Product Definition for Innovative System Services

D3.1

EU-SysFlex

PROGRAMME	H2020 COMPETITIVE LOW CARBON ENERGY 2017-2-SMART-GRIDS
GRANT AGREEMENT NUMBER	773505
PROJECT ACRONYM	EU-SysFlex
DOCUMENT	D3.1
TYPE (DISTRIBUTION LEVEL)	☒ Public ☐ Confidential ☐ Restricted
DUE DELIVERY DATE	31/04/2019
DATE OF DELIVERY	07/06/2019
STATUS AND VERSION	Deliverable Report Outline – V0.6
NUMBER OF PAGES	96
Work Package / TASK RELATED	WP3/Task 3.1
Work Package / TASK RESPONSIBLE	VITO / EirGrid
AUTHOR (S)	Sheila Nolan, Niamh Delaney, Helena Gerard, Enrique Rivero Puente, Ana Virag Goran Strbac, Danny Pudjianto, Yujian Ye, Roberto Moreira, Dimitrios Papadaskalopoulos, Stephen Woodhouse, Kostas Theodoropoulos, Marie-Ann Evans, Sylvie Magois, Maider Serra, Philippe Loevenbruck, Wojciech Lubczynski, Przemysław Kacprzak, Anna Wronka, Alan Tkaczyk, Jan Budke, Corentin Evens, Bernardo Silva, José Villar.

DOCUMENT HISTORY

VERS	ISSUE DATE	CONTENT AND CHANGES
0.1	02/05/2018	Deliverable Report Outline
0.2	12/04/2019	Report sent to WP lead and TM for review
0.3	20/05/2019	Report sent to PMB for review
0.4	31/05/2019	Report following PMB review
0.5	03/06/2019	Minor updates
0.6	07/06/2019	Final Version

DOCUMENT APPROVERS

PARTNER	APPROVER
Helena Gerard (VITO), Marie-Ann Evans (EDF)	Technical verification
John Lowry (EIRGRID)	Validation

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

AEMO	Australian Electricity Market Operator
aFRR	Automatic Frequency Restoration Reserve
AIS	All-Island Power System
AS	Ancillary Services
CE	Continental Europe
DER	Distributed Energy Resources
DRR	Dynamic Reactive Response
DSO	Distribution System Operator
DSR	Demand Side Response
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EU-SysFlex	Pan-European System with an efficient coordinated use of flexibilities for the integration of a large share of Renewable Energy Source
FCR	Frequency Containment Reserve
FPFAPR	Fast Post-Fault Power Recovery
FRR	Frequency Restoration Reserve
FRT	Fault ride through
LMP	Locational Marginal Pricing
mFRR	Manual Frequency Restoration Reserve
MVA	Mega Volt Ampere
MO	Market Operator
MVAr	Mega Volt Ampere Reactive
POR	Primary Operating Reserve
RoCoF	Rate of Change of Frequency
RES	Renewable Energy Sources
RRD	Replacement Reserve Desynchronised
RRS	Replacement Reserve Synchronised
SIR	Synchronous Inertial Response
SNSP	System Non Synchronous Penetration
SO	System Operator
SONI	System Operator Northern Ireland
SOR	Secondary Operating Reserve
SSRP	Steady State Reactive Power
TOR	Tertiary Operating Reserve
TSO	Transmission System Operator
VDIFD	Voltage Dip-Induced Frequency Deviation
WP	Work Package

EXECUTIVE SUMMARY

The transition to power systems with very high levels of variable renewable generation is likely to result in fundamental changes to the technical, as well as the financial, characteristics of power systems. In the context of the EU-SysFlex project, high levels of renewable generation are defined as being installed capacities of renewables that succeed in meeting at least 50% of the total annual electricity demand.

Transitioning from power systems which have traditionally been dominated by large synchronous generating units to systems with high levels of variable non-synchronous renewable technologies has been shown to result in technical challenges for operating power systems safely and reliably. This is due to the non-synchronous nature of these technologies as well as the variable nature of the underlying resource. These challenges, if not addressed, can have an impact on the security and stability of the power system. These challenges, or technical scarcities, are typically the result of the displacement of conventional generation and due to increasing levels of non-synchronous renewable generation and can be categorised and summarised as follows:

- Lack of frequency control
- Lack of voltage control
- Rotor angle instability
- Network congestion
- Degradation of system adequacy