltage, frequency transient, oscillatory) can be carried out to enable system operators to determine the impact of likely contingencies and identify critical scenarios and corresponding mitigation measures. Furthermore, by extending the application of wide-area measurement systems which integrate phasor measurement units, operators can further monitor disturbances and obtain data for offline analysis and model validation.

In summary, and on the basis of work undertaken in the EU-SysFlex demonstration projects, the following high-level recommendations are provided for consideration by system operators. These are not listed in any particular order, as case-specific factors may determine prioritisation applied by a given actor depending on their remit [D4.7]:

- Evolutionary development of system operator EMS, as described above, and related training, such that control centre staff are prepared for extreme scenarios which may manifest themselves on European power systems in the future.
- Leveraging increased value from forecasting, such that an accurate estimate of the infeed from renewable generators can be included in scheduling/unit commitment calculations, and capability to operate flexibly can be reliably estimated and hence accurately bid in service markets, possibly with the inclusion of optimisation approaches.
- Implementation of a testing platform or process, such that the “real-world” performance of new technology types (or existing technology types providing new services) can be assessed. The result of this assessment can serve as an evidence base for benchmarking future performance and qualification of new participants via a more streamlined, standardised process.
- Adoption of analytical means of TSO-DSO coordination, such that the DSO network and DSO connected resources can help to alleviate congestion and voltage control issues at the TSO level, including means of eliminating operating points or bids that lead to violation of operational limits or non-compliance with, e.g. P-Q “windows” at interface nodes.
- Facilitation of aggregation of decentralised resources and, especially, “virtual power plant” approaches, such that the capabilities of various generation technology types can be synergistically combined in order to increase service provision by RES, and possibly also by demand, where managed actively. This may have the added benefit of overcoming regulatory barriers to participation in service markets by variable generation sources, where, for example, it is not guaranteed that both upward and downward regulation can be provided by a given technology operating in isolation.
- Facilitation of “big data” approaches, which may yield time, cost and performance benefits in comparison to traditional systems as volumes of data increase with the arrival of numerous, decentralised renewable generation and flexibility providers. It can also help to circumvent confidentiality issues, while providing an appropriate level of information to customers and market participants.

The following sub-sections describe works carried out in EU-SysFlex towards a dispatcher training system, and a qualification and trial process. The next sections will provide an overview of operating tools, TSO-DSO coordination, aggregation of decentralised resources, and data management based on EU-SysFlex demonstration projects.

6.1.1 DISPATCH TRAINING SIMULATOR

A prototype Decision Support Tool (DST) was developed by this project and integrated on the integrated Polish TSO Dispatcher Training Simulator (DTS). The DST is built from two modules:

- Cross-Border Coordination Module (CBCM): Coordination of phase-shifting transformers (PST) and generation redispatch to manage cross-border congestion.
- Dispatch & Scheduling Module using a security-constrained Optimal Power Flow (SCOPF-DSM): Optimises system services provision from new technologies.

The Decision Support Tool was used to simulate security-constrained optimised power flow for multiple time periods with a number of potential contingencies, and on this basis to provide a time series of "preventive" and "corrective" control actions (should contingencies occur) to the operator in an understandable format. Figure 6-1 shows the interactions between stakeholders and the functionality of the decision support tool in the energy market [D4.3], which enables the Operator to take action based on a chosen objective function, such as minimisation of redispatch cost, active or reactive power loss, number of redispatch actions or maximisation of reactive power reserves.

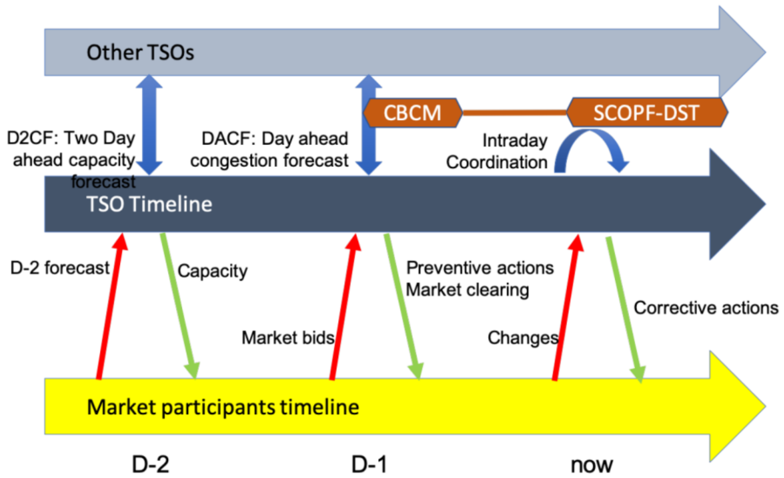


FIGURE 6-1: FUNCTION OF DECISION SUPPORT TOOL AND ITS MODULES IN THE ENERGY MARKET [D4.3]

With the task at hand growing in complexity and the array of tools/services growing, a means to train and prepare operators to maximise these new analytical capabilities, and system services is necessary. A DTS was developed by this project to explore the challenges in training system operators, considering emergent challenges to be encountered in a high VRES system. The DTS is based on the ARISTO engine (DTS-ARISTO), a tool enabling the training in real-time of power system dispatching, including activities.

This has allowed for the simulation of selected TSO processes using new system services and technologies as power system flexibility providers in a high RES-E European network.

DTS tools give TSOs and DSOs dispatchers many opportunities to prepare for extreme operational situations when operators learn how to use new flexibility services, system-level special protection schemes, automation systems, decision support tools, etc. More details can be found in [D4.3].

6.1.2 QUALIFICATION TRIAL PROCESS

The utilisation of new/unproven technologies and services does present a risk, and the platform to trial and assess these technologies is of great importance to SOs. The Qualification Trial Process is the mechanism through which the TSOs in Ireland and Northern Ireland are managing the transition to a wider portfolio of system service providers. The QTP is a platform to trial services from new technologies and provides a route to an enduring flexibility products' market.

The aim is to identify operational complexities that may be associated with new technologies, or the delivery of new System Services. In doing so, SOs can develop a deep understanding of these complexities and suggest solutions regarding how to best integrate these technologies at scale on the power system on the Island of Ireland and Europe.

This has allowed for the identification and resolution of operational protocols, determination to be made on technology capability and communication challenges. The FlexTech Technology Integration Initiative (FlexTech) has been utilised as a platform for active engagement between the TSOs, DSOs, industry, regulators and other stakeholders to maximise opportunities for effective use of new and existing technologies.

Key principles of QTP include running trials at a small scale to mitigate risk, assessment on a technology class basis rather than the service provider, participant failure viewed as learning rather than permanent exclusion, and that QTP success does not guarantee that a service provider will obtain a contract in the main procurement process.

A number of trials have been explored on the Irish and Northern Irish systems through this process:

- 2017 QTP: Capabilities from technologies such as wind, DSM, and energy storage to provide Fast Frequency Response, Primary, Secondary, and Tertiary Operating Reserve (POR, SOR, TOR), Fast Post-Fault Active Power Recovery (FPFAPR) and Dynamic Reactive Response across various technology classes.
- 2018 QTP: Residential Service Provision (to identify the potential of residential, consumer-based demand response to provide flexible capabilities), Steady State Reactive Power-SSRP (to provide reactive power support from distribution connected wind) and Control and Signals (to address and identify the barriers to market participation and increase SO visibility).
- 2019 QTP: Solar photovoltaic System Service Provision (FFR, POR, SOR, TOR, SSRP, FPFAPR and DRR), Residential Service Providers (to investigate the operational complexities associated with automated response from in-home technology, following the 2018 QTP), Communication (to enable a two-way communication solution between a small scale or aggregated service provider and the SO, following 2018 QTP).

More details can be found in [D4.4, D4.5, D4.6] and appendix VIII.

6.2 DECISION SUPPORT TOOLS

With the complexity of network operation, and challenges faced set to become more frequent and complex, a paradigm shift is required on the part of system operators, from experience-based judgment in system operation to decision making supported by analytical tools, and from direct control of assets to procurement of energy and services via market frameworks.

Several decision support tools with different objectives and scopes have been developed and implemented in different EU-SysFlex demonstration projects. These solutions have been evaluated by scalability and replicability analysis, verifying that they are scalable across large power system areas, and replicable from one country/area to the next. The following sections give a quick overview of these tools.

6.2.1 SYSTEM OPERATOR TOOLS

6.2.1.1 GERMAN DEMONSTRATION

Within the German demonstration, two tools were developed that help schedule preventive and corrective measures in congestion management and voltage control. IEE.NetOpt was tested under operational conditions in the grid control centre of the DSO MITNETZ STROM. This tool supports, via a security-constrained optimal power flow, the decision-making process of the operator in preventing congestion and voltage issues. IEE.NetOpt uses grid topology data, and related data in CIM-CGMES format, together with schedules and forecasts of infeed and consumption to predict up to 48 h ahead contingencies and propose measures to ease them. The tool is in line with the requirements of today’s regulatory framework, which means that a function is integrated that computes and generates segregated lists of available active and reactive power flexibilities at the DSO-TSO interface, as well as handling aggregated set points at these interfaces to realise those that use decentralised generating units. With this, the TSO has all the information needed as input for its own congestion management to calculate the best option to prevent contingencies with the activation of flexibility in the distribution grid without jeopardising distribution grid stability. Additionally, the combination of active and reactive power management allows more efficient use of flexibilities. This tool was tested with the DST described above.

The second tool of the German demonstration focuses even more so on the interdependencies of active and reactive power management at DSO-TSO interfaces. The PQ-Maps tool was tested with a partial grid of MITNETZ STROM. This tool predicts the joint active and reactive power ranges that can be exchanged at DSO-TSO interfaces, while using the available flexibility resources at the distribution network without compromising its operation. The information presented by the PQ-Maps provides significant support for planning and operational domain. Thus, PQ-Maps enhances the accuracy in defining contractual values of electrical energy exchange between transmission and distribution systems.

Furthermore, PQ-Maps helps the DSO avoid penalties due to possible violations of power exchange defined by the TSO. Moreover, if the TSO has several DSO grid interconnection substations, the tool performs the PQ-Maps for each interconnection, enabling how active and reactive power are redistributed throughout the DSO-TSO interconnections. Currently, the tool cannot be used in daily operation because German regulations require schedule-based congestion management (redispatch) for the segregated information of each of the activated flexibility. This needed function is not yet integrated into PQ-Maps.

The approach of PQ-Maps in comparison to IEE.NetOpt is the use of historical data, instead of transmission grid topology data. Both approaches show good accuracy. It is shown that the better the input accuracy, the better the results. If the DSO obtains data of the observability area of the transmission grid, IEE.NetOpt works with high accuracy. On the other hand, disclosing transmission grid data to the DSO could raise confidentiality issues. If this data is not available, IEE.NetOpt can only secure accuracy due to the process approach in the German demonstration of executing every 15 minutes an optimisation with updated input. PQ-Maps, on the other hand, uses equivalents of the transmission grid created from historical data. With this approach, data from the observability area of the transmission grid is not needed, but the risk of low accuracy is higher if the historical data does not represent the transmission behaviour. If no historical data from the transmission grid is available, results of the ranges of active and reactive power at the DSO-TSO boundaries are not reliable. Taking this into account, the advantage of IEE.NetOpt, in this case, is that congestion management and voltage control in the distribution grid is still manageable. More details have been provided in [D6.2, D6.5] and Appendix I.

6.2.1.2 ITALIAN DEMONSTRATION

The Italian demonstration has developed different tools, including a forecasting tool, state estimation (SE) tool, reactive power calculation tool, optimal power flow tool. The main purpose of the forecasting tool is to provide, for each HV/MV transformer of the primary substation, the active and reactive power values of PV generators, loads and other sources, by updating them every 20 seconds. The local SCADA aggregates the available data by exploiting many inputs related to the real structure of the MV network fed by each MV bus-bar of a primary substation. Data is sent to the TSO every 20 seconds. More in detail, this functionality includes the Nowcast algorithm, which performs estimated production from solar sources within a 20-second cycle. In the Italian demo, the generation forecast is the input for the functionalities of state estimation, and voltage regulation integrated into the network calculation algorithm system. The SE algorithm is composed of three main modules:

- Power Flow;
- Simple State Estimation; and
- Complete State Estimation.

The power flow module is based only on the voltage measurements of the Primary Substation High Voltage (HV) busbar, and on the load and generation profiles of the Medium Voltage (MV) customers (Generators, Passive Customers, “Prosumers”) and MV/LV (Low Voltage) transformers. The Simple SE is based on all relevant measurements available at the Primary Substation level (HV and MV bus-bar voltages, MV feeder currents, active and reactive power flows on the HV/MV transformers). Lastly, the Complete SE is able to process even the available measures on the MV network (voltages on MV bus-bars, active and reactive power flows on branches, current flows on branches). The algorithm triggers every 15 minutes, or reacts after network changes (such as remote-control reconfigurations, or automatic manoeuvres for network restoration). The SE tool receives as inputs the grid topology, measurements and forecasts, and generates a description of the system in terms of active and reactive power and voltage at MV nodes.

The reactive power calculation function, accompanying the optimal power flow tool, allows the DSO to determine the reactive power provided by local resources to the TSO in real-time (based on actual data), or the future availability of the network to provide voltage control (using forecasts). The DSO can manage its own assets and other DERs through the optimisation tool, minimising dispatching costs and avoiding network violations and curtailment. Different types of constraints can be considered in the optimisation problem, including power exchange at the HV/MV primary substation node, which allows modelling of the constrained profile of P/Q (acrive/reactive power) flows resulting from a specific request from the TSO network. Other features of this tool are:

- Flexibility aggregation; essential for calculating the correct set-points for DSO assets and DERs, respecting the constraints of both the DSO and TSO networks; and
- Reactive power capability calculation; which allows estimating the maximum reactive power that can be exchanged with the transmission network.

The objective of the optimisation process is to minimise the active and reactive power modulation of the available generators with respect to the initial starting point. More details can be found in [D6.2, D6.5] and Appendix II.

6.2.1.3 FLEXIBILITY HUB DEMONSTRATION

The Flexibility Hub (FlexHub) demonstration in Portugal has developed several tools to provide different services for the TSO.

A local market to provide reactive power from resources connected to the distribution grid is proposed to compensate for the reduction in resources currently providing this service. The market allows the DSO to balance the reactive power of its grid, and to provide the TSO reactive power needs at the TSO-DSO connection point, guaranteeing that reactive power activation does not compromise the DSO grid constraints.

The Traffic Light Qualification tool provides a verification process to determine if activation of the physical resources corresponding to the bid could compromise secure operation of the distribution grid. The TLQ indicates if the resources offered can be activated totally (green light), partially (yellow light) or cannot be activated (red light) due to violations of distribution network constraints where they are connected. The bid may then be cleared totally, partially or discarded. The TLQ process is repeated each time the TSO selects a new bid with resources in the distribution grid.

The increasing proliferation of distributed resources will transform distribution grids (traditionally more resistive) into grids with more complex dynamic behaviours, and therefore, with larger impacts on the dynamics of the whole power system. The dynamic equivalent model tool developed by this demonstrator represents the dynamic behaviour of the distribution grid at the HV/MV boundary substation (TSO/DSO interface), following transmission grid disturbances. The model has been proved to be representative and robust for radial MV distribution networks, with a wide fleet of generation system technologies and loads. The structure may also be representative for HV distribution (even for meshed configurations), as long as it is connected to the transmission network at a single electrical point. More details can be found in [D4.7, D7.2] and Appendix V.

6.2.2 AGGREGATOR/VPP TOOLS

6.2.2.1 FINNISH DEMONSTRATION

In the Finnish demonstration, a set of forecasting and optimisation tools was developed specifically for each asset type. A forecasting tool was created for the use of the DSO for the reactive power market demonstration. In addition, four aggregator tools were developed to forecast asset availability, and enable the aggregator to operate in the TSO ancillary markets, define the optimal bidding sizes and times, and define the available potential in current and future scenarios. These tools are as follows:

1. Forecast of customer-owned batteries is generated for the aggregator in the context of individual households owning PV panels and a battery. Its primary use is to store and consume locally as much of the energy produced by the household PV as possible. The objective of the forecast is to identify how much of the battery capacity must be reserved for that purpose, and cannot bid on other markets.
2. Electric vehicle forecasting tool for the aggregator forms the basis of an optimisation tool to bid the capacity available from a set of public EV charging stations into system service markets. The forecast is intended to give an estimate of how much capacity can be made available for specific markets. In this case, the target markets relate to FCR.
3. For households with electric storage heating that can be controlled through the DSO's Automatic Meter Reading (AMR) systems, the aggregator forecasting tool estimates the heating needs for houses with a hot water storage unit used for space heating and domestic hot water. It forecasts the heating needs throughout the day, but can also predict how the heating system will react to changes and commands resulting from the operation of the AMR-connected switches.
4. PQ-window compliance forecasting tool for the DSO is a preliminary step in operating the DSO-managed reactive power market. This tool was developed to determine the amount of reactive power the DSO requires from the market.

This demonstration has also developed two optimisation tools:

1. BESS optimisation tool aims to maximise the revenues obtained from the BESS by participating in the FCR-N market.
2. Optimisation tool for a EV charging station aims to determine how much power the aggregator should bid on the markets.

An important result of the optimisation process is that, by running it against historical data, or against possible future scenarios, the aggregator could estimate the value they could extract from providing the service. That value can then be used to decide the willingness of the aggregator to participate. Also, by sharing revenues, users could be convinced to participate in ways that would increase the potential. More details are available in [D6.2, D6.5, D6.9] and Appendix III.

6.2.2.2 PORTUGUESE VPP DEMONSTRATION

The Portuguese VPP demonstration is composed of an algorithmic core (VPP core), a control unit (VPP Controller) and different integration components, such as user interfaces, data connectors, etc. VPP Core provides the following main services:

- Economic dispatch optimisation of the VPP on a five-minute to one-hour time scale, with a 24 h to 72 h prediction horizon; and
- Combined (stochastic) optimisation of market participation (energy and ancillary service markets) and power dispatching, based on the forecast of available power from renewable resources and market prices.

The VPP Controller provides the following services:

- Implementation of the dispatch power schedules of the VPP Core on a timescale of five seconds to one minute, i.e. sending power set points and market bids and returning information to the VPP Core (availability of generation resources, accepted bids in markets, etc.);
- Deviation handling, i.e. manage power imbalances; and
- Technical integration with DSO network (communication with power generation units and market trading interfaces).

VPP Core consists of a forecasting module that produces time series forecasts and uncertainty quantification for available power of renewable resources, energy markets and ancillary services prices, energy spot market clearing prices (day-ahead & intraday), and ancillary service prices.

VPP Core also incorporates a Predictive Power Dispatch Optimisation Module that takes forecast information and computes economically optimal output [D4.7]:

- Market participation decision support (bidding in day-ahead & intraday, ancillary service markets);
- Power dispatch decisions for the power production units (after market bids are accepted)

More details are available in [D4.7, D7.2] and Appendix IV.

6.2.2.3 FRENCH VPP DEMONSTRATION

The French VPP demonstration developed EMS controlling tools to handle aggregation of numerous technologies facilitating the provision of system services. It is composed of two control layers, as follows:

- Operational planning scheduler, responsible for providing day-ahead/intraday service schedules;
- Short-Term Control function that provides short-term adjustment capacities.

The operational planning scheduler aims to define those services to be provided by each resource (PV farm, wind farm, BESS and controllable load) in upcoming hours with a fixed sampling interval (e.g. next 36-48 hours at 30-

minute resolution). More precisely, it determines the sequence of service setpoints for all resources for all sampling intervals considered. For instance, it defines BESS upward and downward power reserves from, for example, 8:00 to 8:30 if it is expected to deliver the FCR service. In order to facilitate scheduling calculations in the demonstration, the following inputs are required:

- Wind & PV forecasts;
- Service price forecast; and
- Present status and potential performance which can be delivered by each technology.

The scheduler can then be updated every 30 minutes to provide the most accurate forecasting information. The base model provides two services:

- Energy arbitrage using all resources, through D-1 and energy purchases/sales; and
- Symmetrical FCR, provided by the BESS.

Therefore, the model can provide a generation and services schedule day ahead and provide updated intraday schedules at 30 minute resolution.

The Stochastic Optimisation Method is a two-stage stochastic algorithm that has been adopted to overcome the limitations of deterministic optimisation. The algorithm adopts the following approach:

1. The first-stage decision is the aggregator’s commitment to the day-ahead markets, i.e. the day-ahead energy sales/purchases and the level of FCR; and
2. Recourse decisions represent VPP flexibility to compensate for generation forecast errors, i.e. BESS power, curtailed renewable energy and/or intraday energy sales/purchases.

Appendix VI and project deliverables [4.7, 8.2] provide more information about this demonstration.

6.3 TSO-DSO COORDINATION

As discussed previously, adoption of enhanced TSO-DSO coordination, such that distribution-connected resources can help to alleviate system issues at the TSO level, is an essential requirement in the future power system due to the significant share of such resources in the distribution network. However, operational challenges arise as the use of DER by different operators may trigger conflicts between serving local or national or regional objectives. This emphasises again that stronger TSO-DSO coordination is required to maximise the synergy of using distributed resources to provide multiple services.

As discussed in Section 5.2, the EU-SysFlex project has investigated two coordination approaches, incremental and whole-system frameworks, to bridge and enhance TSO-DSO integration while enabling maximum use of DER, and stimulating competition in the provision of transmission services by local DER and transmission connected resources [D3.4].

The incremental coordination approach is based on the principle that DSOs will facilitate the available capacity of DER services to be offered to wholesale electricity markets (both energy and system services). DSOs ensure that utilisation of the offered capacity does not violate distribution network constraints. In this context, the concept of virtual power plant is used to aggregate the capacity, and energy, that can be harnessed from DERs while ensuring secure distribution network operation. Local electricity (energy and ancillary service) markets can be developed to promote competition between local resources to stimulate cost-efficient operation. In addition to the capacity provided by DERs, distribution network assets can also be used to provide services to transmission. By controlling distributed reactive compensation, and, to some extent, active and reactive distribution power losses, power flows at the TSO and DSO coupling points can be adjusted to meet national electricity system requirements.

The second approach is to optimise the use of DER capacities for TSO and DSOs simultaneously. In principle, this optimises all connected plant at transmission and distribution concurrently. This approach is ideal from an optimality point of view; however, it is very challenging from computation and control viewpoints. The second approach requires centralised electricity markets for all plant (including DERs)[14] and centralised system operation. It requires a central entity that fully integrates TSO and DSOs system operation to optimise the whole system. Therefore, it may not be compatible with existing operational structures, whereby a TSO focuses on the national transmission system operation, while DSOs operate distribution networks.

The performance differences between the first and second approach for optimal utilisation of DER capacities can be minimised if the allocation of DER flexibility can be revised to consider both transmission and distribution requirements in real-time. This can be facilitated if market operation is close to real-time (e.g. 15 - 30 minutes ahead) and distribution network operation is sufficiently flexible. See project deliverable [D3.4] for further information on the coordinating approaches.

This project has also investigated cross-border coordination between TSOs, with the results illustrating how cross-border coordination of balancing capacity (BC) markets can lead to more cost-efficient system operation. When cheaper BC is available in neighbouring control zones, BC exchange allows for import of that capacity (and vice versa). Cross-border coordination enables increased generation from less flexible capacity, both “slow” conventional and renewable technologies, which is often cheaper. This happens because BC exchange allows for importing flexibility from other control areas, thus reducing the technical constraints on online capacity within a control area. This can free up low-marginal cost capacity initially (partly) allocated to provide BC, allowing increased contributions from low-marginal cost, low-flexibility capacity, and even reduce curtailment at times of high renewable infeeds. As the stringency of flexibility requirements varies with time and place, different control areas can benefit from these effects at different times. The benefits of a coordinated approach are greater as the share of renewables increases. Moreover, cross-border coordination reduces the overall need for BC, which has the potential to drive the most significant cost savings. On the one hand, it allows for a reinforced version of the

[14] A centralised electricity market is a single market place where all providers (small and large) and users meet. This requires both transmission and distribution models to be considered during the market clearing process to maximise synergy, and prevent conflicts of using DERs for both transmission and distribution needs.

second effect described here, i.e. lowering the technical constraints on the power system portfolios, thus allowing for more low-marginal cost capacity to be used for electricity generation. On the other hand, and probably more significantly, it reduces the need to build new "back-up capacity". More details on cross-border coordination requirements can be found in [D3.4].

The following sub-sections provide a high-level overview of some EU-SysFlex demonstration projects that have developed improved coordination mechanisms between TSO and DSO.

6.3.1 GERMAN DEMONSTRATION

In the German demonstrator, the TSO sends a direct request to the DSO informing them of the specific flexibilities (active or reactive power) which are needed to perform the required system service. It is then the DSO's responsibility to fulfil this request (for congestion). Therefore, the TSO is not directly controlling any assets, devices, and/or generation units connected to the distribution networks, as this may create problems, such as congestion in the distribution grid. DSOs take care that TSO requests are fulfilled, but in such a way that no additional congestion is created in the distribution grid, guaranteeing congestion-free, secure and reliable distribution system operation.

The tools of the German demonstration, as described above, support DSO-TSO coordination in providing information about available flexibility at DSO-TSO interfaces in day-ahead and intraday timeframes. This information brings benefit only if a process is defined to exchange information in an updated/continuous manner. The defined process in the German demonstration is based on the existing redispatch process. Due to similar information requirements for active and reactive power management, parallel processes for redispatch and voltage control were described. There is a difference in time to update information between day-ahead and intraday. The guiding principle is that the closer to real-time, the more accurate the input information needs to be. With this process, TSO-DSO coordination for preventive and corrective measures in active and reactive power management is executable without risking reliable, stable and efficient supply. Another principle of the tested and proven coordination scheme is the shared system-wide responsibility, with a respective focus on one's own grid. Figure 6-2 illustrates the day-ahead process for active power flexibility provision based on TSO requests, which has been designed and implemented by the German demonstrator. Congestion management results using day-ahead TSO-DSO coordination for a winter day are presented in Figure 6-3. Based on the initial simulation, several congestion areas for the EHV/HV Grid Connection Points (GCPs) have been identified (solid lines). It can be observed that the proposed use of active power flexibilities from DSO-interconnected RES significantly contributed to congestion mitigation in the EHV grid (dash-dotted lines). For each GCP, there are no overloading states identified following mitigation actions. The outcome was achieved using only DSO-interconnected active power flexibilities; no actions on the EHV transmission grid were considered. As a result, the coordination tool provides an alternative for TSOs in terms of congestion management, introducing novelty in the field of utilising flexible assets located on the DSO grid to benefit the TSO grid [D4.3]. For more details regarding the process developed by this demonstrator, see [D6.1, D6.6, D6.7] and Appendix I.

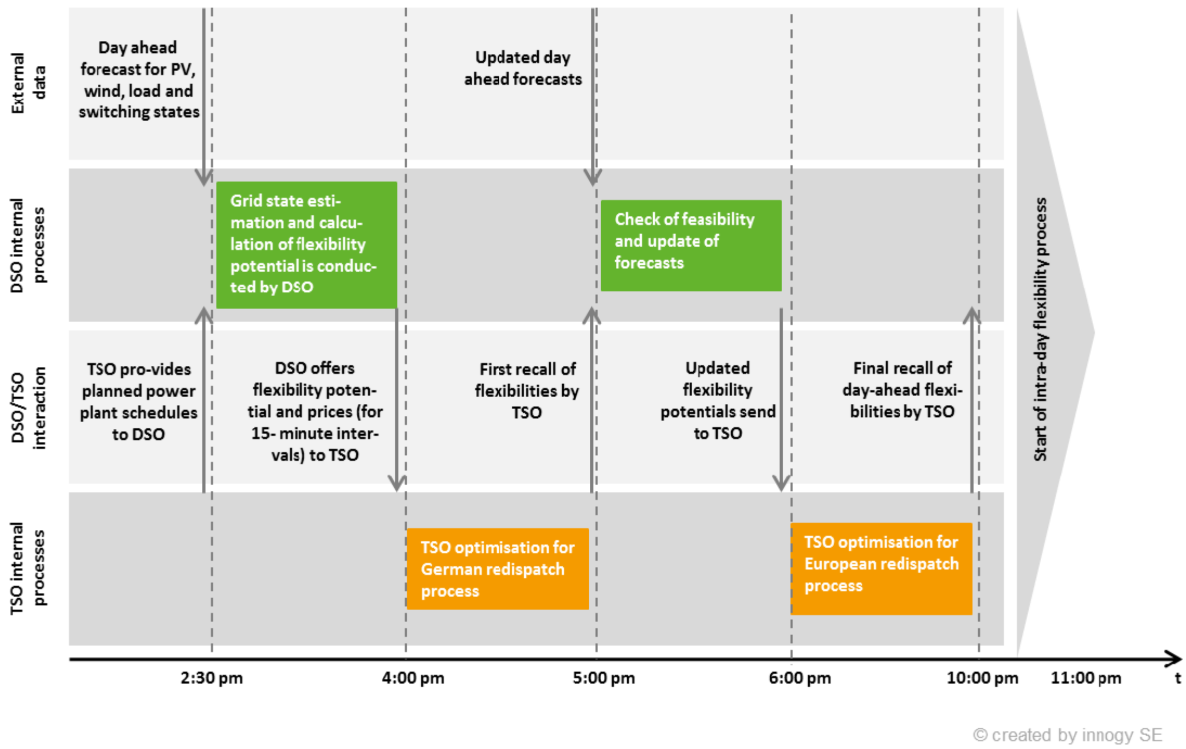


FIGURE 6-2: DAY-AHEAD PROCESS FOR ACTIVE POWER FLEXIBILITIES-GERMAN DEMONSTRATION [D6.6]

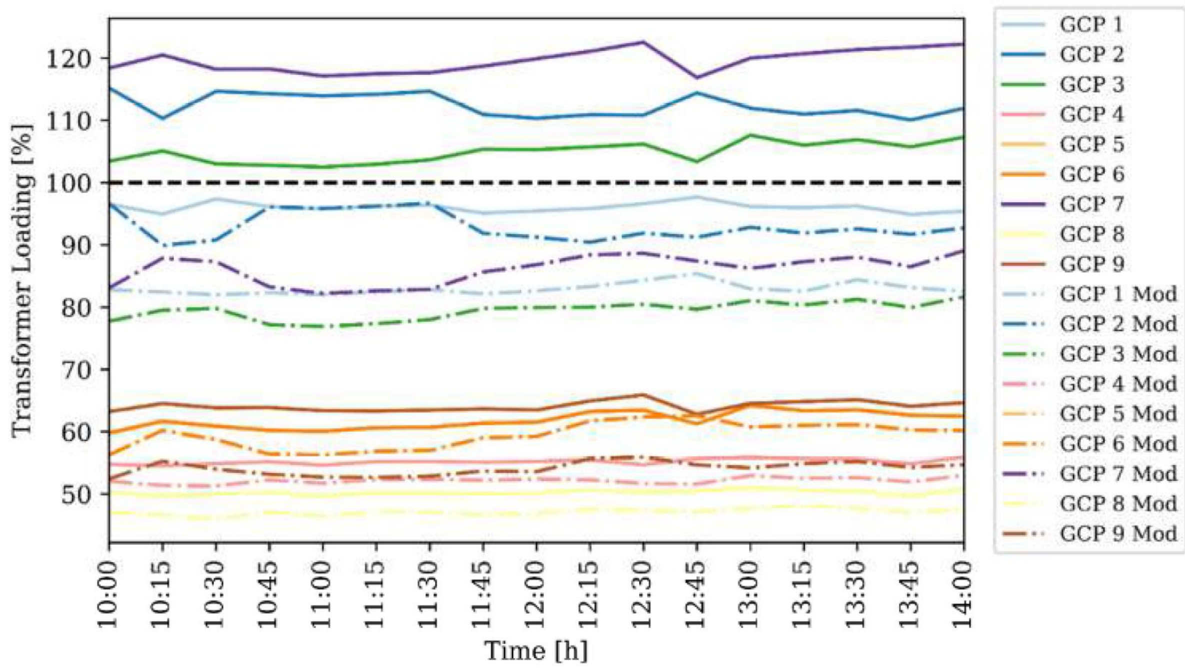


FIGURE 6-3: CONGESTION MANAGEMENT USING DAY-AHEAD TSO-DSO COORDINATION, PROPOSED BY GERMAN DEMONSTRATION [D4.3]

6.3.2 ITALIAN DEMONSTRATION

The Italian TSO, Terna, prescribes all activities regarding remote control and measurement acquisition for the operation of all plants connected to the National Transmission Network, which includes, amongst others, all primary substations of the connected DSOs. In particular, the TSO requires DSOs to send:

- Real-time positions of all circuit breakers of the HV/MV Transformers;
- Real-time measurements of active and reactive power at the HV/MV transformers.

The Italian Demo's SCADA (as a DSO) is designed to provide all such information to the TSO SCADA according to system operation guidelines. Within the project objectives, the DSO provides aggregated network capability information at its interface with the TSO, which is represented by the HV/MV primary substation. The DSO needs to perform congestion management and voltage regulation on its grid. It can also facilitate and support the provision of some network services to the TSO by decentralised resources.

Under this scenario, the TSO must address transmission network constraints, and must know the energy output of all plants connected to the distribution network. Therefore, it is necessary to review and update the coordination/interaction processes between these two actors. The Italian demonstrator has deployed this process in its SCADA architecture, developing fields related to reactive power capability and TSO aggregated set point request of voltage and reactive power. The Italian Demonstrator tested an automated coordination process between the DSO and TSO using an IEC 104 protocol simulator, which acts as a substitute for the transmission of some specific signals and measurements between the DSO and TSO. Figure 6-4 depicts the Italian demonstration architecture. Figure 6-5 shows the optimised reactive power profiles of flexible resources in a simulated case where 4 PV generators (at G8, G19, G20, G25 nodes on the demonstration Grid), 1 storage (BESS), and 2 STATCOMs are involved [D6.5]. In addition to the resource profiles, the set-point profile and base reactive power profile are included for clarity. This later profile represents the reactive power absorption of the loads and the reactive power injection due to the capacitive reactance of the network. It is worth mentioning that the demonstrator network is quite large, which entails a strong power injection due to network capacitive reactance (3 MVAr on average); this aspect, in conjunction with the low load consumption, turns the base reactive power profile into a substantial reactive power injection versus the transmission network. The demonstrator tools, as depicted in Figure 6-5, can control the assets and follow the external TSO set-point for an entire day. More details and tests results are available in [D6.1, D6.6, D6.8] and Appendix II.

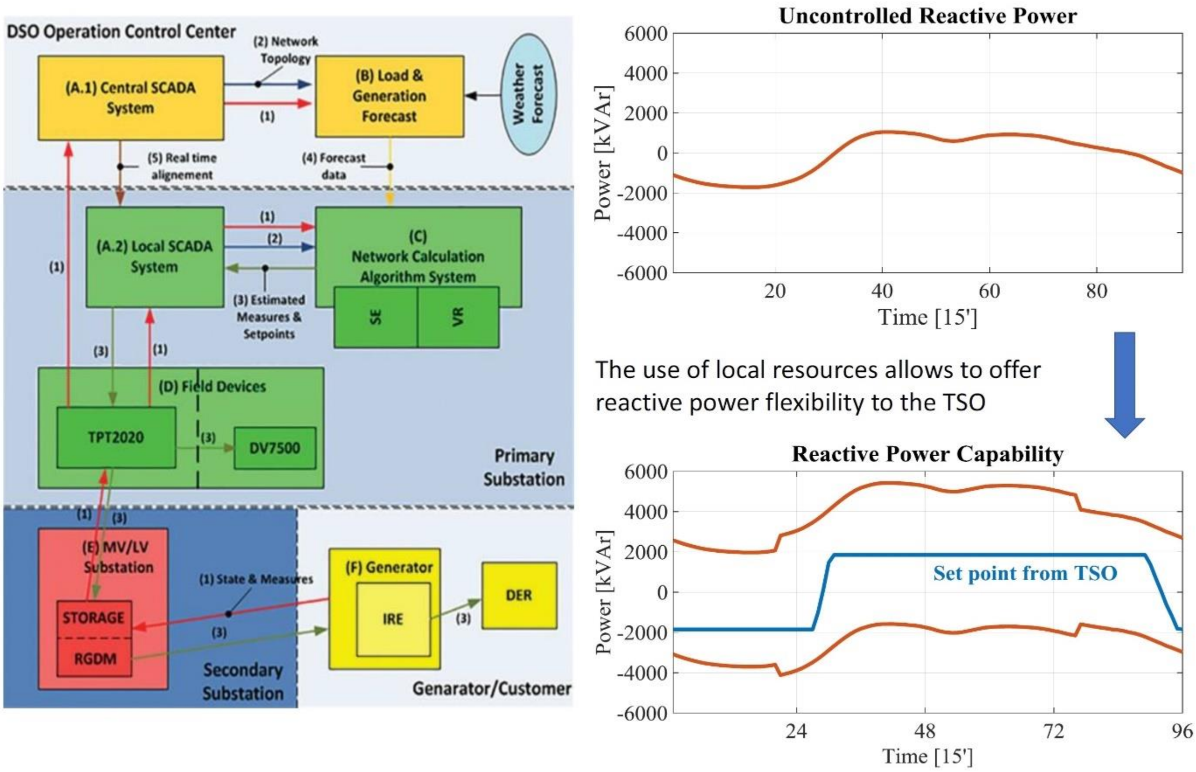


FIGURE 6-4: GENERAL ARCHITECTURE OF THE ITALIAN DEMONSTRATION [D6.6]

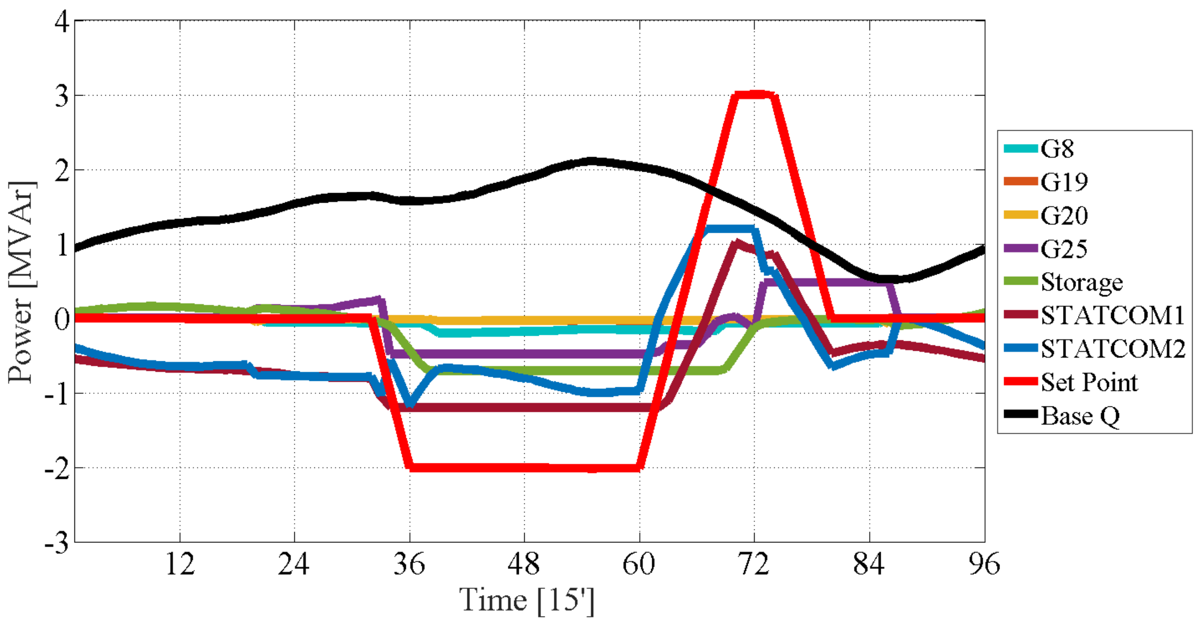


FIGURE 6-5: REACTIVE POWER PROFILES OF THE INVOLVED FLEXIBLE RESOURCES FOR REACTIVE POWER SUPPORT, ITALIAN DEMONSTRATION [D6.5]

6.3.3 FLEXIBILITY HUB DEMONSTRATION

The Flexibility Hub (FlexHub demonstration) coordinated by the DSO aims to operate as a flexibility market facilitator, and provide a local reactive power market for the DSO to balance the reactive power of its grid, to provide reactive power flexibility to the TSO at the TSO-DSO connection point, and also provide technical validation of the active power flexibility activated by the TSO from resources connected to the distribution system. The reactive power market is based on welfare maximisation with grid constraints, while validation of the active power uses the Traffic Light Qualification tool, which determines if the distribution-connected resources are allowed to provide the requested service, due to violations of local distribution network constraints, by indicating three statuses: green (totally activated), yellow (partially activated), or red (not activated). The FlexHub also provides an equivalent dynamic model of the distribution grid, to be used in frequency and voltage disturbance analysis at the DSO/TSO interface node. The FlexHub is, therefore, a new platform concept to promote interaction and coordination between the TSO and DSO for enhanced system operation for short-term (active and reactive power) and long-term (planning based on equivalent DSO grid model) system needs. Figure 6-6 outlines the general architecture of the FlexHub demonstration. Figure 6-7 shows the capacitive (a) and inductive (b) reactive power cleared (in orange) for a simulated case-study with a scaled-up TSO-needs profile (in red) for a particular day. This aim of this case study was to estimate the reactive power flexibility limits of the Portuguese FlexHub demo network. 6 scenarios were considered, as depicted in Table 6-1. For each scenario, it is possible to compare the reactive power cleared with the capacitive/inductive reactive power available (in blue) and the DSO needs (in green) to balance its reactive power grid. In general, with voltage limits set to ± 10 % of the nominal voltage, there are no restrictions regarding the flexibility cleared. If we compare the available flexibility of scenario R2V+ (2 resources providing upto 35.4 MVar) with scenario R7V+ (7 resources providing upto 106.7 MVar), these results support the potential of the proposed local reactive market to provide market-based reactive power flexibility for TSO needs and logically, the strong impact of the existing liquidity [D7.6]. Further results and performance tests of this demonstration can be found in [D4.7, D7.2, D7.6] and Appendix V.

TABLE 6-1: OVERVIEW OF SCENARIOS CONSIDERED IN REACTIVE POWER FLEXIBILITY PERFORMANCE TEST – FLEXHUB [D7.6]

Scenario Name	Flexible resources	Voltage constraints limits
R2V+	Barroso II (Wind farm, 12.3 MW) Barroso III (Wind farm, 23.1 MW)	Upper limit: 1.1 p.u. Lower limit: 0.90 p.u.
R2V-	Barroso II Barroso III	Upper limit: 1.05 p.u. Lower limit: 0.95 p.u.
R3V+	Barroso II Barroso III Caniçada (Capacitor banks, 2* 4.43 MVar)	Upper limit: 1.1 p.u. Lower limit: 0.90 p.u.
R3V-	Barroso II Barroso III Caniçada	Upper limit: 1.05 p.u. Lower limit: 0.95 p.u.
R7V+	Barroso II Barroso III Caniçada 4 additional wind Farms (2*12.3+2*23.1 MW)	Upper limit: 1.1 p.u. Lower limit: 0.90 p.u.

R7V-	Barroso II Barroso III Caniçada 4 additional wind Farms (2*12.3+2*23.1 MW)	Upper limit: 1.05 p.u. Lower limit: 0.95 p.u.

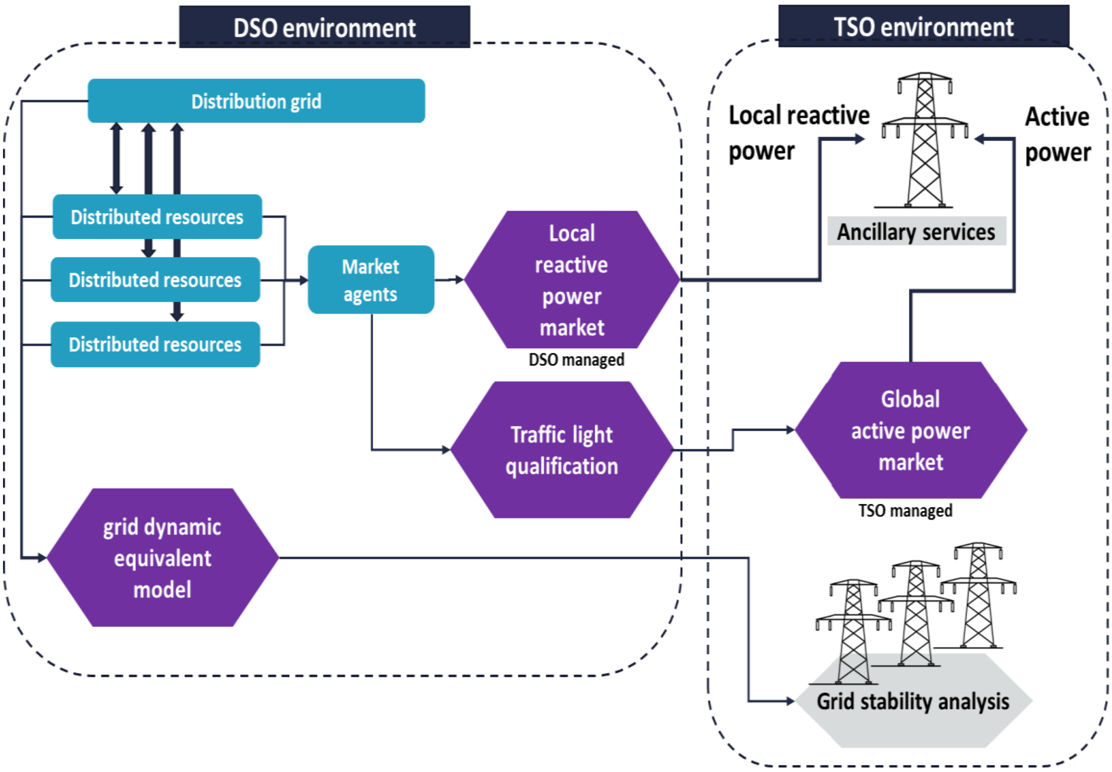
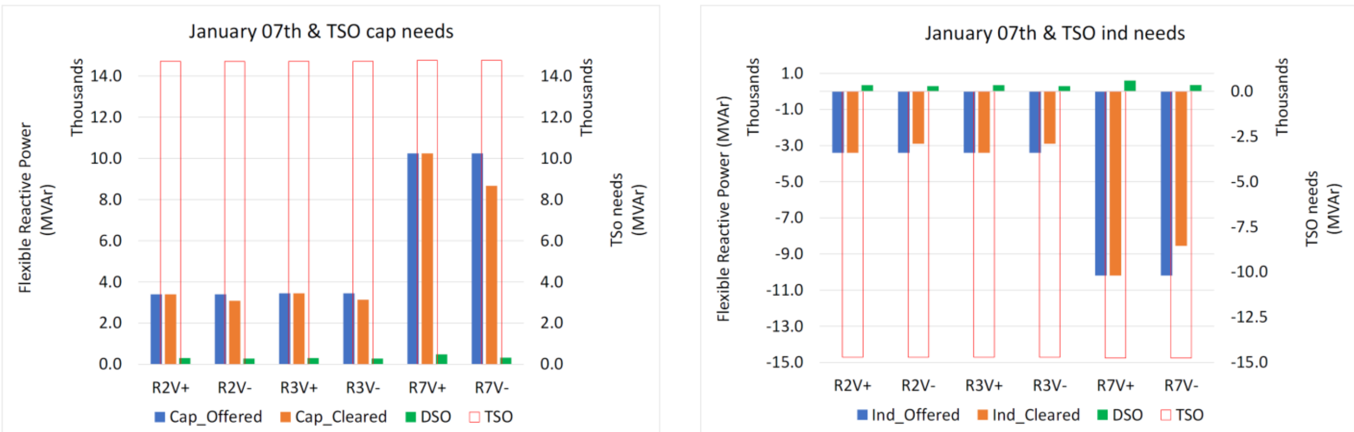


FIGURE 6-6: OVERVIEW OF FLEXIBILITY HUB [D4.7]



(a) (b)

FIGURE 6-7: REACTIVE POWER INCREMENT FOR SCALED TSO CAPACITIVE (A) AND INDUCTIVE (B) NEEDS – FLEXHUB [D7.6]

6.3.4 DATA EXCHANGE DEMONSTRATIONS

Interoperability of flexibility services is an important issue for coordination between system operators. To this end, focus must be placed on data interoperability next to harmonising regulatory/business processes. Therefore, the data exchange demonstrations (led by Estonia) designed some system use cases for a 'Flexibility Platform' to address issues of homogeneous and secure data management through the concept of a data exchange platform. In this platform, proper data management contributes to the participation of stakeholders across geographical borders and of any asset. The flexibility platform is a single marketplace concept whereby any flexibility buyer (typically TSO and DSO) can meet any flexibility service provider to trade any flexibility product. Furthermore, products are designed, and processes implemented so that the same resource can serve several buyers and several flexibility services simultaneously. All this facilitates liquidity, because flexibility providers possess easy access to the market, and resources are not forced to split between a variety of products, services and marketplaces. The flexibility platform is a de facto TSO-DSO coordination platform because it entails multiple steps and functionalities to support the seamless cooperation of distribution and transmission system operators. These include definition of common flexibility products, joint prequalification and procurement of flexibility, coordinated grid impact assessment, in order to identify restrictions for flexibility activation, activation of the same flexibility for both TSO and DSO needs, settlement of flexibility, taking into account synergies, as such TSO-DSO coordination does not, and should not, necessarily mean direct interaction between them. More details can be found in [D9.3-9.4] and Appendix VII.

6.4 AGGREGATION OF DECENTRALISED RESOURCES

Although renewable generation, such as wind and solar, are of variable nature, they are still capable of providing different system services with good performance through appropriate control strategies. However, when they offer system services individually, they mobilise only part of the resource's power/energy capacities, and do not generate sufficient revenue to reach profitability. Besides, as resources have their own operational limits (e.g. dependency of wind/PV generation on local weather conditions, or dependency on maximum charge/discharge of a battery to its current state of charge), they are generally not available at the same time to provide a given service [D8.3]. Therefore, aggregation of decentralised and distributed resources needs to be facilitated such that the capabilities of various technologies can be synergistically combined to increase service provision. The VPP is a concept of joint operation control of multiple power production units. By virtually combining different assets (e.g. renewable resources, such as wind and solar power, conventional generation units, such as diesel generators and storage, including batteries and pumped hydro plants) the overall power generation and flexibility of the energy production can be increased [D7.2]. Meanwhile, energy storage is essential for VPPs, since it can increase the flexibility, allowing time shifting of power production/consumption, and the ability to cope with forecast deviations, and therefore, they enable a VPP to intelligently participate in the market, benefiting from price differences [D7.6].

Pooling multiple (independent) renewable energy plants will have positive effects on imbalances and revenue because, within the portfolio, positive and negative forecasting errors tend to cancel each other out. Moreover, if local balancing of power generation and consumption is possible, the capacities to be traded and the frequency of trades on energy/reserve markets will be reduced significantly. This will reduce the importance of market price forecasts, bidding strategies, and uncertainty handling on the overall profit for these applications [D7.6].

As mentioned above, aggregation, here in the form of a VPP, is one solution to prevent individual resource shortfalls through optimal use of multiple assets. For example, while wind or PV resources can (normally) only provide downward reserves, pooling them with storage systems in a VPP provides the opportunity of offering upward reserve, as well. On the other hand, VRES could be used to charge storage, when necessary, to avoid unnecessary renewable curtailment or energy purchases from the grid. Therefore, VPPs can prevent shortfalls at the asset level, and increase revenues at the VPP level. From this point of view, VPPs could be a solution to allow participation of renewables in existing market products, while preventing shortfalls of individual resources. While a service could only be provided upward or downward from an asset level, a VPP can offer symmetrical products and aligns with existing market products [8.3].

The communication infrastructure of a VPP is of great importance, considering the potential for wide geographical distribution of the assets. It needs to be robust and secure. In addition to dynamic and stable data exchange requirements, cyber security is an important concern that should be addressed. Also, efficient and remote adaptation of local controllers/software should be allowed to better follow fast-moving grid-side requirements and market rules. Network access is a primary issue when considering VPP communication. The communication medium chosen should be as reliable and robust as possible. Also, supervision and monitoring of the telecom assets must be implemented to guarantee availability and cybersecurity. ICT (Information & Communication Technology) components, and operational control modules and hardware, should be physically separated to ensure no interference. VPN and Internet Protocol Security (IPsec tunnel) infrastructure also need to be implemented to secure and encrypt data exchanges between operational sites [D8.1].

The reliability of distributed small-scale resources is generally lower than traditional solutions. Some resources, such as demand response from electric vehicles or electric heating loads, are not initially dedicated to providing system services; therefore, their availability will be temporal. The reliability of some other technologies, such as storage, to provide grid services also depends on their energy storage capacity. One of the system operator's main difficulties for using, for example, demand response as a provider of system services, is a lack of understanding of how reliable these resources can be [10.3]. Aggregating, as described before, increases system operator confidence in using such resources, and enables better risk management at aggregator and system levels. This would also simplify system operators' tasks of managing different services providers by reducing the number of parties SO interact with.

In existing flexibility markets in continental European power system, it is difficult for new players, such as renewables or VPPs, to make profits while providing system services. Further adaptations to existing markets (such as a closer-to-real-time market, integrating all technologies, more flexible market rules, etc.), designing new markets for new scarcities, and addressing financial issues (by assessing the problem of cost recovery considering all revenues streams) are needed to promote the participation of new actors in flexibility provision. National regulations also need to evolve faster to allow local flexibility markets, and to provide incentives to integrate distributed flexibility into their operation and planning process while properly assessing the benefits compared to traditional grid reinforcement.

It should be noted that aggregation always must consider the requirements of the flexibility buyer and, at the same time, the impact on the transmission network. It is imperative that the aggregation of DSO connected flexibility products to meet TSO needs shall not jeopardise distribution network operation. Therefore, strong links between the aggregation and coordination process cannot be neglected.

A brief description of some EU-SysFlex demonstration projects with innovations that facilitate the aggregation of decentralised and distributed resources is presented in the following sub-sections.

6.4.1 FINNISH DEMONSTRATION

The objective of the Finnish demonstrator was to increase the use of market-based concepts and VPPs to support the operation of transmission and distribution networks. This demonstration project integrates small, so far untapped, flexible assets on the medium and low voltage grid for aggregation processes, and offers the flexibility of these assets to TSO ancillary (frequency) services and DSO needs.

In Finland, the provision of ancillary services to the TSO is completely market-based, which means that the market prices of services are determined by the TSO’s demand for services, and the supply of services, and the price at which they are offered. At present, assets participating in markets are typically industrial-sized loads or generation connected to the medium voltage (20/10 kV) or transmission grid. The size of these assets is in the multi-megawatt scale. This demonstration brings small-scale loads and generation assets connected to low or medium voltage levels to the market. The size of these smaller assets covers a range of some dozen to hundreds of kilowatts. The flexible assets considered are an industrial-sized BESS (battery energy storage system), customer and office scale batteries, EV charging systems and residential electricity storage heating loads. The process developed and implemented enables the TSO to address its need for increased flexibility cost-efficiently using new kinds of distributed assets. This is achieved through aggregators, who bring these assets to the markets and, in turn, receive a financial benefit through remuneration. Figure 6-8 presents an overview of the Finnish demonstration [D6.6]. A battery energy storage system (BESS, 1.2 MW and 600 kWh, ±900 kVAR) located in Suvilahti, Helsinki (referred to as “Suvilahti BESS”) operated for most of 2020 (beginning in February) in Fingrid’s FCR-N market. Table 6-2 presents the revenue from the reserve market, service provision of aggregation platform, distribution energy and power costs, and the annual net profit. As can be seen, the earned net profit is significant, despite the high power tariff while operating the BESS [D6.9]. More information regarding the demonstrator innovative solutions, and performance, are available in [D6.1, D6.6, D6.9] and Appendix III.

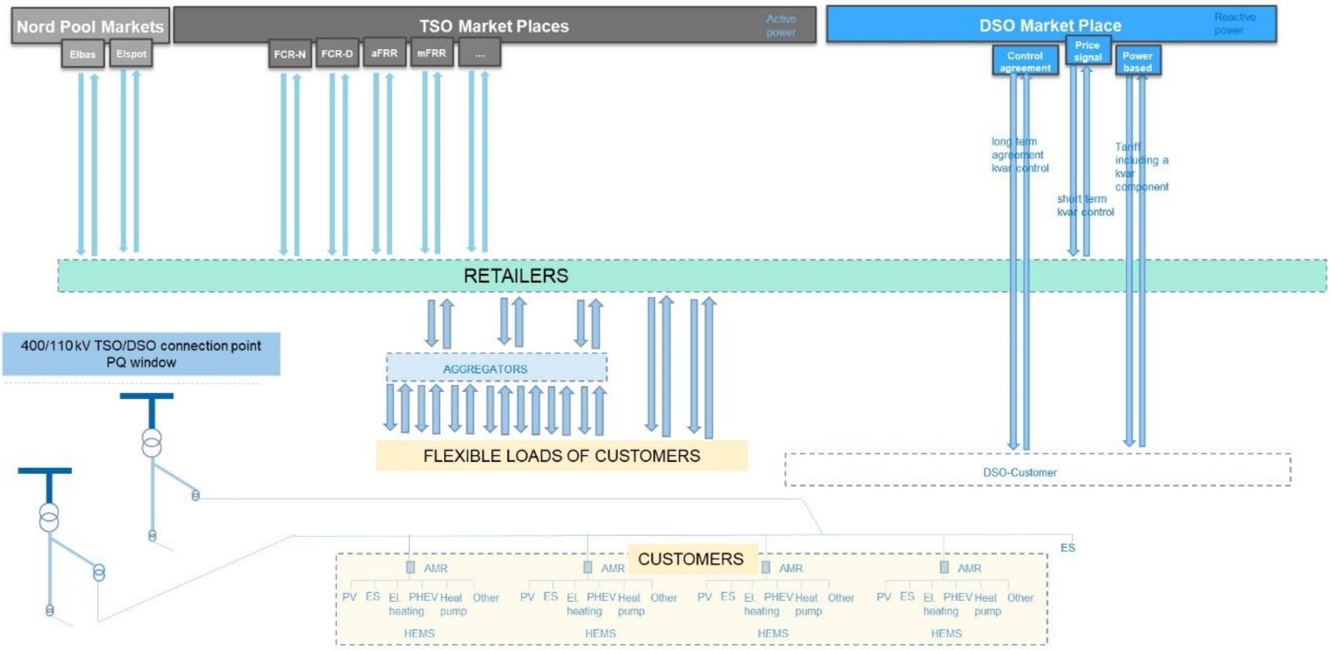


FIGURE 6-8: OVERVIEW OF FINNISH DEMONSTRATION [D6.6]

TABLE 6-2: TOTAL PROFIT OF SUVILAHTI BESS IN FCR-N MARKET OPERATION – FINNISH DEMONSTRATION [6.9]

2020	Revenue [€]	Service provision [€]	Distribution, energy [€]	Distribution, power [€]
January	-	-	-	-
February	2901,00	-435,15	-373,7	-1512,48
March	4552,28	-682,84	-235,73	-912,64
April	628,48	-94,27	-154,34	-916,32
May	7468,21	-1120,23	-163,18	-942,08
June	5596,75	-839,51	-169,93	-1387,36
July	7681,46	-1152,22	-169,99	-816,96
August	2439,34	-365,90	-166,74	-732,32
September	3051,45	-457,72	-246,83	-1637,6
October	3743,91	-561,59	-286,86	-1126,08
November	6174,86	-926,23	-332,24	-2005,6
December	946,11	-141,92	-445,15	-1413,12
Average	4107,62	-616,14	-249,52	-1218,41
Total	45183,85	-6777,58	-2744,69	-13402,56
Profit	22259,02 € 2023,55 €/month			

6.4.2 PORTUGUESE VPP DEMONSTRATION

The VPP demonstration in Portugal uses flexibility provided by large-scale storage and RES power plants (wind farms) at the transmission level to evaluate optimised operation of a variable speed pumped storage power plant with the ability to provide dynamic FRR combined with wind farms, as well as demonstrating the ability of the aggregated portfolio to participate in the energy markets and provide flexibility to the system, namely ancillary services.

This demonstration developed innovative tools (as described in 6.2.2) for the management of large-scale resources within a generation portfolio. The demonstration aimed to provide an environment to extend these concepts to a different range of large-scale storage technologies, and to increase the technology readiness level of potential solutions. Figure 6-9 gives a general overview of the VPP concept, modules and operational principles [4.7]. Table 6-3 compares the simulation results of single asset mode versus VPP mode. These scenarios consist of the Venda Nova III pumped hydro storage (VN III) and the Falperra and Alto da Coutada wind farms (WPs). For the first two scenarios, the single component tries to sell its power to the day-ahead, intraday and aFRR reserve markets. In the third scenario, the power of these components is sold in an aggregated manner to the markets. In all scenarios, the market bid and dispatch optimisation workflows aim to maximise overall revenue and minimise imbalance costs. As seen in Table 6-3, the results demonstrate the superiority of VPP mode over single modes, achieving higher revenue and lower imbalance costs [D7.6]. More details on the developed software and installed hardware, as well as the performance of the demonstrated VPP, can be found in [D4.7, D7.2, D7.6] and Appendix IV.

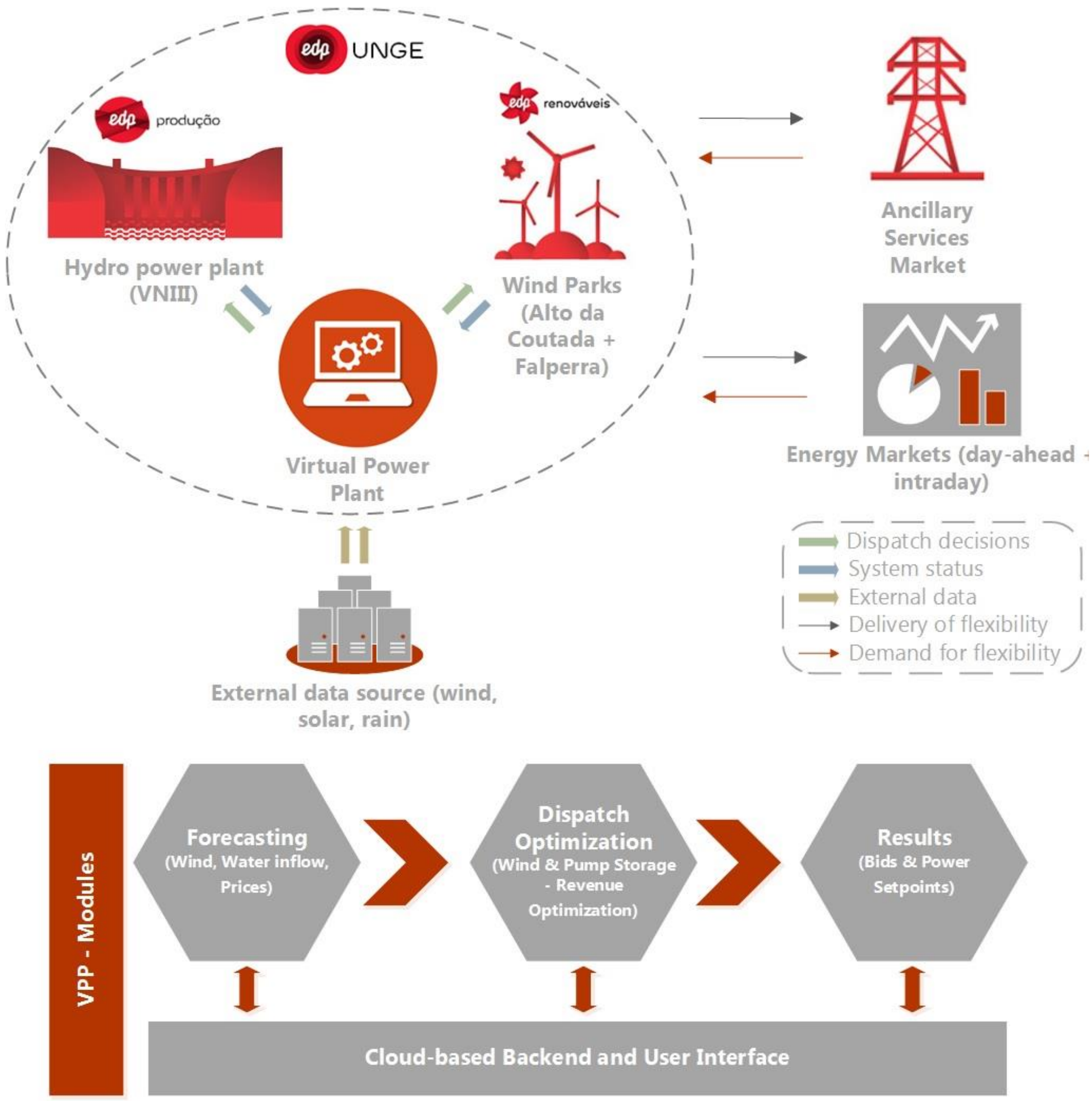


FIGURE 6-9: ARCHITECTURE OF PORTUGUESE VIRTUAL POWER PLANT [D7.2]

TABLE 6-3: COMPARISON OF TOTAL PROFIT OF VPP MODE VS. SINGLE ASSETS – PORTUGUESE VPP DEMONSTRATION [D7.6]

Scenario	Scenario Description	Net Profit Energy [M€]	Net Profit Reserve [M€]	Profit Sum [M€]	Imbalances [GWh]	Imbalance Penalties
1a	**VNIII**	11.79	1.75	13.54	55.7	429.9
1b	**WPs**	11.42	0	11.42	39.1	396.9
1	**Sum of VNIII + WPs**	23.21	1.75	24.96	84.8	826.8
2	**VPP**	23.49	1.88	25.37	69.4	515.1

6.4.3 FRENCH VPP DEMONSTRATION

The French demonstrator proposed an aggregation approach based on the VPP concept, which aims to develop and experiment with an innovative multi-services, multi-resources control approach.

In order to operate the demonstrator, composed of multiple and different resources, and to ensure optimal coordination of multi-services provision, centralised control functions were built, including renewable generation forecasting tools, as well as the EMS, providing both day-ahead/intraday schedules and short-term program adjustment capacities. An advanced communication infrastructure was also implemented to ensure fast, accurate and reliable information, and data exchange between the EMS and each asset. The overall operational structure is illustrated in Figure 6-10 [D8.3]. Figure 6-11 shows the experimental results for a 1-hour test of multi-services provision by the BESS through VPP control. It was observed that the three frequency services were appropriately and simultaneously activated according to the grid frequency and FRR activation signal, in parallel with SOC (state of charge) control. It was also found that through relevant controller design and feedback signals measurement, the resultant power at the PoC (point of connection) could be decomposed to the power output dedicated to each service, while the performance of different services can be assessed individually when simultaneously activated. This allows system operators to verify whether storage provides effective contributions, by responding correctly to different indicators of power system needs, and will be key to enabling the provision of multi-services in practice. For further details on this demonstration and the field-test results, see Appendix VI and the project deliverables [D4.7, D8.2, D8.3, D8.4].

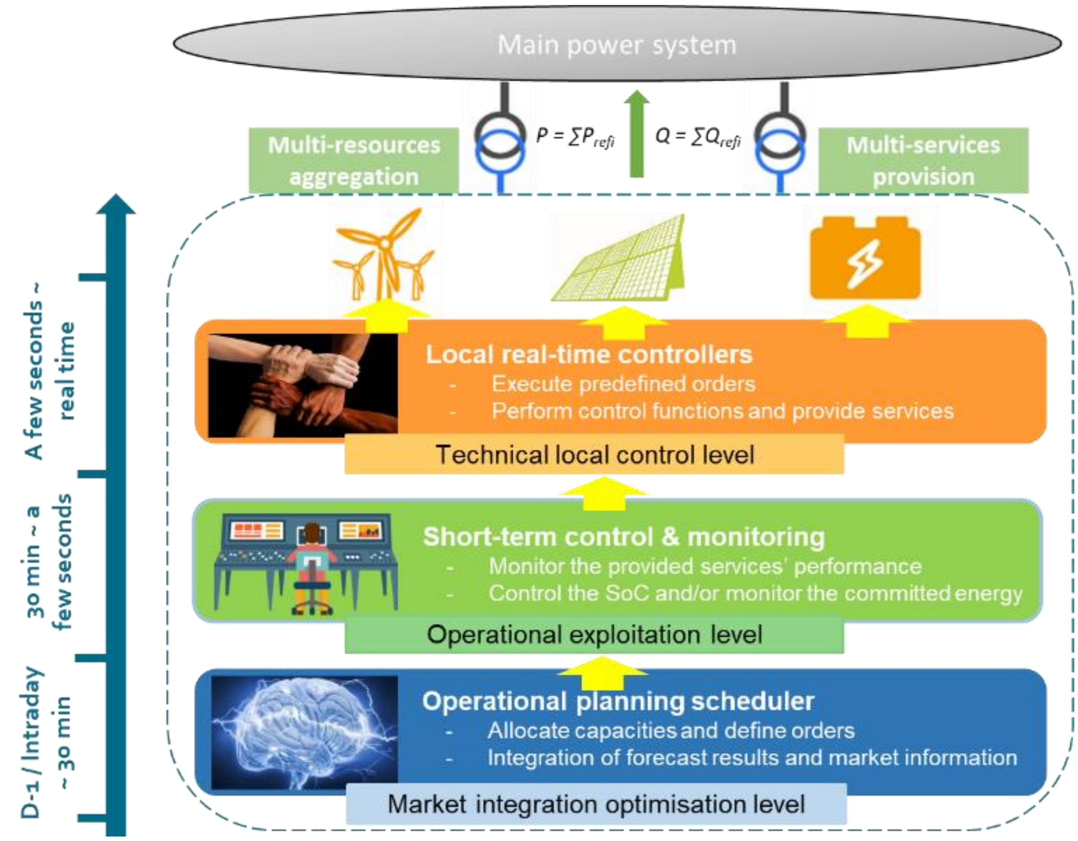


FIGURE 6-10: ARCHITECTURE OF FRENCH VIRTUAL POWER PLANT [D8.3]

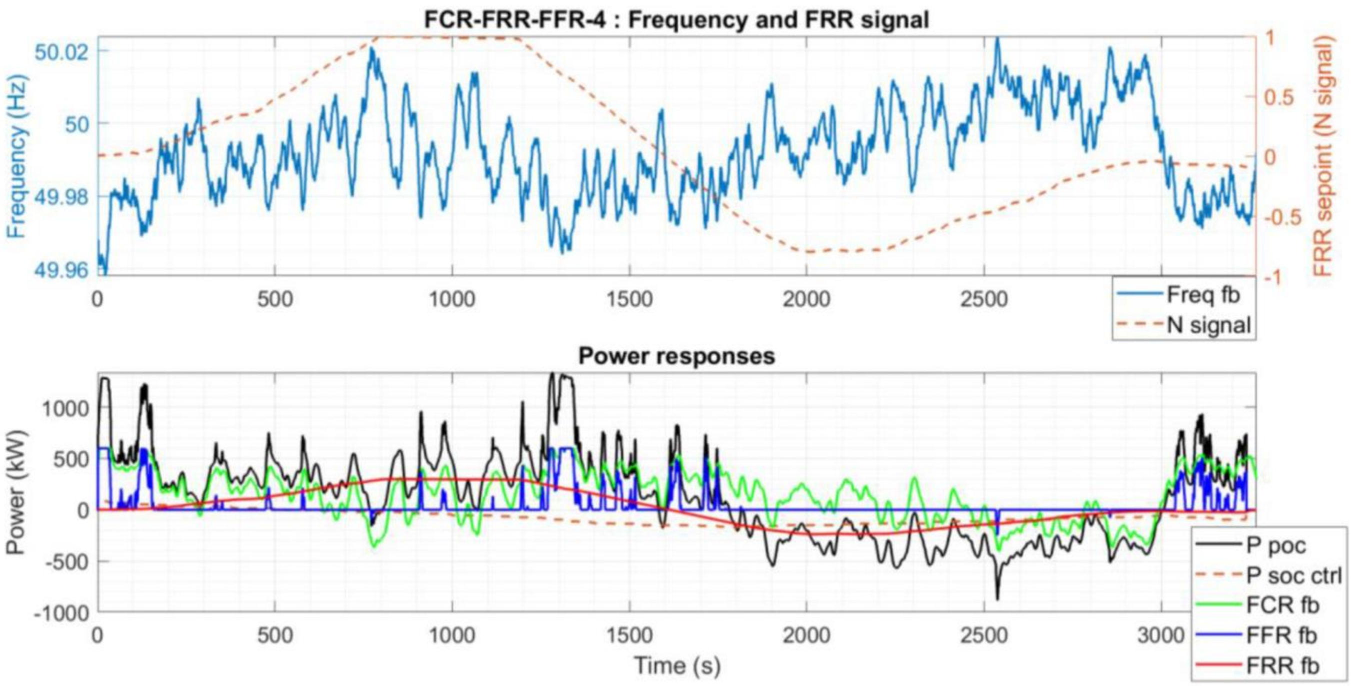


FIGURE 6-11: MULTI-SERVICE PROVISION BY BESS – FRENCH VPP DEMONSTRATION [D8.3]

6.4.4 DATA EXCHANGE DEMONSTRATIONS

A significant volume of system services can be provided by a large number of small DSR units (households and other small consumers/prosumers). Low entry barriers (set-up costs, price, bid size, etc.) are key elements to reach a critical number of units to be able to fully integrate these decentralised resources in the energy flexibility market. In addition to the physical units, applications and algorithms were developed to efficiently and effectively combine the small units to the grid. It is evident that evolving data exchange platforms around the EU have made supplier switching much easier. The objective of 'Affordable Tool', developed by Data exchange demonstrations (led by Estonia), is to bring active smaller customers to the energy market through the provision of flexibility services. Such a platform empowers consumers to choose between different application and energy efficiency services provided by Energy Service Companies (ESCOs), and other emerging stakeholders in the energy market, by ensuring a trustworthy and user-friendly service without costs hindering market development. This consequently facilitates the emergence of new users and businesses. These synergies can be realised by linking together national data exchange platforms and customer-oriented applications. More details can be found in [D9.3-9.4].

6.5 DATA MANAGEMENT

The emergence of numerous decentralised new renewable energy and flexibility providers, down to the prosumer scale, implies an increasing challenge in terms of digitalisation and all the data to be subsequently managed. EU-SysFlex explored interoperability for data management and exchanges in this context. The two main objectives were:

- Provide recommendations for data management in flexibility, when applied at scale from an IT perspective.
- Develop a customer-centric data exchange model for an energy flexibility market, serving all stakeholders (TSOs, DSOs, suppliers, flexibility providers, ESCOs, etc.), including across European borders.

The extracted recommendations were tested in the Data exchange demonstration package, which involved several demonstrators focused on aspects of data management, including cross-border communication between different data exchange platforms, and with different stakeholders, in order to facilitate cross-border exchange of flexibility services [D9.3-D9.4].

The customer perspective is taken as the starting point in data discussions. Of course, the needs of SOs and other stakeholders must be considered. However, they are of little use if customer interests are undermined. By saying 'customer', then most people mean consumers, but also prosumers and other smaller (distributed) players. Therefore, customers are not the same as passive consumers. On the contrary, they are welcome to actively participate in the market. For active market participation, one needs really **easy access to the market**. This is just the proper market, where smaller distributed resources can sell their flexible demand, or generation, to system operators (but also trade flexibility between themselves), although most likely through aggregators. So how can aggregators easily access the market?

First, a proper market place is needed, which is about rules, and about technical systems to make it happen ('flexibility platforms'). This market place should be designed to achieve the highest liquidity, bringing together different flexibility providers, buyers and products over different time horizons and different geographical areas. Second, and to make the market happen, **easy access to data** is needed. A lack of proper information has been seen as a major market barrier, including by customers themselves. Data should not be hidden or protected unnecessarily. It should be public, as much as possible, while respecting personal privacy, market interests of commercial players, and the system security responsibility of regulated players.

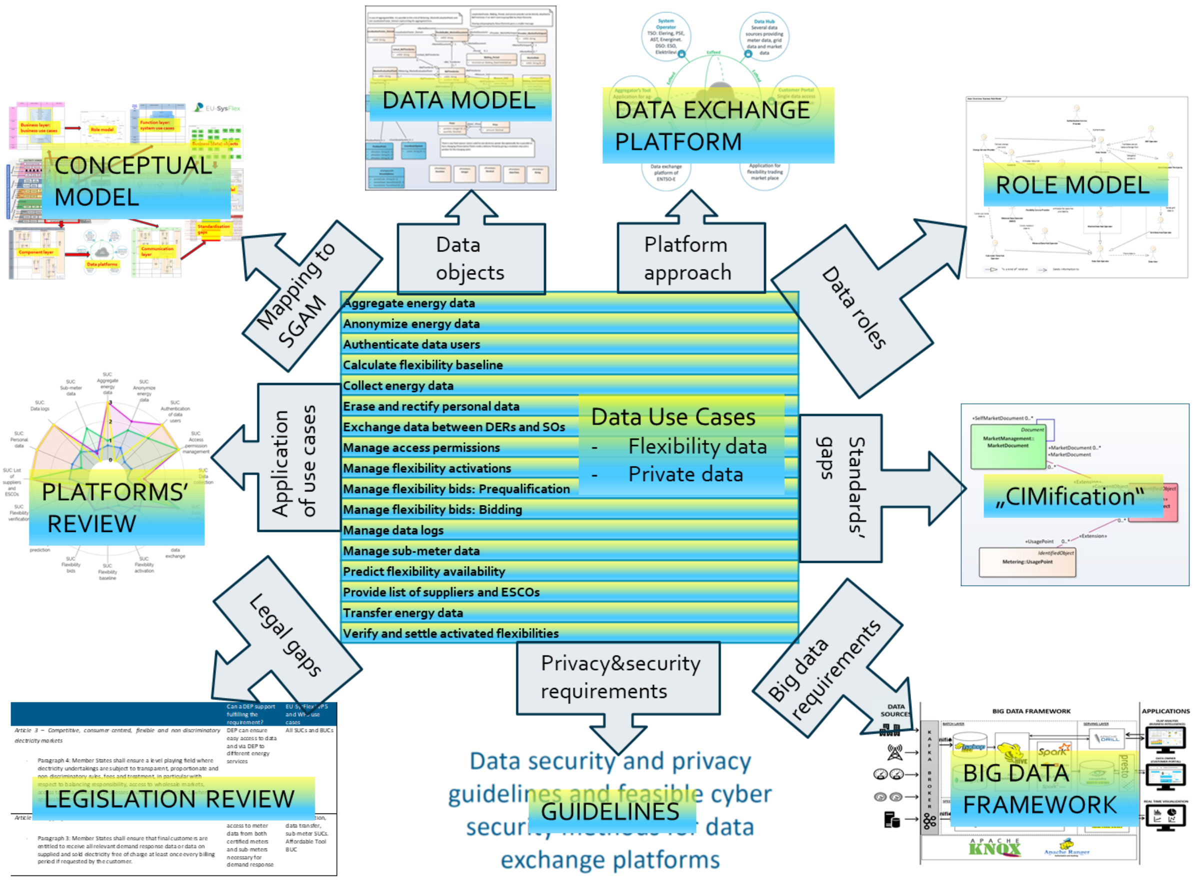


FIGURE 6-12: EU-SYSFLEX DATA MANAGEMENT FRAMEWORK

Customers should be the ones deciding who, how, and when their flexibility and data can be used. Easy market and data access should be designed to avoid customers being locked-in to a single system operator, to a single flexibility service, or to a single market platform. The aim is a single European energy market, while getting there should be ensured through interoperability of a variety of market places and data platforms.

6.5.1 CROSS-BORDER AND CROSS-SECTOR DATA EXCHANGE

Based on an understanding of the high-level needs of the EU-SysFlex demonstrators, a set of Data Exchange System Use Cases (SUCs) were identified. Sixteen SUCs were selected for the full description. SUCs are agnostic to related business processes; as far as possible, most of these address more than one category of Business Use Case, which means that it is possible to achieve universal data management processes, i.e. efficiency gains in the energy sector and across sectors. This is specifically valid in the case of 'private data' SUCs (e.g. data user authentication, management of data logs, management of data access permissions). Another category is dedicated to 'flexibility data' SUCs, where some assumptions from a market design perspective were made (e.g. flexibility bid management and flexibility activation management, in which case, alternative SUCs were developed).

Data exchange SUCs laid the foundation for many other activities, i.e. data modelling, standardisation, big data analysis, security and privacy issues. Also, these SUCs were, to a large extent, implemented and tested in the data exchange demonstrators, in particular for scalability and replicability purposes. According to the analysis, the Data Exchange Platform is a core system, followed by Flexibility Platform, Data Hub and (third party) application. The Flexibility Platform's key functionality is to support specific market processes, while the other three are core systems to organise data exchange.

Interoperability is an explicit focus of EU-SysFlex, as it enables the exchange of any data type between multiple stakeholders and multiple systems, but without full harmonisation of all aspects. Therefore, EU-SysFlex prioritises mutual understanding in terms of business processes, data exchange functionalities and data models, rather than harmonising data formats and communication protocols. Interoperability should allow the co-existence of multiple formats and protocols.

Data exchange model for Europe based on SGAM (Smart Grid Architecture Model) is the core goal of the EU-SysFlex data management framework. It looks at interoperability at all layers of SGAM (Business, Function, Information, Communication and Component layers). EU-SysFlex data SUCs were modelled for each SGAM interoperability layer. A model for data roles was elaborated as part of the business layer. The data exchange platform constituted a central system on the component layer. Information and communication standards gaps were assessed, while business objects and data models were elaborated on the information layer. It was recognised that a way to address the challenge of cross-border and cross-sector data exchange would be through interoperability requirements. Therefore, EU-SysFlex proposes a generic model to address interoperability at any level, and agreeing to a common approach, which includes proposals to extend and adjust well-known existing concepts, such as Smart Grid Architecture Model, Harmonised Role Model, and Common Information Model (CIM) to further ensure a common vocabulary.

Based on roles appearing in SUCs, a **data role model** was elaborated. Most of the identified Business Roles can be mapped to the HEMRM (Harmonised Electricity Market Role Model) of ENTSO-E, EFET and ebIX®. However, several new roles were identified, reflecting new business and IT needs. These include Authentication Service Provider, Customer Portal Operatory, Data Delegated Third Party, Data Owner, Data User, DEP Operator, Flexibility Service Provider, Optimisation Operator. The new roles and associated classes were reported to holders of HEMRM.

The data SUCs were developed around the concept of a Data Exchange Platform (DEP). However, it was realised that it would not be feasible to have a single platform for all countries and for any data type. Preferably, interoperability between different platforms needs to be ensured. Furthermore, interoperability of different data models (e.g. centralised data collection in data hubs, distributed data exchange via DEP, bilateral data exchanges) needs to be achieved. This could be accomplished through legislative requirements, standards, best practices and open-source promotion. However, some kind of cooperation, i.e. governance model, is still required to make all this happen.

As part of EU electricity market directive 2019/944, validated historical consumption data shall be made available to final customers on request, easily and securely, and at no additional cost. To comply with this, several countries are currently implementing solutions for access to, and exchange of, meter data, including central national data hubs, but there are also several countries that have already implemented similar solutions. In addition to central solutions, more decentralised options exist (e.g. in Austria) for meter data access and exchange. Regardless of the level of (de)centralisation, all solutions must be interoperable inside the given country, as well as across borders in the coming years. While decentralised solutions were not investigated in detail, several interviews were performed with data platform operators (DPOs). These '**data (access & exchange) platforms**'[15] are mainly owned and operated by TSOs and DSOs today, although the aim is, to a large extent, for them to be an independent party, providing secure, reliable and qualitative data for different stakeholders. The core business for these data platforms is to provide access to data for different stakeholders. The future of data platforms, according to the DPOs, lies in a mix between the focus on today's business but also to enable a more market-oriented business, where all kinds of consumers and generators can benefit from the data platforms. There is also a focus on including more data, as well as other types of data, and/or allowing third-party applications to connect to the data platform, among other things, to be part of a flexibility market for the energy system.

An environment for executing EU-SysFlex **data exchange demonstrators** was established – "Estfeed research environment". Different demonstrators address cross-border data exchange, synergies from common metering and operational data management, synergies from cross-sectoral data exchange, single data exchange interface for customers, and market stakeholders. Existing technologies applied for demonstrators include data exchange platforms Estfeed (including data hub and customer portal), Unified eXchange Platform (UXP), X-Road and ECCo SP (ENTSO-E Communication & Connectivity Service Platform), EMS components for flexibility management, Sharemind for privacy-preserving data exchange, KSI Blockchain technology stack and Black Lantern anti-tamper hardware for cybersecurity, Big Data management components.

Cross-border data exchange was demonstrated whereby residents of one country were able to access their meter data and share data with other stakeholders using services (e.g. consent management) provided by DEP located in another country; it is possible to remove barriers from accessing meter data from different organisations in different countries. The biggest obstacle is differing levels of authentication available in different

[15] The term 'data (access & exchange) platform' captures the concepts of both 'data hub' and 'data exchange platform', in most cases data hub acting also as DEP.

countries. However, this is being solved within the scope of eIDAS (European Regulation on electronic IDentification, Authentication and trust Services).

Data providers and data users, connected to different DEPs (ECCo SP, Estfeed), can exchange data by ensuring interoperability of DEPs. This was demonstrated for private data sharing use case, whereby one platform benefitted from consent services provided by another platform. The demonstration was able to add value to ECCo SP by using the consent checking capabilities of Estfeed, which allowed it to validate that the application behind ECCo SP had data owner consent to receive private data.

Cross-sector data exchange was demonstrated, which proposed a way to add value to users of one system (meter data hub) with data enrichment from another system (building register). The demonstration showed that if the two systems have not been intended to exchange data, it can sometimes be difficult to reliably link the data (quality of 'customer address' was much lower in one system than the other).

Legal interoperability is another required dimension for moving towards the overarching interoperability. An overview of **legal requirements** was completed, whereby 10 EU legal texts were reviewed, and 74 articles, in total, were identified as relevant for data exchange and for a data exchange platform supporting the fulfilment of the respective legal requirement. Out of these cases, 66 are addressed in EU-SysFlex.

While data exchange standards, in general, have been investigated, part of the focus was specifically on data necessary for flexibility market functioning, due to the general objectives of EU-SysFlex. The EU-SysFlex project aims to identify issues and solutions associated with integrating large-scale renewable energy, and create a plan to provide practical assistance to power system operators across Europe. This plan should involve data exchange requirements, including **needs for further standardisation**. Data exchange has increasing importance for a liquid flexibility market involving various services and products, with many flexibility providers, and a strong need for TSO-DSO coordination for acquiring flexibility. The objective of the standardisation gap analysis was to identify whether, and which, existing standards and specifications there were at the time of assessment related to the data exchange system use cases identified in EU-SysFlex. Although the data exchange system use cases were all built around the concept of the Data Exchange Platform, the standards and specifications investigated can and should, in most cases, be applied equally in different data exchange models – platform-based distributed data exchange, platform-based centralised data storage, bilateral data exchange. It would not take much effort to translate the original API of an implementation (e.g. "Flexibility Platform") into CIM compliant API, and to replace the existing API with a CIM compliant API.

"CIMification" is the term proposed by EU-SysFlex to illustrate the need for, and benefits of, further interoperability through a single information model, such as CIM. Enlarging CIM usage makes sense in the context of European regulation and, more precisely, of the Clean Energy Package. It is essential to consolidate the CIM model by defining new profiles. Moreover, the methodology associated with CIM usage is well documented and well supported by some tools. Enhancing CIM will facilitate vendor adoption and support of CIM by vendors. It will also facilitate compliance testing and certification, and facilitate the organisation of interoperability tests between different vendors. Defining CIM canonical data model will facilitate cross-sector data exchange, e.g. by extending CIM and/or integrating canonical data models from other sectors with CIM. Two Business Objects were

CIMified. As a result, CIM profiling of the 'Customer Consent' business object confirmed the need for CIM extensions. Regarding the 'Flexibility Bid' business object, it was revealed that no CIM extensions are needed for the mFRR type product, which can be used for both balancing and congestion management. More detailed discussions and investigations of the data exchange considerations can be found in [D5.1, D5.2, D5.5, D9.3-D9.4] and Appendix VII.

6.5.2 DATA PRIVACY AND SECURITY

Personal data protection must be considered at all stages when building a data exchange platform. System operators and all DEP users must ensure that internal measures and processing consents are obtained and cyber security measures applied to avoid external threats. There is a high risk that energy data managers, who are responsible for protecting data privacy, cannot apply sufficient security measures, as they could be unaware of some links or processes that use private data without making the use clearly visible. This can lead to data leaks and increase cyberattacks against energy sector systems. Current legislation and standards provide generally sufficient guidelines on how to ensure data protection through technology design, especially when updates to ePR (ePrivacy Regulation) and NIS[16], new Network Code on Cybersecurity, ISO/IEC 2700X:2021, etc., enter into force in the near future. While regulation (e.g. GDPR) applies across the European Union, interpretations can differ (e.g. for smart meter data collection and processing).

Governance and control mechanisms need support from participating organisations to make policy and business decisions, and pave the way for different technological solutions and capabilities to achieve **cyber security by design** as a main building block enabled from the beginning. Also, slow technology adaption by energy sector participants is a bottleneck in coping with cyber security challenges. The current legislation and regulatory framework that provides guidelines for cyber security principles and standards covers the topic of this report well. Work on the cyber security aspects of energy platforms must continue to be prepared for future threats.

There is a lack of communication to exchange data about **cyber incidents,** both in the energy sector in general but also in the energy data exchange domain specifically. Experiences from different sector technology providers and system operators needs to be shared and used among energy sector participants, in order to learn from mistakes and achievements relating to cyber incidents. While the new Network Code on Cybersecurity will address some issues, unfortunately, information sharing (e.g. on vulnerabilities, misconfigurations, 0-day exploits) between adversaries is much more efficient.

It is not possible to outsource **data platform critical infrastructure** from an organisation's jurisdiction area (to third parties outside physical country borders), unless there are direct steps made at the national legislation level. Some data processed by critical infrastructure may be difficult to access by partners from other countries due to country-level legislation, which limits the setup for an energy data exchange platform. It is recommended to have detailed risk assessments of the DPIA (Data Protection Impact Assessment) when outsourcing critical infrastructure to a third-party provider. Evidence from security & privacy demonstrators proved that it is possible

[16] Directive on Security of Network and Information Systems

to integrate **alternative signing mechanisms** to critical logs (Black Lantern infrastructure in this case) that provide information about the data exchange and participants. The risk of losing critical data logs was reduced from three aspects: a) signing with different technology; b) adding additional log storage; c) including anti-tamper infrastructure to an existing solution.

Using dedicated **privacy-preserving technologies** (Sharemind in this case), it is possible to preserve data owner privacy while allowing a third party application (Flexibility Platform in this case) to receive a calculated result based on such private data (calculation of Flexibility Service Provider's baseline in this case). The use of DEP (Estfeed) ensures that the data owner is aware that the data is only used for the given (baseline calculation) purposes, but in a privacy-preserving way. Adopting privacy by design, and privacy-enhancing technologies, will enable adherence to data protection laws, increase consumer trust and enable new business models. However, new technologies may be disruptive to current approaches, meaning that privacy, and the security to ensure it, should be considered from the early stages of (re-)designing a system. To find the detailed works and recommendations regarding data privacy and security, see [D5.4].

6.5.3 BIG DATA CONSIDERATIONS

Forty-eight **big data related requirements** were identified in the EU-SysFlex data exchange use cases. These requirements are currently addressed only partly in selected data platform solutions around the globe, as these platforms were initially developed to address different needs. The largest gaps occur in the area of support for flexibility services and near real-time communication with SCADA systems. A big data framework can be designed to match all these 48 big data requirements. Nevertheless, the framework relies on a combination of various open-source components and not one unique multi-purpose component.

An assessment of the data exchange cost for energy service providers reveals that the flexibility service start-up cost is dominant over the data storage capacity cost where high-throughput capacity is necessary. However, the storage capacity cost becomes dominant when a larger volume of storage is required; therefore, storage sizing needs to be investigated thoroughly.

Several case studies focused on flexibility prediction and baselines. The following findings summarise the results of these studies:

- Data requirements for prediction and monitoring flexibilities are likely to increase significantly due to increased demand for flexibility services, and the trend to provision by smaller units.
- Traditional assessments of baseline electricity load during a demand response event are based on analytical calculations which assume repeating patterns and/or regularity. To increase accuracy during irregular periods, more advanced models are needed. Machine learning, with input from influencing ambient factors, can contribute to a significant improvement in baseline modelling.
- Neural network-based machine learning methods can be applied to short-term load forecasting in the energy sector, with high performance compared to industry-standard baseline models. Multivariate LSTM (Long-short Term Memory) models exhibited high accuracy, while univariate LSTM models exhibited high

robustness in various scenarios; CNN-based (Convolutional Neural Network-based) models exhibited high accuracy in forecasts of future flexibility.

- By applying the latest machine learning methods, it is possible to compute and deliver to DSOs more than 1500 residual load forecasts for transformer stations every 15 minutes, employing a marginal computational load.
- Study on “Privacy-preserving data analysis” explores the possibility to use privacy-enhancing technologies in the energy sector.
- It was demonstrated that DEP could transport to any third-party application results from big data framework; an end-to-end big data process was demonstrated: raw data was collected from external APIs, processed in batch and near-real-time with AI algorithms, results were stored in a serving layer and made available through request/response API. This deployed architecture performed as required, at least within a context where frequency requests were not high, with limited size data results and without specific latency constraints.

The project deliverable [5.3] provides more details on studies and findings relating to big data considerations.

7. CONCLUSION

The findings and outcomes of the EU-SysFlex project were incorporated into this flexibility roadmap to create a pathway that supports large-scale renewable energy integration across Europe. This roadmap is based on the scalability and replicability analysis of project demonstration solutions, as well as analysis and investigations into technical scarcities, mitigations, system services and market designs, system operator procedures, and data management. EU-SysFlex focused on key pan-European policy recommendations that can be followed to assist us in reaching our renewable energy ambition. These fundamental guidelines and policy recommendations could then be used to help develop detailed national and regional action plans.

Individual systems and market dynamics within each state and synchronous area should be carefully taken into account from a European perspective. Each national and regional power system has its own distinct characteristics, such as the level of interconnection, the nature of the current generating portfolio, the maturity of the system services market, laws and regulations, etc. It is necessary to implement consistent strategies at the European level in order to maximise effectiveness and efficiency while also acknowledging the needs of different nations. This roadmap lays out a common policy guideline at the European level to move toward net-Zero ambition.

The following are the eight key messages and policy recommendations obtained and developed by EU-SysFlex analyses and trials, which serve as the fundamental core of this roadmap:

1. **As we transition to a European power system with a high share of variable renewables significant technical scarcities in flexibility appear.**

Some technical scarcities represent emerging areas of concern, while others are well-known, but are exacerbated by the transition to high levels of renewables. The non-synchronous nature of wind and solar resources represents a particular challenge. All scarcities require mitigation measures to ensure continued safe, secure and efficient power system operation to support Europe's renewable and net-zero ambition.

2. **Enhanced services will be required from a wide range of technologies in order to mitigate the identified technical scarcities and ensure the required system flexibility.**

In addition to enhancing the system services provided by existing resources, new resources, such as variable renewable technologies, energy storage, and demand-side response, can offer the required system flexibility. Active participation from all technologies, new and existing, is required.

3. **Existing energy market structures will not guarantee the required flexibility and volume of system services to address the identified technical scarcities and support investment in low carbon generation.**

Relying on existing energy market structures will result in future financial shortfalls for all generating technologies, due to reduced energy revenues in the long-term horizon.

4. **New flexibility products and market evolution are required to ensure the provision of sufficient system services capability to mitigate the identified technical scarcities.**

In addition to creating new flexibility products, unnecessary entry barriers to flexibility markets must be removed, to embrace new and emerging technologies, based on reviewing existing specifications for flexibility products and their incorporation in electricity markets.

5. **New operator decision support tools with enhanced forecasting, state estimation and optimisation capabilities are required for the future power system to activate new flexibilities.**

Demonstrations were successful in showcasing the potential of a range of emerging technologies. However, rollout trials are required to fully understand their reliability and their ability to provide all of the flexibility required for an environment with high shares of wind and solar generation.

6. **Efficient coordination between transmission system operators (TSOs) and distribution system operators (DSOs) is critical given the significant share of future resources connecting to the distribution network.**

Extensive trials and demonstrations, supplemented by scalability and replicability analyses, provide validation that a dedicated coordination approach is required, so that all assets connected at any layer of the power system can be utilised to the mutual benefit of both TSO and DSO.

7. **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.

8. **A customer-centric approach including standardised access to data and data-driven services is crucial to guarantee stakeholder and information system interoperability for effective data exchanges at the European level.**

Interoperability is a key requirement for the future power system in which new and numerous players will handle and share large volumes of energy-related data. Data platforms based on standardisation can progressively achieve secure and privacy-respecting cross-border and cross-sector data exchanges.

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ANNEX I. GERMANY DEMONSTRATOR: FLEXIBILITY FROM DISTRIBUTION GRIDS FOR ACTIVE AND REACTIVE POWER PROVISION

OVERVIEW

The aim of the German Demonstrator was to enable the provision of flexibility services from DSO connected sources to the TSO, for TSO congestion management due to line loadings and voltage limit violations. In addition, the DSO itself uses the same services in order to sustain stable and reliable grid operation in the distribution grid. For these flexibility services, active and reactive power provision from assets in the distribution grid are managed. Primarily, conventional, as well as RES generation, units in the high voltage grid, in Germany, namely 110 kV, will provide these flexibility services. For active power flexibilities, assets not directly connected to the HV grid but rather connected to lower voltage levels can also be utilised. Flexibilities are not prioritised according to voltage level, but rather according to sensitivities on congestion and costs. The German Demonstrator took place in a distribution grid with a RES share that significantly exceeded the total local consumption.

KEY FEATURES

- Integrates new and improved forecast for RES-E generation and load
- Schedule based co-optimising for congestion management and voltage control
- Includes RES-E in schedule-based congestion management and reactive power management coordinated between TSO and DSO
- Transforms optimisation results into control signals within automated processing for reactive power management
- Enhances grid efficiency in the distribution grid.

IMPLEMENTATION APPROACH

Figure A1-1 depicts a simplified communication model of the German Demonstrator that shows the DSO-centric approach in utilising flexibilities in the distribution grid for the transmission grid without jeopardising grid stability in the distribution grid.

As an additional benefit, this approach supports high resiliency of grid operation. Despite the demonstrator’s regulated environment, it is applicable to market-based flexibility procurement, as the flexibility optimisation approach is independent of the market design approach.

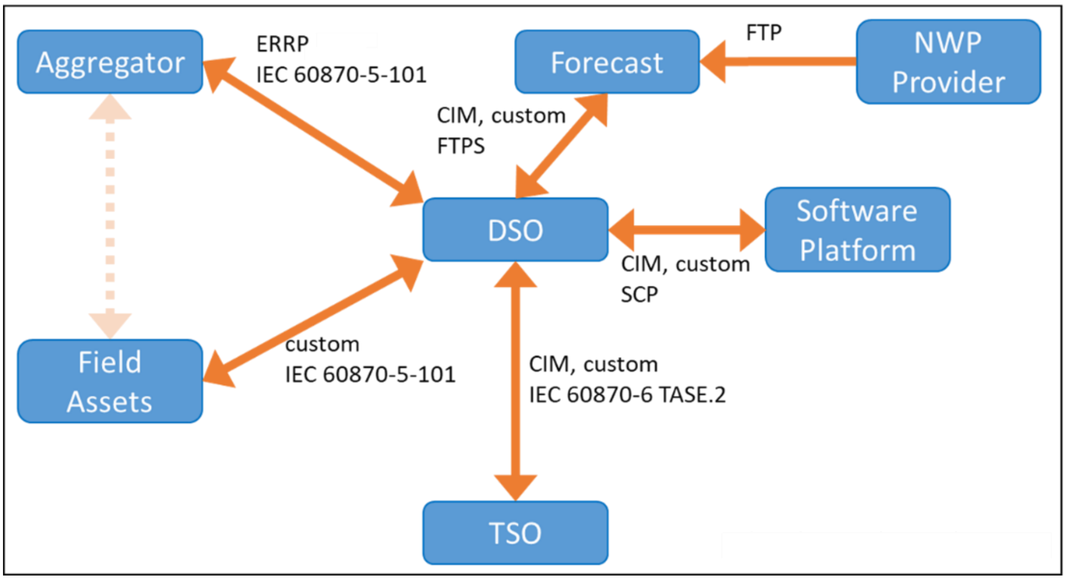


FIGURE A1-1: GERMAN DEMONSTRATOR ARCHITECTURE

The accuracy of calculations and optimisation depends on several factors. As seen in the following graph, the TSO influences the distribution grid, and, therefore, data from the TSO need to be considered in calculating the limits of available flexibility provision. The German demonstration showed that these uncertainties are higher for reactive power management compared to active power management. Due to high forecast uncertainty, the resulting impact on uncertainty for schedule-based procurement of flexibilities is even higher.

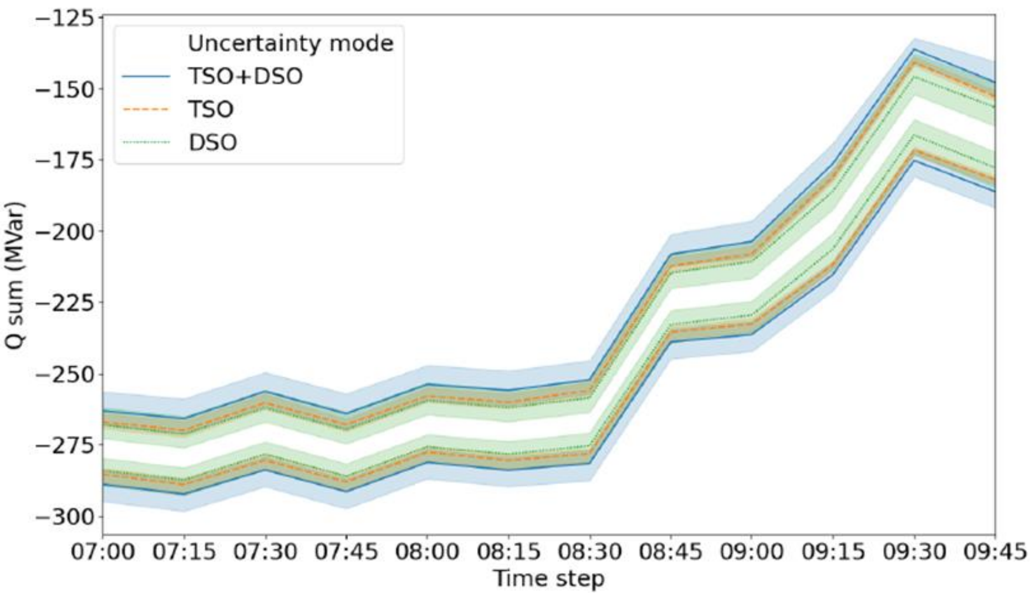


FIGURE A1-2: MODELLING THE UNCERTAINTY OF AVAILABLE REACTIVE POWER FLEXIBILITY (GERMAN DEMONSTRATOR)

FINDINGS

The German demonstrator developed and proved a schedule-based active and reactive power management process, including RES from distribution grids, which improves the volume and diversity of flexibility products/resources in the TSO portfolio. This demonstration also provided practical evidence for successful coordinated TSO/DSO congestion management and voltage control. The developed tool for voltage control allowed the DSO to improve efficiency in grid operation. Additionally, the tool disencumbers operational staff from complexity by providing predicted optimised grid states and proposing the needed set points of flexibility to achieve these optimised grid states in the distribution grid. The most efficient use of flexibilities can only be achieved by considering active and reactive power management at the same time.

In combining predicted optimised congestion-free grid states in the distribution grid for the DSO, and available flexibility range for the TSO, the processes and tools of the German demonstration contributed to a reliable, safe and secure energy system with a high RES share.

KEY ACHIEVEMENTS

- Improved schedule-based congestion management and voltage control for DSO
- Definition of DSO-TSO coordination process to enhance utilisation of flexibility for TSO for congestion management and voltage control
- New function of automation of coordinated TSO/DSO voltage control management
- Improved accuracy of RES feed-in forecast by 5% and for load by 8%
- Reduction of grid losses by 5%

RECOMMENDATIONS AND LESSONS

An efficient and effective TSO-DSO coordination process should be based on the following principles:

- Every system operator is responsible for its own grid.
- Every system operator predicts the available flexibility potential in its own grid.
- System operators from connected grids are informed about available flexibility potential.
- Flexibility selection and activation is carried out by the system operator where the flexibility is connected.
- Both TSO and DSO needs and constraints are taken into account.

Data management principle, “data thrift”, followed by the German demonstrator proved its feasibility, and is based on the following aspects:

- Grid data always stays in the sphere of the respective system operator.
- Grid impact analysis remains the responsibility of the respective system operator.
- Data exchange is aggregated as much as possible to reduce complexity.

ANNEX II. ITALY DEMONSTRATOR: FLEXIBILITY SERVICES PROVISION FROM RESOURCES CONNECTED TO THE MV DSO NETWORK

OVERVIEW

The Italian Demonstrator explored the evolution of distribution network infrastructure, by integrating monitoring systems with advanced smart grid devices, in order to drive toward a new grid approach, in terms of operation and infrastructure, supporting ancillary services provision to the transmission network, taking into account both TSO and DSO needs and constraints, and introducing the flexibility services.

This is possible due to:

- Tools, systems and devices development and integration within the DSO infrastructure;
- Implementation of developments aimed at improving coordination between the TSO and DSO;
- Improvement of distribution network observability and forecasting systems;
- Optimisation of distribution network operation by exploiting DERs and DSO assets.

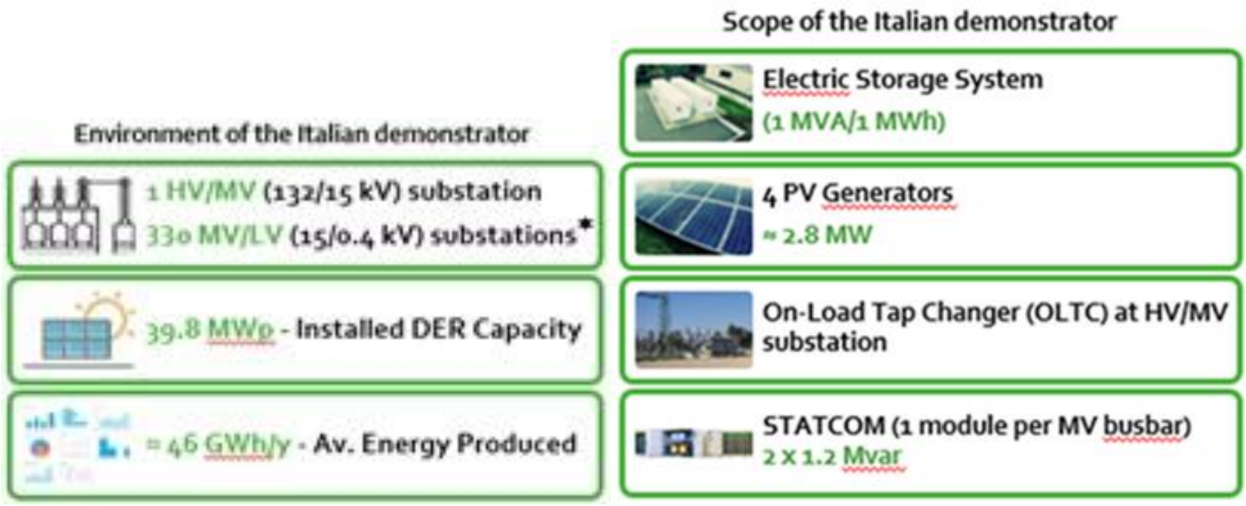


FIGURE A2-1: ITALIAN DEMO SCOPE (*VALUE UPDATED ON 19/10/2020)

KEY FEATURES

The Italian Demo introduces the following innovative elements:

- Exploitation of STATCOMs, for voltage support, reactive power regulation and power factor correction;
- Aggregated reactive power capability calculation, which allows the DSO to share with the TSO the amount of reactive power that can be provided by local resources;
- Improved network calculation platform for computing active and reactive power set-points at the Primary Substation;
- Improvement of data exchange between DSO and TSO for better observability of aggregated decentralised resources at the primary substation interface.

- Congestion management and frequency balancing services, which involve RES and Storage, have been simulated; for voltage regulation features, all the available resources are included within the experimentation.
- New automated coordination process between DSO and TSO, realised using an IEC 104 protocol simulator, which acts as a substitute in the transmission of some specific signals and measurements between the DSO and TSO.

IMPLEMENTATION APPROACH

The Italian Demonstrator includes and exploits the integration of SCADA systems and a set of Smart Grid devices, called to perform remote control and monitoring of the distribution network, fault detection and regulation issues on RES and DSO assets.

SCADA Systems

The Central SCADA is the monitoring and remote control system of the regional distribution network. It includes a database of the electrical network, and sends commands to devices in the Primary Substations and to remotely controlled Secondary Substations. The Local SCADA, located in Quarto Primary Substation, is synchronised with the Central SCADA; it collects field measurements, routes the local set-points to be implemented by TPT2020 at each resource or DSO asset, and runs the NCAS (Network Calculation Algorithm Systems), which performs State Estimation and Network Optimisation calculations.

Regarding TSO coordination aspects, the SCADA systems are interfaced with a TSO protocol simulator.

Smart grid devices

The HV/MV substation RTU (TPT2020) implements standard remote-control features and manages advanced voltage regulation functions. It sends commands and setpoints to the following Primary and Secondary Substation IEDs:

- **DV7500** – Integrated Transformer Protection. It performs automatic voltage regulation, acting on the OLTCs of HV/MV Transformers;
- **DV7203** – HV/MV Substation feeder protection panel, with advanced network automation features;
- **RGDM** – MV/LV Substation advanced fault detector, able to guarantee advanced network automation features, it can communicate with **ERI** (Energy Regulation Interface) to establish set-points on full controllable PV plants.

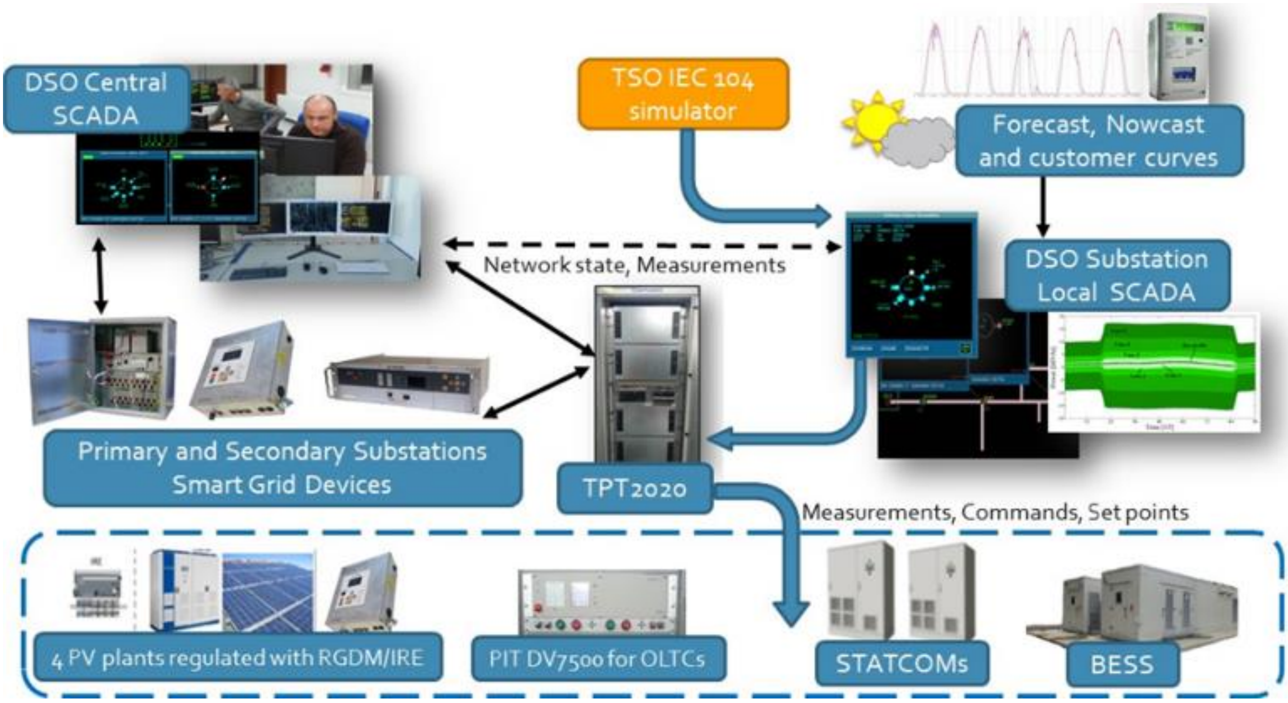


FIGURE A2-2: OVERVIEW OF ITALIAN DEMONSTRATOR OPERATION ARCHITECTURE BASED ON SMART GRID SOLUTIONS

Integration tests

Integration tests were performed within the Smart Grid “Grid-in-the-loop” Test System of E-Distribuzione in Milan by using a Real-Time Digital Simulator (RTDS). The simulated digital and analogue quantities were imported/exported from, and to, real IEDs. Results show that the SCADA acquires all measurements and signals from the configured smart grid devices and sends all commands, such as Q set points, to the simulated PV plant and V set points to the DV7500.

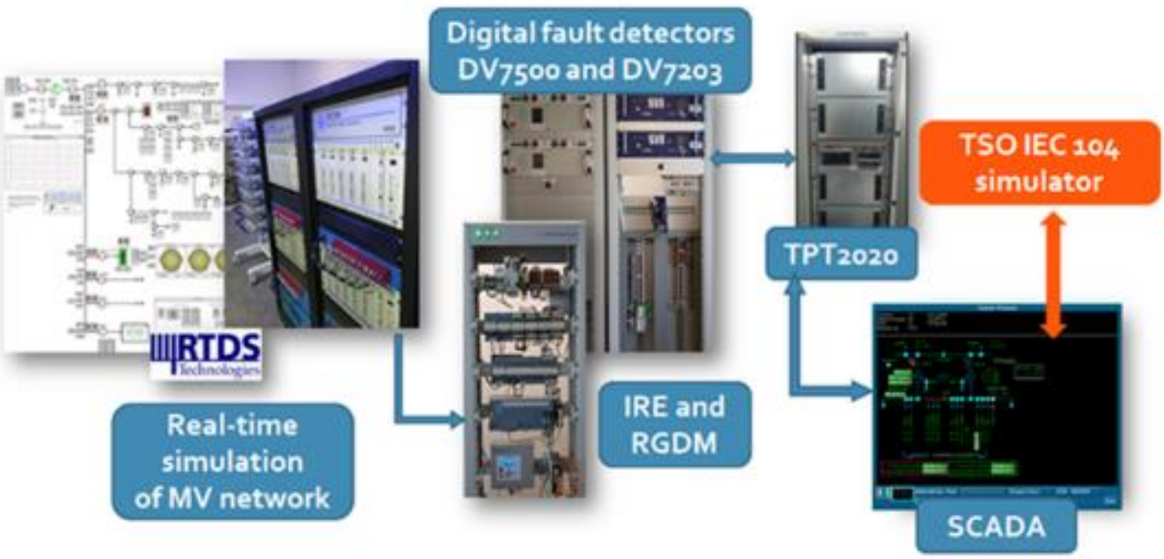


FIGURE A2-3: INTEGRATION TESTS DEVICES AND SIMULATORS IN ITALIAN DEMONSTRATOR

STATCOM

A STATCOM is an electrical device capable of injecting modulated reactive power to the network to which it is connected. From a network operation perspective, STATCOMs are comparable to rotating synchronous compensators. Not being a rotating device, it is not affected by mechanical inertia, and so it can provide a faster response for power factor correction and voltage stabilisation.

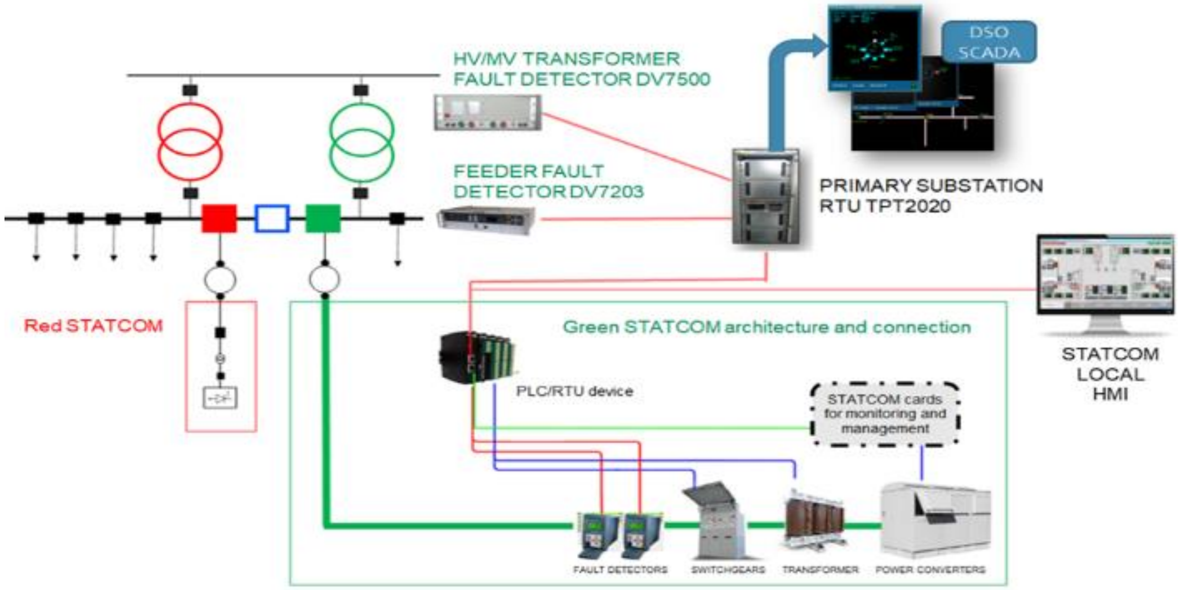


FIGURE A2-4: ITALIAN DEMONSTRATOR'S OPERATING STRUCTURE AND NETWORK, INCLUDING A STATCOM

FINDINGS

The first important benefit derived from the developments made within the demonstrator involve improved observability of resources connected to the distribution network.

The advanced forecast, combined with network state estimation and a function to calculate reactive power capability, demonstrate that the DSO can provide the TSO with reliable information on the amount of power, in particular reactive, that can be provided by local resources.

Besides, improved observability of distributed resources, the approach also supports network state estimation, contributing to better network management.

Results from offline and real-time tests demonstrate the capability of the DSO to support TSO requests. Considering also that the STATCOM is a new device for the E-distribuzione infrastructure, the project tests represented the opportunity to demonstrate its successful operation, in terms of reactive power capability management, and providing the following benefits: limiting reactive power flows at the Primary Substation; meeting TSO requests at TSO/DSO interface; supporting Voltage Control; power factor compensation.

KEY ACHIEVEMENTS

Results from the Italian demo prove that E-distribuzione can implement an efficient solution to:

- Provide aggregated information of network capability at its interface with the TSO;
- Provide the TSO with better observability of DERs, making use of forecasting tools for enhanced network state estimation and computation of reactive power capability;
- Improved data exchange between the two System Operators, to guarantee safe operation of the electrical system;
- Demonstrate STATCOM usefulness, in terms of reactive power management.

STATCOM operation on the distribution network enables the following benefits:

- Limiting reactive power flows at the Primary Substation;
- Meeting TSO requests at TSO/DSO interface;
- Supporting voltage control;
- Power factor compensation.

RECOMMENDATIONS AND LESSONS

Efficient and effective TSO-DSO coordination process should be based on the following principles:

- DSOs need to adopt smart grid solutions to improve network operation, to encourage power aggregation and RES participation in the ancillary service market
- Increased system observability in distribution grids should be achieved
- New assets (such as STATCOMs) integrated into the system can be crucial to meet TSO and DSO mutual needs
- Flexibility share from different types of flexible resources can give strong regulation capability across the entire day
- DSO must optimise the distribution network, both for its own scopes, and to satisfy TSO requests, exploiting new SCADA functionalities and an advanced Smart Grid infrastructure.
- For efficient and effective DSO/TSO coordination, the process for flexibility selection and activation should be automated, as far as possible.
- Forecasting, optimisation, control logic, as well as reliable communication systems, are needed to enable utilisation of assets in flexibility markets.

ANNEX III. FINLAND DEMONSTRATOR: MARKET BASED INTEGRATION OF DISTRIBUTED RESOURCES IN TRANSMISSION SYSTEM OPERATION

OVERVIEW

The objective of the 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, so far untapped, flexible assets on the medium and low voltage grid to aggregation processes, and offer the flexibility of these assets to TSO ancillary (frequency) services and DSO needs. Active, as well as reactive, power management were applied as flexibility services.

Assets in the active power demos:

- Industrial-scale BESS 1.2 MW/0.6 MWh;
- Medium-scale BESS 0.1 MW/0.13 MWh;
- Residential-scale BESS 40 kW;
- EV charge points 22 kW AC / 50 KW DC;
- Simulated residential heating loads 20 MW.

Assets in the reactive power demo:

- PV-plant 0.8 MVar
- Industrial-scale BESS 0.9 MVar

KEY FEATURES

- Aggregation of small, distributed assets to TSO ancillary services and for DSO reactive power compensation needs;
- Developing and piloting suitable interfaces to connect the small, distributed assets to the aggregation platform;
- Developing tools to forecast the available capacity from different resources, and developing control logic to optimise use of the resources.

IMPLEMENTATION APPROACH

The core of the virtual power plant is an aggregation platform. Four commercial aggregation platforms were tested. The main objectives for an aggregation platform were the ability to add new assets to the platform and to control the attached assets according to the use cases. In addition to the tested and implemented platforms, interfaces, and communications presented in Figure A3-1 for the TSO ancillary services, corresponding controls were demonstrated for the DSO reactive power market demonstration.

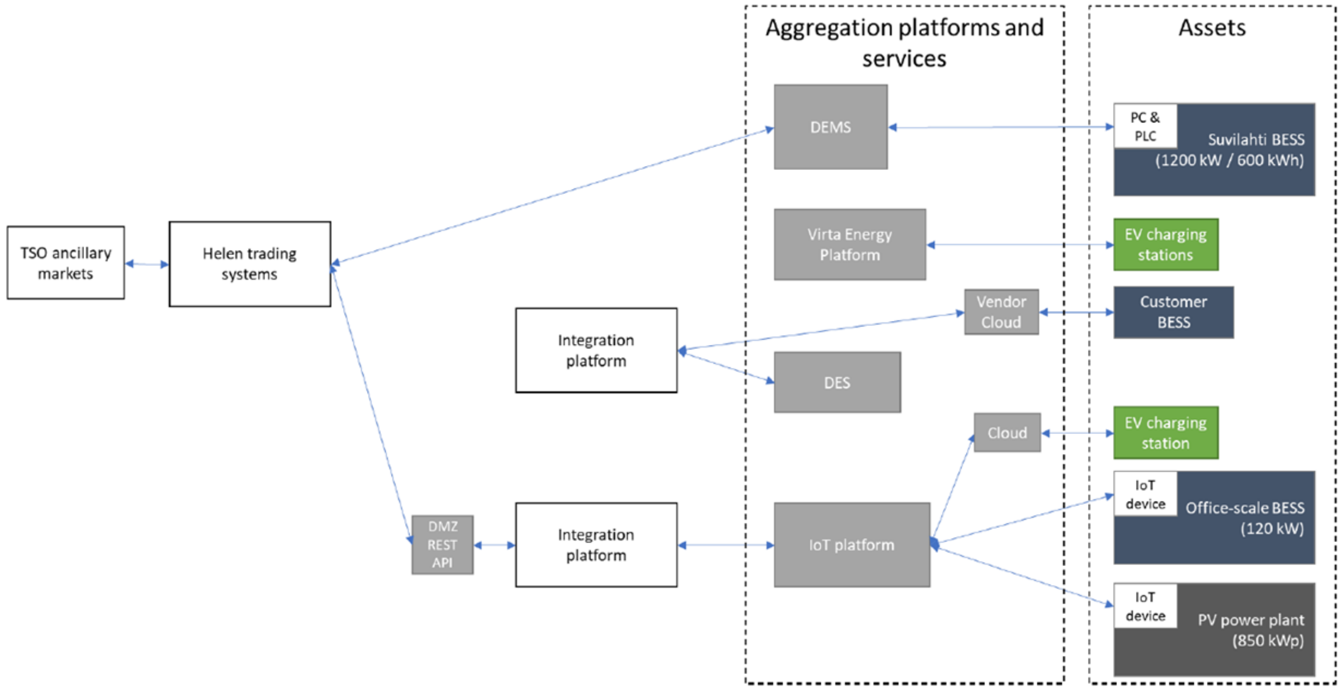


FIGURE A3-1: OVERVIEW OF THE DEVELOPMENTS IN SYSTEMS AND INTERFACES IN THE FINNISH DEMONSTRATION

FINDINGS

The share of RES is increasing in the Nordic and Finnish power system. The Finnish demo demonstrated how small, distributed, so far untapped, MV / LV assets can be aggregated to be utilised in TSO ancillary service markets and for DSO needs. At the same time, this will contribute to a higher amount of flexibilities, representing various sets of new types of assets. Sophisticated forecasting and optimisation methods contribute to more reliable market operation, which promotes favourable development of the operational environment for the TSO, aggregator, DSO, and customers. As a practical business achievement, the industrial-scale and office-scale batteries were operated in the actual TSO FCR-N market. Figure 4-3, in Chapter 4, depicted successful operation of the medium-scale BESS in providing FCR-N service. 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.

KEY ACHIEVEMENTS

- Development of a set of forecasting/optimisation tools to estimate the available flexibility of LV/MV assets for TSO ancillary services;
- Accomplishing technical proof of concept of distributed flexibility resources BESS (residential, medium and industrial scale), PV and EV charging points, and controlling these assets according to market actions;
- Operating BESSs in an actual TSO market;
- Technical proof of concept for a new market mechanism to manage reactive power at the TSO/DSO connection point.

RECOMMENDATIONS AND LESSONS

For efficient use of small, distributed assets in a power system, the following are recommended:

- Characteristics of aggregation platforms (easy connection of assets, standardised interfaces and communication) play a key role in promoting replicability and scalability. A reliable and agile platform is essential in integrating different services.
- Forecasting and optimisation of the availability of distributed energy resources should be further developed to ensure successful market operation.
- All technologies should be treated in a neutral way, with future power systems consisting of a more diverse set of flexible assets.
- Acceptance by end-use customers owning flexible assets is to be identified and supported.
- Ancillary market rules should be developed to allow smaller units and various, possibly new, types of assets.

ANNEX IV. PORTUGAL DEMONSTRATOR: VIRTUAL POWER PLANT, MAXIMISING THE FLEXIBILITY FROM THE AGGREGATION OF DIFFERENT RENEWABLE GENERATION TECHNOLOGIES

OVERVIEW

A virtual power plant is a concept of joint operational control of multiple power production units. By virtually combining/pooling different generation assets, the flexibility of energy production can be increased.

A virtual power plant uses flexibility from centralised resources: provided by large-scale storage and RES power at the transmission level to test the optimised operation of a variable speed pumped storage power plant, with the capacity to provide dynamic FRR combined with wind farms, as well as demonstrating the ability of the aggregated portfolio to participate in energy markets, and provide flexibility to the system, via frequency regulation and balancing reserves.

KEY FEATURES

- Decision support tool for improved real-time management of a storage and generation portfolio, based on mathematical models, including short-term balancing operations
- Tool that integrates forecasting modules for market prices and energy supply;
- Should be used as a market bidding suite for different markets, respecting medium-term strategies for storage management;
- Expected to challenge regulatory constraints, and support emerging balancing area concepts with technology hybridisation;

IMPLEMENTATION APPROACH

The VPP tool developed includes two main elements: VPP Core and VPP Controller. The VPP Core is a cloud-deployed software module responsible for performing stochastic optimisation of VPP control. Operation is orchestrated by a workflow engine that allows periodic execution of necessary tasks, such as the creation of market bids (capacities and prices), calculation of power dispatch schedules, and transfer of data between inner and outer data sources.

The main algorithmic modules of the VPP Core are:

- Forecasting Module, gathers forecasts of natural resources, unit availability, system situation, and market prices;
- Dispatch Optimisation module, performs dispatch of each unit, with bids sent to the different markets.

The VPP Controller implements the calculated schedules, handles deviations, and provides feedback from the generating units to the VPP Core.

The demo case studied included three EDP assets: a Variable Speed Hydro Power Plant 756 MW (Venda Nova III) and two Wind Farms: Alto da Coutada (115 MW from 57 turbines) and Falperra (50 MW, 25 turbines).

Testing included an offline testing phase, dedicated to preparing the online demo, and ensuring the validity of procedures, as well as testing wider scenarios and evaluating their economic benefits.

The online demonstration was carried out to prove the technical feasibility of the approach by autonomously controlling the pumped hydro storage in VNIII for deviation handling of wind farm power output. A general overview of the Portuguese VPP demonstration was previously provided in Chapter 6 (Figure 6-9).

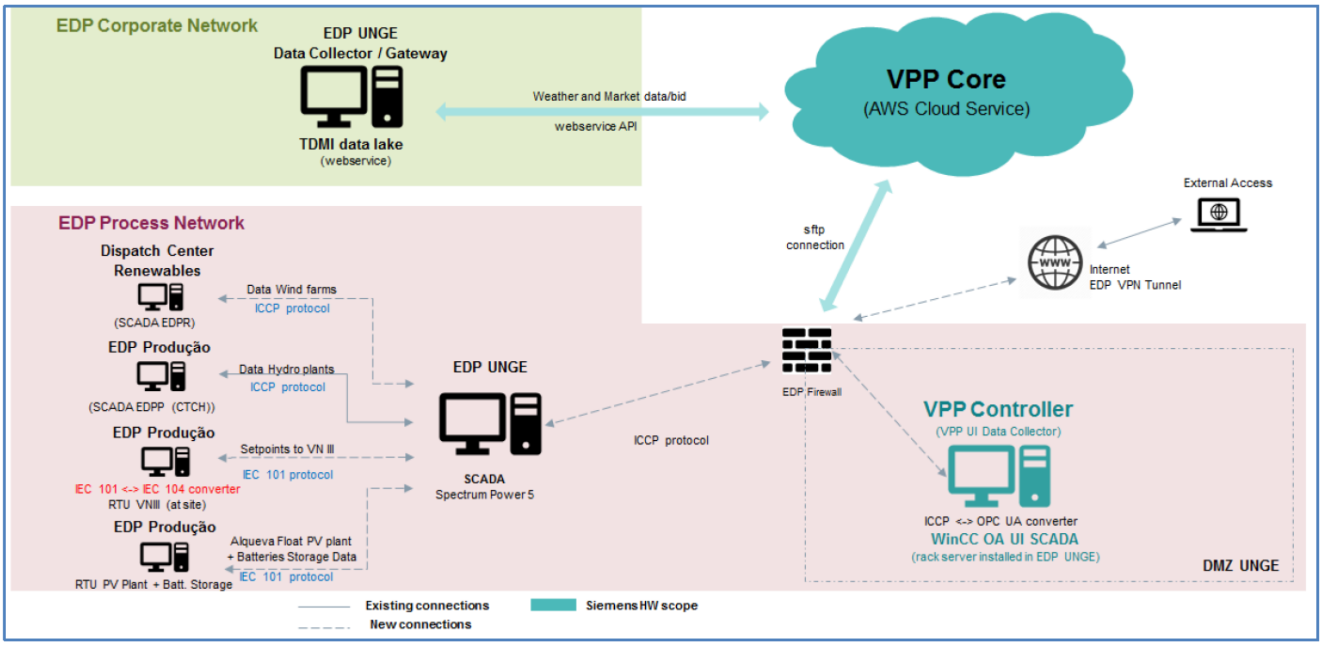


FIGURE A4-1: ARCHITECTURE OF PORTUGUESE VIRTUAL POWER PLANT

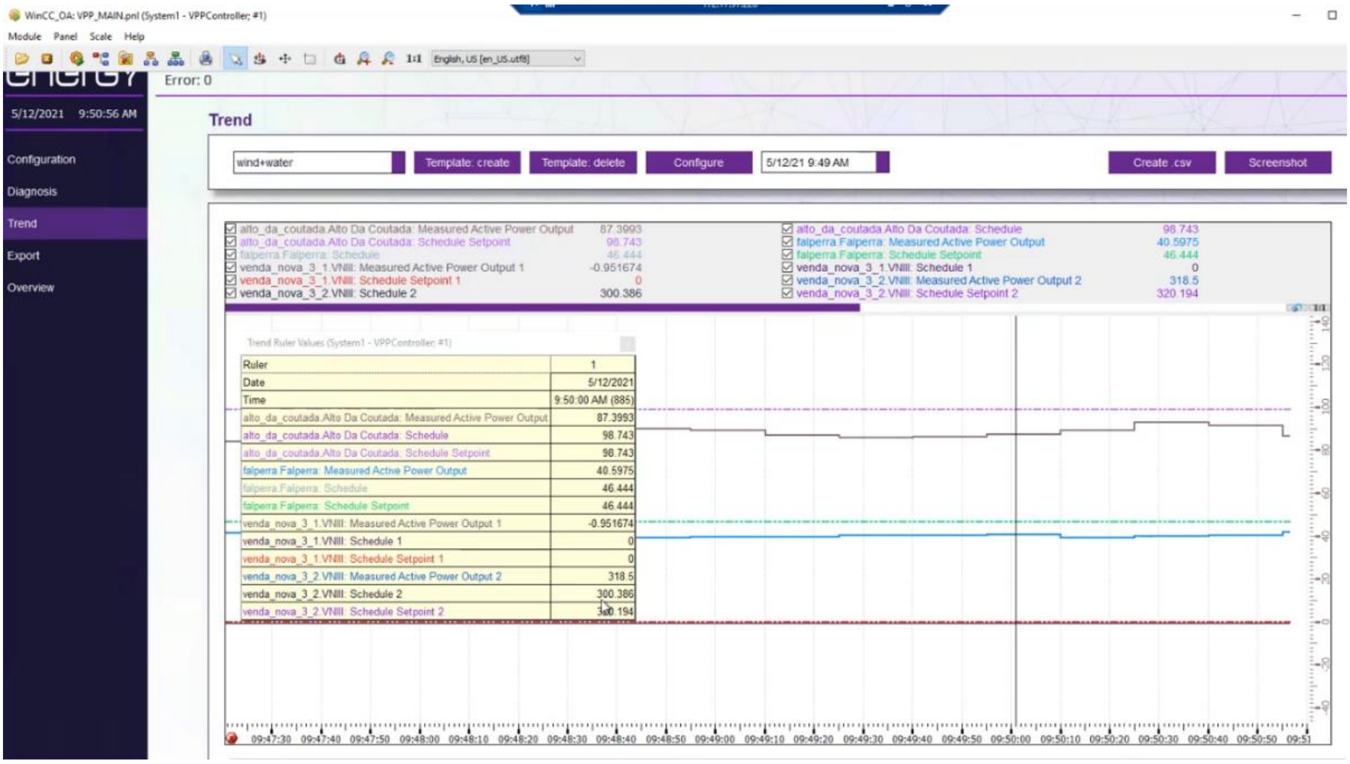
FINDINGS

The VPP was proven as an effective tool to manage a pool of resources, i.e. executing portfolio management of different types of RES units. Pooling different RES units helps to reduce forecasting errors, thus lowering imbalances, which may result in a more stable overall system.

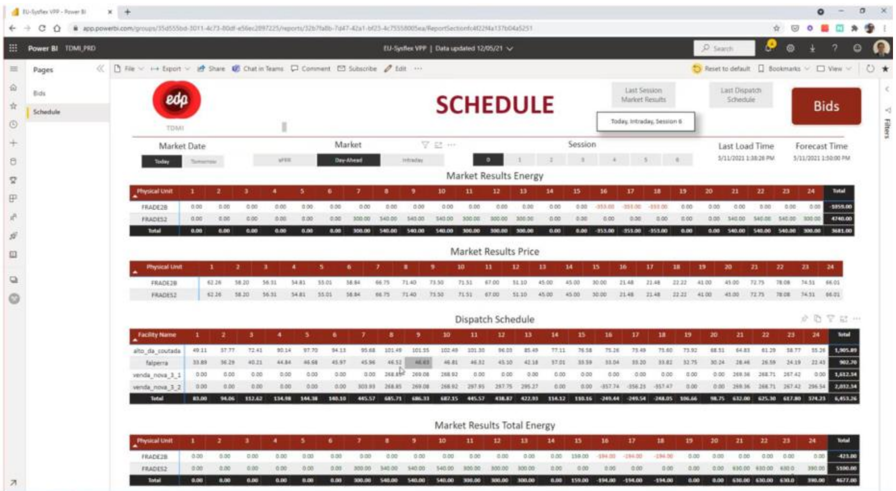
As increasingly more variable renewables join the energy system, aggregating them into VPPs with controllable units/storage (such as hydro) for joint operation and market participation emerges as a viable option for integration into the system. This is expected to also foster the addition of RES, with easier and smoother integration, from both the standpoint of the unit owner/operator, and the system operator, to jointly aim for a secure and stable decarbonised energy system.

KEY ACHIEVEMENTS:

- New tool for optimised management of unit portfolios;
- Alternative way to integrate renewables in the power system as feed-in tariffs fade out;
- Leading to a reduction in deviations and imbalances (as compared to the case with units participating individually in the market);
- Showing the benefits of hybridising different generation/storage technologies.



(a)



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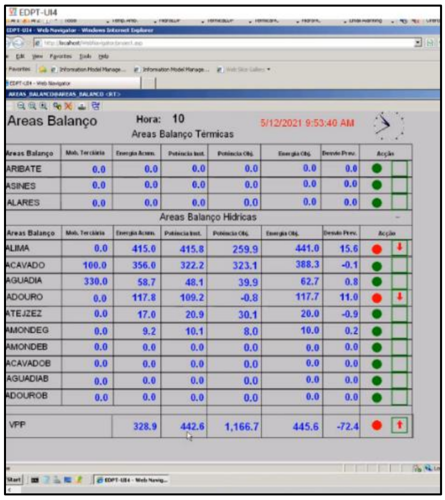

(c)

FIGURE A4-2: ONLINE TESTING SCREEN OF PORTUGUESE VIRTUAL POWER PLANT: A) VPP CONTROLLER; B) UNGE: UNIT SCHEDULING; C) EDPP: VPP AS A BALANCING AREA

RECOMMENDATIONS AND LESSONS

- Pooling of variable producers (as renewable resources) reduces relative forecasting errors, which leads to a reduction in generation imbalances, as well as an increase in overall producer revenue, and showcases the benefits of joint market participation enabled by the VPP concept.
- Pooling of producers and consumers reduces the effects of market price forecast uncertainty. Local balancing of power generation and consumption reduces the overall capacities to be traded on energy/reserve markets.
- Energy storage can shift power production and consumption, perform price arbitrage on markets and handle forecast deviations.
- Main lever for improving overall performance of the VPP Core is more accurate forecasting of market prices, as well as further enhancement of algorithmic features for market bidding strategies and handling forecast uncertainty.
- National regulatory frameworks must still evolve to allow the VPP concept, i.e. joint dispatch and operation of different types of generation units, to be implemented.

ANNEX V. PORTUGAL DEMONSTRATOR: FLEXIBILITY HUB, PROVISION OF ACTIVE AND REACTIVE POWER AND DYNAMIC GRID MODELS TO THE TSO USING DSO GRID-CONNECTED RESOURCES

OVERVIEW

The Flexibility Hub (or FlexHub) is a TSO-DSO coordination platform that addresses three innovative services:

- PT-FXH-RP: provision of distributed reactive power flexibility to the TSO at the TSO-DSO connection point, and to the DSO to balance its grid with a close to the real-time intraday market.
- PT-FXH-AP: DSO traffic light qualification (TLQ) procedure to validate activation of distributed resources to provide active power to the TSO at the TSO-DSO connection point, designed to be integrated into an extended version of the current restoration reserve market.
- PT-FXH-DM: Equivalent Dynamic Model of the DSO grid for analysis of voltage and frequency disturbances

KEY FEATURES

- New reactive power close to real-time market to unlock distributed reactive power flexibility for the TSO and DSO. Clearing is performed with a multi-temporal optimal power flow (MOPF) that maximises social welfare.
- New DSO tool, aligned with EU regulation and ENTSOe-E.DSO ASM report to validate activation of distributed active power flexibility. The MOPF checks that no distribution grid constraints are violated, and allows the delivery horizon to be extended, and more complex assets, such as storage facilities, to be represented.
- Dynamic characterisation of distribution grids for voltage and frequency disturbances for TSO dynamic grid analysis

IMPLEMENTATION APPROACH

A market platform was developed for the PT-FXH-RP and PT-FXH-AP demonstrators that manages grid topological information, grid forecasts and bids from market participants, and uses a MOPF to clear the reactive power market, or to compute traffic light qualification of the active power flexibility offered. Settlement and reporting procedures are also available. The platform has two running modes: online, for physical tests, where all participants interact until setpoints are sent to the flexible assets, and offline, with additional components (such as market agents) for full offline simulations. PT-FXH-RP BUC was demonstrated for the Frades 60 kV E-REDES grid (with Caniçada 2 steps 3.43 MVar E-Redes Capacitor banks, and Barroso II – 12.3MW and Barroso III – 23.1 MW EDPR Wind Farms as flexible resources), while the PT-FXH-RP was demonstrated for Évora 15 kV E-Redes grid (with Valverde 480 kW/360 kWh E-Redes storage and Monte das Flores 2.5 MW EDPR PV installations). In the online mode, grid topology updates and forecasts are sent by web service (SOAP protocol) in XML format and bids via sFTP. Setpoints are validated with Dplan before being applied to the assets.

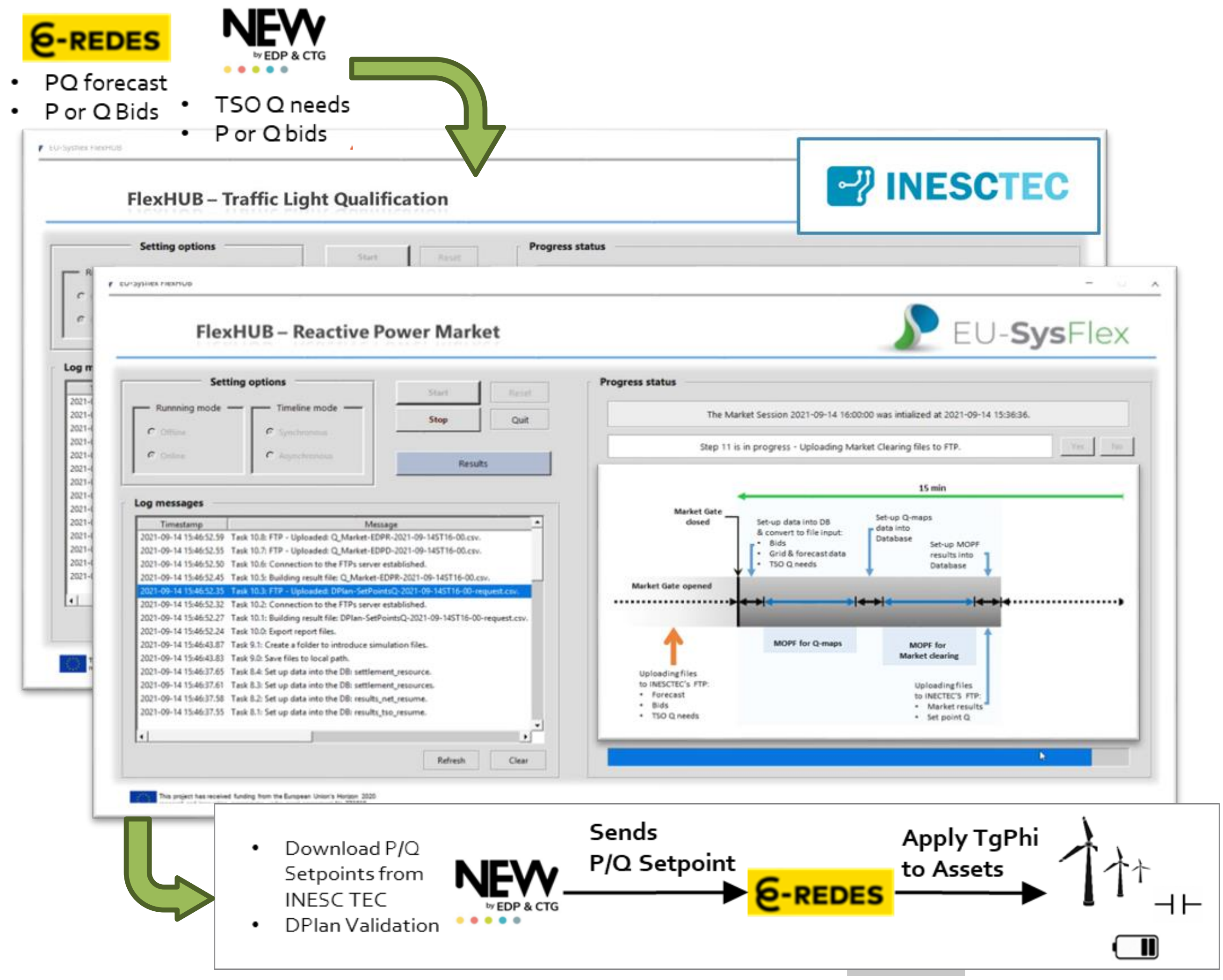

FIGURE A5-1: FLEXHUB MARKET PLATFORM

PT-FXH-DM is based on a "grey-box"-based aggregated representation of the main grid elements, whose parameters are fitted with historical, or detailed model simulated, data using an ESPO algorithm. The general architecture of the FlexHub demonstration was previously illustrated in Chapter 6 (Figure 6-6).

FINDINGS

Developing TSO-DSO coordination mechanisms to unlock distributed active and reactive power flexibility seems essential and feasible for improved system operation towards energy system decarbonisation, where traditional generation power plants will be progressively replaced with distributed renewable generation facilities.

The Flexibility Hub platform is a step further towards TSO-DSO coordination, with the provision of market-based short-term active and reactive power to the TSO, and integration of distribution grid characterisation into TSO transmission grid dynamic studies.

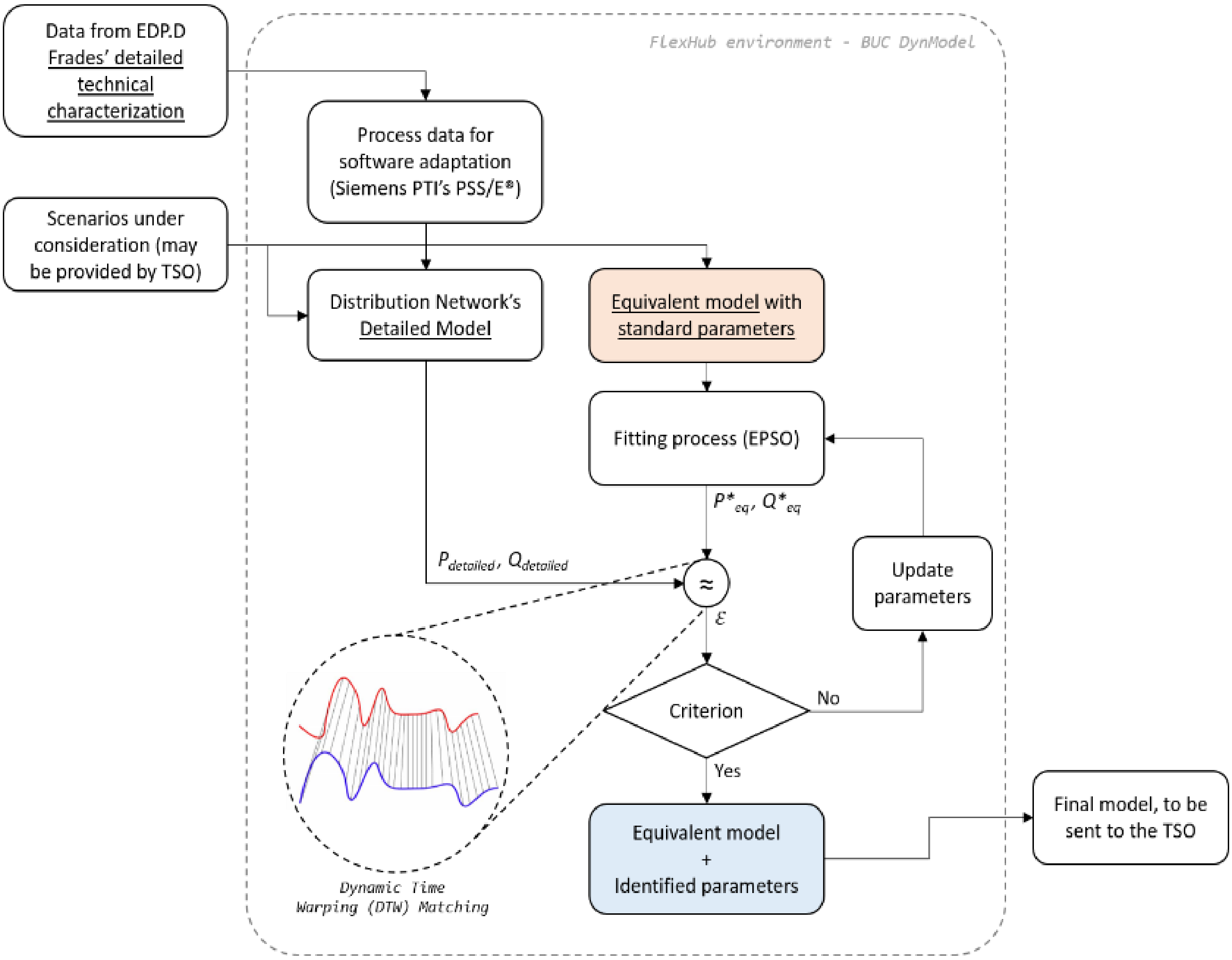

FIGURE A5-2: DYNAMIC MODEL FITTING PROCESS

KEY ACHIEVEMENTS

- New TSO-DSO improved coordination platform for:
  - Short-term active and reactive power flexibility provision.
  - Long term studies coordination, with better characterisation of distribution grid dynamics.
- Market-based mechanisms to incentivise the provision of active and reactive power
- TSO-DSO cost-sharing mechanism for coordinated use of distributed reactive power flexibility.
- Development of market platform simulation framework, MOPF market clearing and TLQ, dynamic model fitting tool.

RECOMMENDATIONS AND LESSONS

- Local flexibility markets for coordinated TSO-DSO use of reactive power seems feasible and promising. However, further studies are needed to assess the benefit for market participants and the potential need for additional incentives.
- The TLQ is aligned with EU regulation and ENTSOe-E.DSO Active System Management as a key step in active power flexibility activation, since all involved system operators should be able to validate the impact of distributed flexibility before its activation. In addition, the TLQ considers complex assets with inter-temporal constraints, such as storage facilities. However, a TSO may need to improve its bids selection procedure to adapt it to larger delivery horizons, more appropriate, for example, to incorporate storage facilities.
- Further work is needed to integrate and test simplified transmission grid models for TSO-DSO coordination, already proposed in the EU-SysFlex WP6 demonstrator, when there are multiple TSO-DSO connection points.
- National regulations should evolve faster to allow local flexibility markets, and to provide incentives to integrate distributed flexibility into their operation and planning processes, while properly assessing the benefits compared to traditional grid reinforcements.
- Accurate, but simplified, models of the distribution grid, not disclosing sensitive distribution grid data, are feasible, and could be of relevance to improve current dynamic TSO analysis.

ANNEX VI. FRANCE DEMONSTRATOR: AGGREGATION APPROACHES FOR PROVISION OF MULTI-SERVICES FROM A PORTFOLIO OF DISTRIBUTED RESOURCES

OVERVIEW

In the context of operating power systems with high shares of variable renewables, a new flexibility requirement is necessary to ensure power system security and reliability. The provision of ancillary services – so far mainly supplied by conventional synchronous units – could also be required from VRG (variable renewable generation), or supplied by storage.

In this context, an aggregation approach based on the concept of a VPP is proposed, which aims at developing and experimenting an innovative multi-service, multi resources control approach. The demonstration was set to provide technical evidence of how the timely provision of the services could be achieved by distributed resources that will be largely present in the future European system, as well as how these new actors could jointly participate in different energy and flexibility markets through an innovative portfolio management.Key Features

- Demonstration of multi-services provision by a multi-resource VPP, including frequency regulation on different timescales, and flexibility services, such as variable generation smoothing.
- Development of a full-chain VPP solution integrating functions of forecasting, optimisation, communication, control, and supervision.
- Demonstration of the capability of wind generation to provide both symmetrical and asymmetrical frequency reserves.
- Performance assessment of the services provided by new actors

IMPLEMENTATION APPROACH

The VPP includes several decentralised assets including a 12-MW windfarm, a photovoltaic generation unit and a 2-MW/3-MWh battery energy storage system. Thanks to a central EMS, the different assets were managed in a coordinated and optimal manner. Based on multiple criteria such as weather forecasts, energy and services market prices and availability of assets, the EMS developed proved capable of providing optimal energy and multi-service schedules for the VPP and of allocating frequency reserve on the controlled assets, at regular intervals, by considering the most recent forecasts and measures. To ensure robust and cyber-secured data exchange between assets and the EMS, a full IEC-61850-based and hardware-agnostic communication platform was created. The architecture of the French virtual power plant is shown in Figure A6-2.

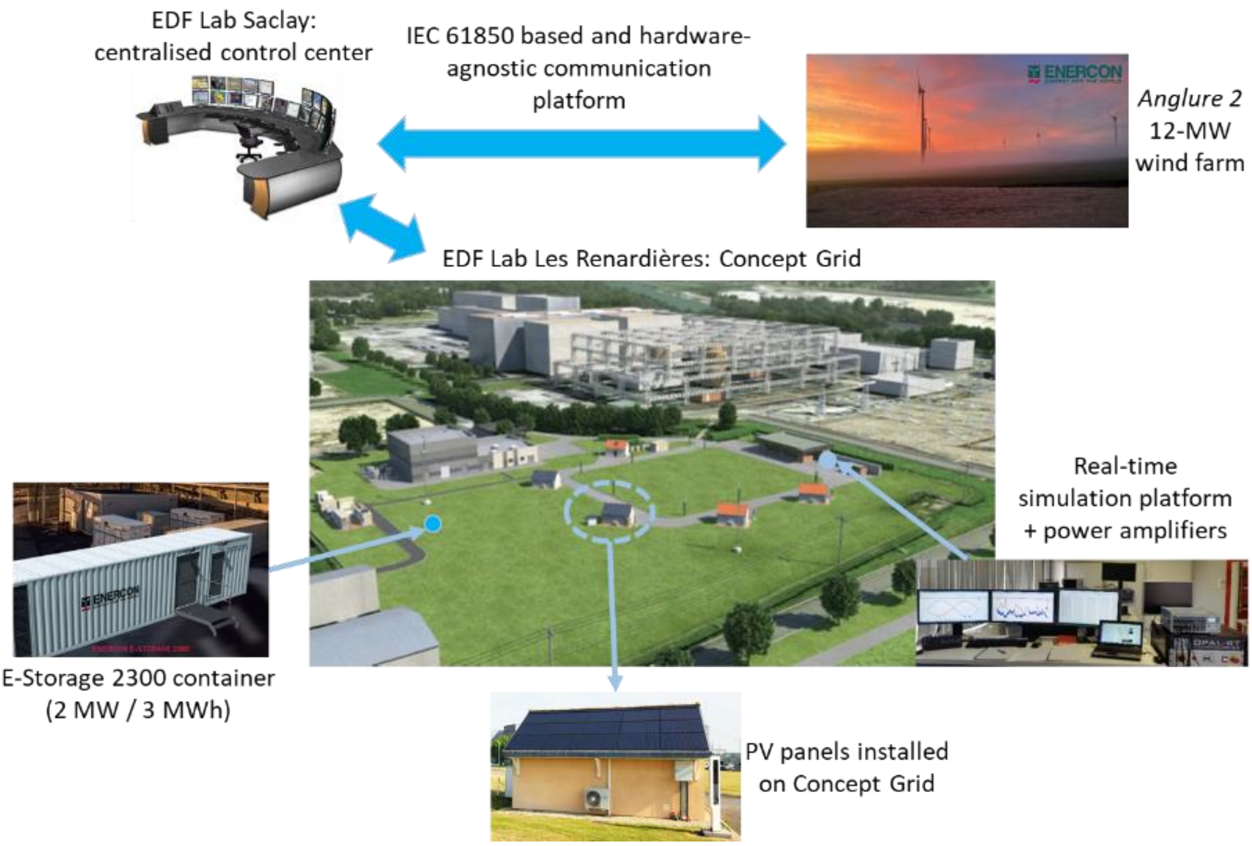

FIGURE A6-1: OVERVIEW OF FRENCH VIRTUAL POWER PLANT

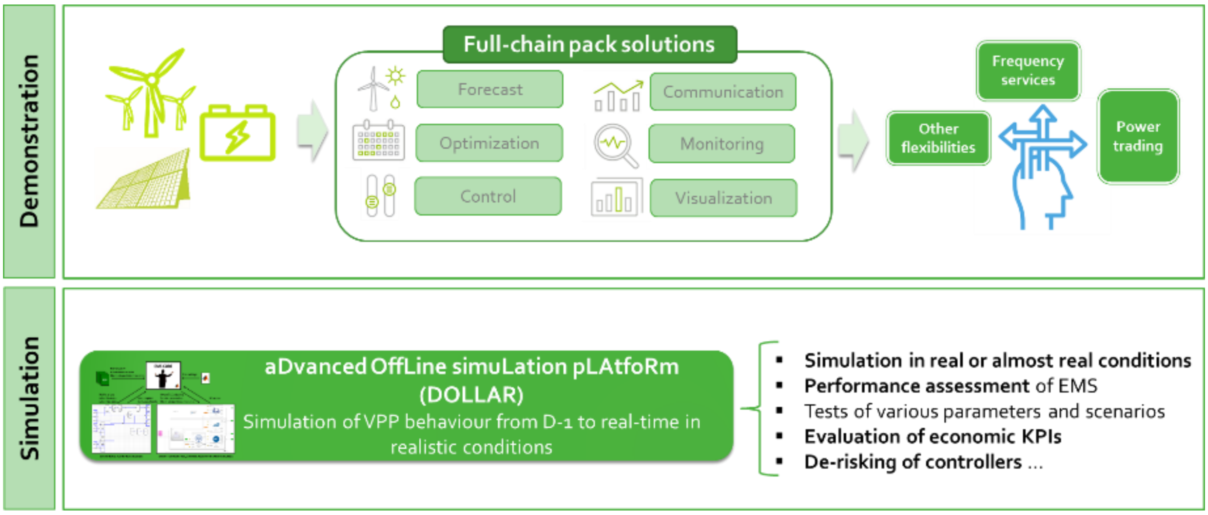

FIGURE A6-2: FRENCH DEMONSTRATION ARCHITECTURE

FINDINGS

The French demonstration provided practical evidence for successful portfolio management of several distributed resources, which have different specificities, for joint participation in the energy market, and coordinated provision of different flexibility services. The VPP proved to be an efficient aggregation approach to reduce the impact of renewable generation variability by lowering power imbalances and enhancing the availability of the power reserve provided at the VPP level. This contributes to more stable power system operation and results in easier integration for renewable generation.

Furthermore, the VPP approach helps to increase renewable generation revenue, in the future, when feed-in tariffs, or other subsidies, could disappear, through participation in ancillary services and flexibility markets. The integration of a storage system in the management pool proved very useful to strengthen the exploitation potential of all flexibilities available within the VPP, thus allowing optimal reserve constitution and easier access to both current and future flexibility markets, which will encourage renewable generations to play a more active role in power system operation.

KEY ACHIEVEMENTS

- Development of an advanced VPP energy management system for optimal management of multi-resources.
- Development of a standardised, cyber-secured and evolutive communication platform, allowing replicability and scalability of the demonstrated solution.
- Long-term technical-economic assessment performed through a dedicated offline simulation platform, which precisely models the behaviour of the entire VPP from day ahead to real time.
- Concept of advanced battery and wind generation local controllers for multi-services provision and activation.

RECOMMENDATIONS AND LESSONS

Lessons:

- Wind farms can efficiently provide frequency services ,such as FFR and FCR (notably in terms of dynamic response).
- Wind farms can suffer from significant financial shortfall if upward reserve needs to be provided, as generation curtailment is necessary during the minimum availability duration imposed by market rules and TSO requirements.
- VPPs have the capacity to enhance the performance of frequency support services and to enable the provision of new flexibilities, when coordinated and optimised control of assets is applied.
- VPPs could be one solution to prevent shortfall of individual assets through optimal use of multiple assets (e.g. downward reserve by windfarms and upward by storage).
- Communication infrastructure is of great importance for reliable VPP operation; it needs to be robust and secured while remaining evolutive.

Recommendations:

- Given the technical capabilities of wind farms in terms of frequency services, SOs could adapt their qualification and performance assessment rules to facilitate wind generation participation (current rules were shaped mainly by considering conventional generation specificities).
- SOs should also consider the participation of VPPs, given the enhanced performance of the provided services compared to individual assets.
- Markets should adapt to encourage the participation of new players, such as renewable producers and VPPs: asymmetrical products should be allowed, considering that wind or PV generation are more suitable for downward reserve only.
- VPPs should be more seriously envisaged, as they would facilitate the participation of new players and small-scale actors in one or several electricity markets, both for energy and flexibility, thus potentially leading to increasing profitability at the VPP level.

ANNEX VII. DATA EXCHANGE DEMONSTRATOR: DEMONSTRATIONS OF CROSS-BORDER AND CROSS-SECTOR DATA EXCHANGES

OVERVIEW

The aim of the Data exchange Demonstrations (led by Estonia) are to implement, on a conceptual level, a number of data exchange system use cases defined for flexibility data exchange, and any other private data exchange based on the Data Exchange Platform (DEP) concept. Several demonstrations focused on aspects of data management, including cross-border communication between different data exchange platforms, and with different stakeholders in order to facilitate cross-border exchange of flexibility services with the following elements:

- Cross-border data exchange between different stakeholders – system operators, market operators, end customers, data hubs, service providers, etc.;
- Handling of personal and commercially sensitive data;
- Affordable application for smaller distributed DSR;
- TSO-DSO flexibility data exchange application;
- User interface – single access point to data, services and applications;
- Combined access to metering and operational data;
- Cross-sectoral data usage;
- Big data collection, storage, processing;
- Cyber security and data privacy requirements.

KEY FEATURES

- Customer-centric cross-border data exchange model for flexible market design serving all stakeholders (TSOs, DSOs, suppliers, flexibility providers, ESCOs, etc.).
- Interoperability of different data exchange platforms, including cross-sector data exchanges.
- Application for flexibility marketplace to support TSO-DSO flexibility data exchange.
- Tool for an aggregator to aggregate smaller distributed flexibility sources enabling affordable access to the market.

IMPLEMENTATION APPROACH

Initial focus was placed on elaborating data exchange system use cases, which range from flexibility market specific (e.g. prequalification SUC) to more agnostic (e.g. consent management SUC). Most SUCs were implemented through ten data exchange demonstrators. The most extensive are the “Flexibility Platform” and “Affordable Tool” demonstrators.

An environment for executing integration tests was set up – “Estfeed research environment”. Existing technologies applied include data exchange platforms Estfeed (including data hub and customer portal), Unified eXchange Platform (UXP), X-Road and ECCo SP (ENTSO-E Communication & Connectivity Service Platform), EMS components for flexibility management, Sharemind for privacy preserving data exchange, KSI Blockchain technology stack and Black Lantern anti tamper hardware for cybersecurity, Big Data management components.

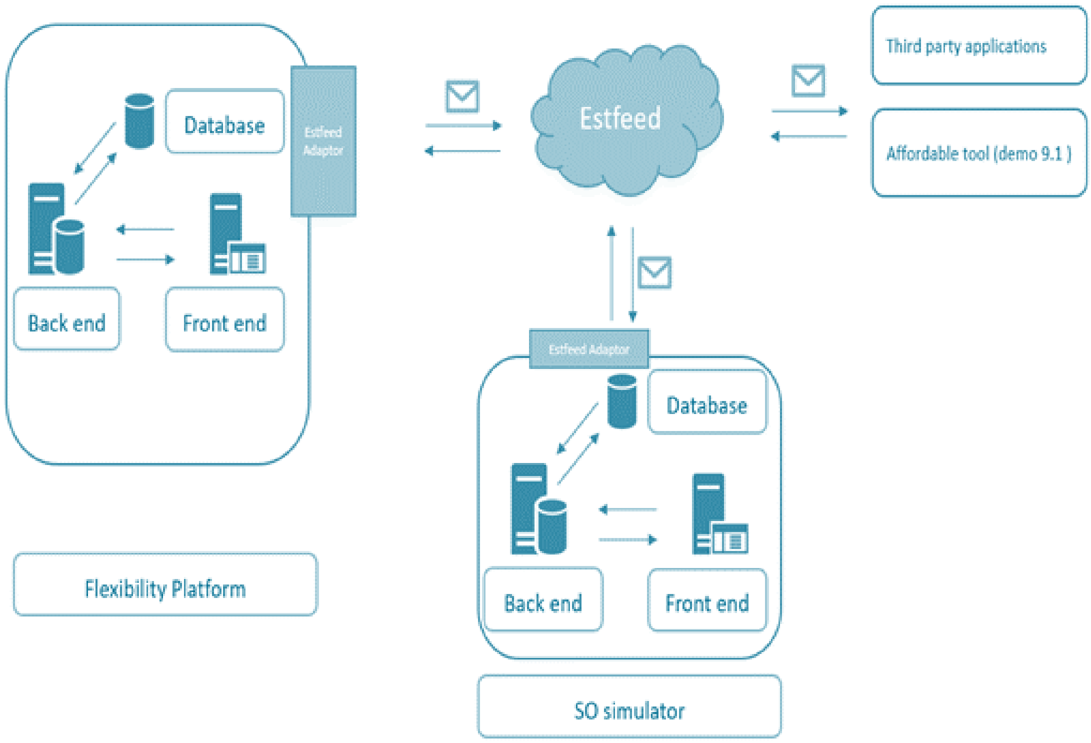

FIGURE A7-1: FLEXIBILITY PLATFORM - OVERALL ARCHITECTURE

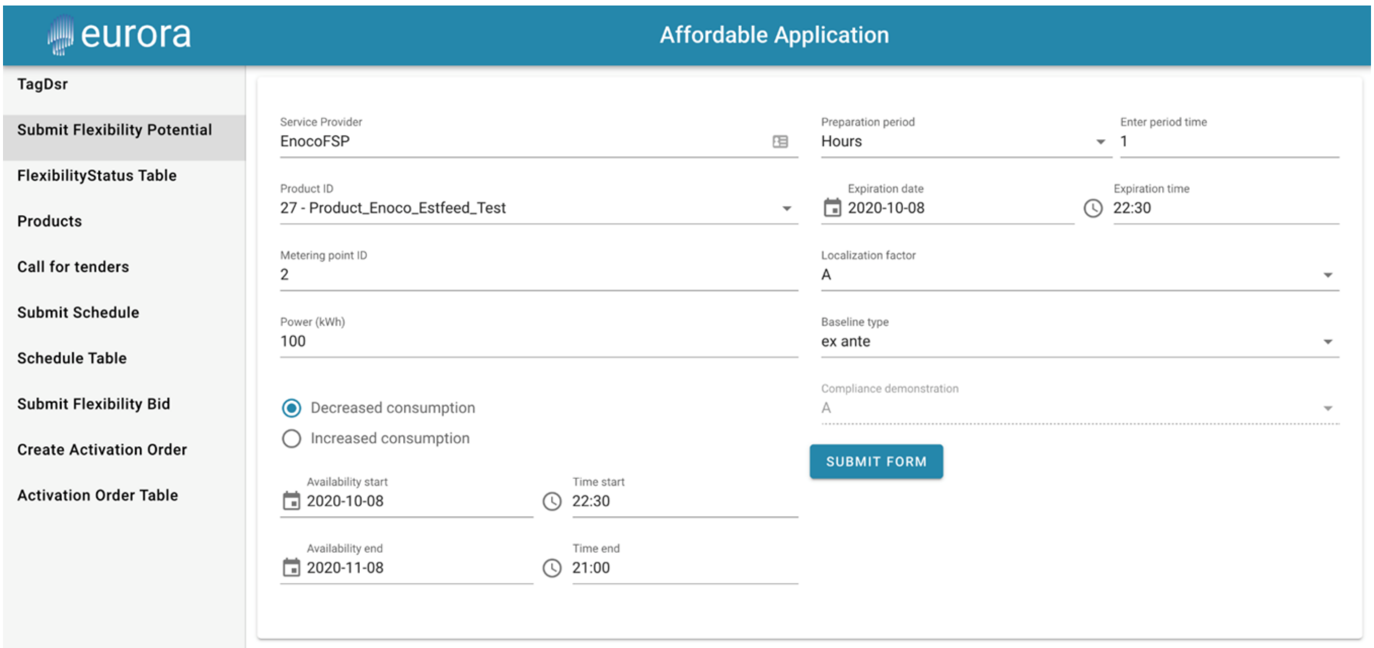

FIGURE A7-2: “AFFORDABLE TOOL”, DEVELOPED BY DATA EXCHANGE DEMONSTRATIONS

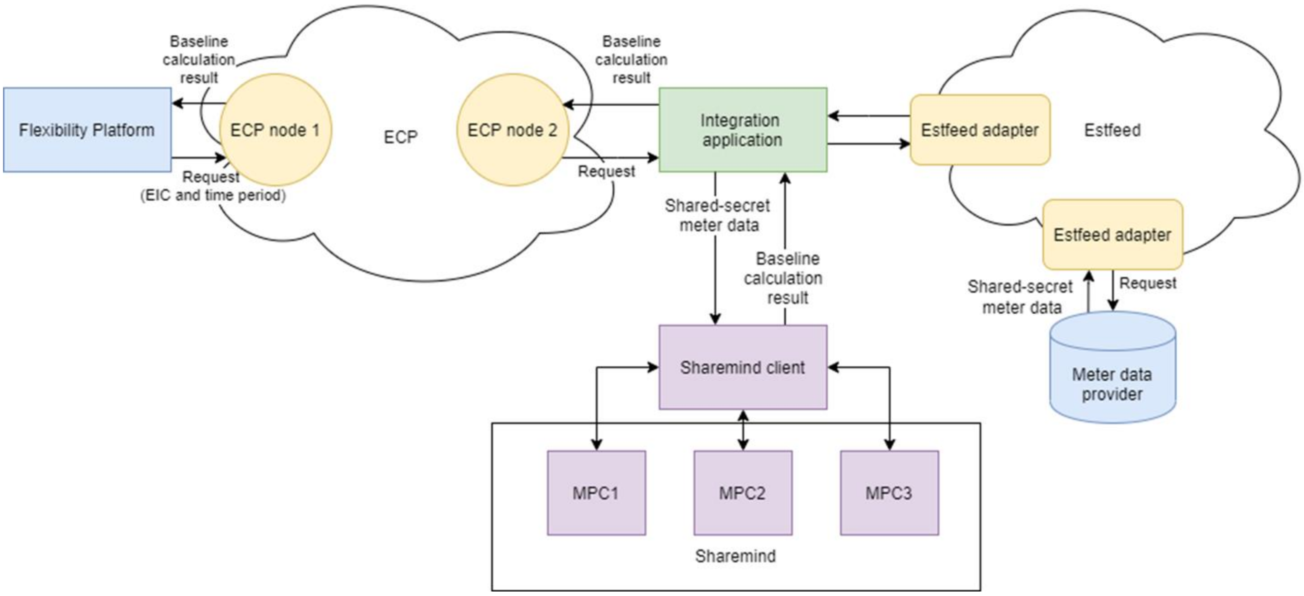

FIGURE A7-3: DATA EXCHANGE FLOW BETWEEN SHAREMIND, ESTFEED, AND FLEXIBILITY PLATFORMS

FINDINGS

To ensure interoperability of flexibility services, focus needs to be placed on data interoperability, next to harmonising regulatory/business processes. The developed solutions address homogeneous and secure data management through the concept of Data Exchange Platform.

DSR units can benefit from tools providing aggregation services, data services provided by DEP, and market services (e.g. bid submission, asset activation) provided by the Flexibility Platform.

Residents of one country are able to access their metering data, and share data with other stakeholders using services (e.g. consent management) provided by a DEP located in another country.

Cross-sector data exchange was demonstrated, which proposed a way to add value to users of one system (e.g. meter data hub) with data enrichment from another system (e.g. building register).

It would not take much effort to translate the original API implementation into a CIM compliant API, and to replace an existing API with a CIM compliant API.

KEY ACHIEVEMENTS

- “Flexibility Platform” for prequalification, trading, activation and verification of any flexibility product connecting all FSPs and system operators;
- “Affordable Tool” for smaller DSR units;
- Cross-border metering data exchange;
- Cross-sector data exchange integrating building information and metering data;
- Integration of two separate Data Exchange Platforms (ECCo SP and Estfeed);

- Big Data Framework;
- Concept of assuring process and log security developed;
- CIM (Common Information Model) profiles elaborated and implemented for Flexibility Platform data model.

RECOMMENDATIONS AND LESSONS

- Proper data management contributes to the flexibility market participation of stakeholders across geographical borders for any asset.
- Proper tools for FSPs to actively bring smaller customers to the energy market
- Accelerated implementation of eIDAS (European Regulation on electronic IDentification, Authentication and trust Services) contributes to cross-border data exchange by making different authentication methods interoperable.
- Data providers and data users connected to different DEPs (ECCo SP, Estfeed) can exchange data by ensuring DEP interoperability.
- Using dedicated privacy-preserving technologies, it is possible to preserve data owner privacy without explicit consent.
- It is possible to integrate alternative signing mechanisms to critical logs that provide information about the data exchange and participants.

ANNEX VIII. IRELAND AND NORTHERN IRELAND TRIAL: QUALIFIER TRIAL PROCESS (QTP)

OVERVIEW

The Qualifier Trial Process acts as a gateway, providing a technical platform to trial resilience services from new technology providers, and providing a route to an enduring market.

The QTP provides the missing link that facilitates the transition from fossil fuel dominance, to a sustainable renewable power system. It is a central piece of a much broader programme of work led by the EirGrid Group to meet medium and long-term RES-E objectives in Ireland and Northern Ireland.

Today, the Ireland and Northern Ireland power system is the first in the world capable of delivering 70% of instantaneous electricity demand from non-synchronous sources, including wind and solar.

KEY FEATURES

- Three phases of the Qualifier Trial Process were carried out:
- **2017**: Wind, Demand Side Management, Synchronous Compensator/Flywheel, Centrally Dispatched Generating Unit & HVDC Interconnectors
- **2018**: Residential Service Provision (Power Off & Save), Steady State Reactive Power & Control and Signals
- **2019/2020**: Solar, Residential Services & Telecommunications
- **Service Provision**: Fast Frequency Response, Reserve, Fast Post-Fault Active Power Recovery and Dynamic Reactive Response Across various technology classes

IMPLEMENTATION APPROACH

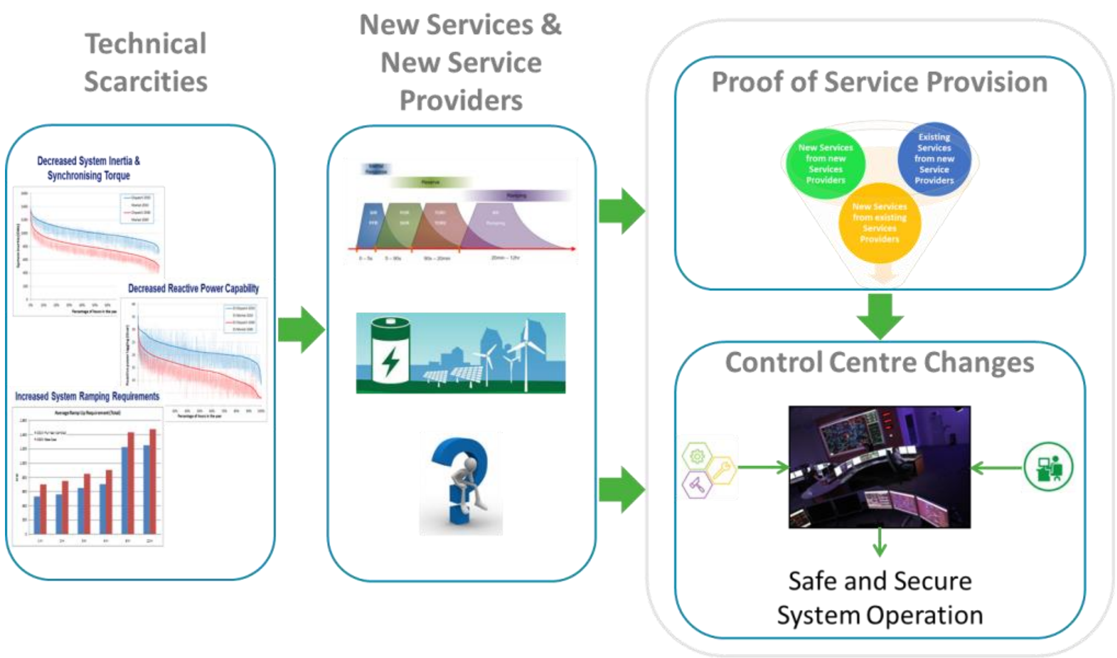

FIGURE A8-1: QUALIFICATION TRIAL PROCESS CONCEPT

QTP is the mechanism through which the TSOs in Ireland and Northern Ireland are managing the transition to a wider portfolio of system service providers. The aim is to identify operational complexities that may be associated with new technologies, or delivery of new System Services. In doing so, EirGrid and SONI can develop a deep understanding of these complexities and suggest solutions on how to best integrate these technologies at scale, on the power system on the Island of Ireland and Europe.

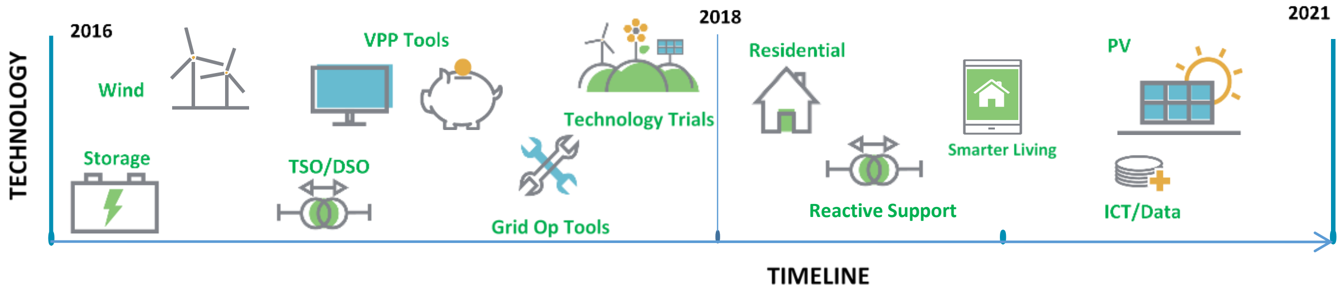

FIGURE A8-2: QUALIFICATION TRIAL PROCESS TIMELINE IN IRELAND AND NORTHERN IRELAND DEMONSTRATOR

FINDINGS

As the System Non-Synchronous Penetration is increased in Ireland and Northern Ireland beyond the current level of 70% (75% under trial), we have to increasingly rely on new technologies to provide the resilience of the system.

QTP is the mechanism through which the TSOs in Ireland and Northern Ireland are managing the transition to a wider portfolio of system service providers. The aim is to identify operational complexities that may be associated with new technologies or services. In doing so, the TSOs can develop a deep understanding of these, and suggest solutions on how to best integrate these technologies at scale, on the power system on the Island of Ireland and Europe.

KEY ACHIEVEMENTS

- Array of technology classes participating across the 2017, 2018 & 2019/2020 QTPs for FFR, POR, SOR & TOR services considered as proven and added to the EirGrid DS3 System Services Proven Technologies List (publicly available)
- Where a technology class was not proven to provide a system service, key learnings developed with the consideration of a potential future trial
- The “FlexTech Initiative” provided the platform for stakeholder engagement (TSOs, DSOs, Industry and Regulators) for identifying opportunities and removing barriers to renewable integration.

RECOMMENDATIONS AND LESSONS

- Key principles include running trials at small-scale to mitigate risk, assessment on a technology class basis rather than service provider, participant failure viewed as learning rather than permanent exclusion, and that QTP success does not guarantee a service provider will obtain a contract in the main procurement process

- As system reliance on non-synchronous VRES generation increases, new services/technologies are required to maintain a reliable and secure system at steadily growing SNSP levels. QTP has provided a necessary platform to prove these technology classes
- The FlexTech Technology Integration initiative has provided SOs, regulatory bodies and industry with the capability to engage with the objective of maximising the opportunity to make effective use of new and existing technologies to meet the needs of the future power system

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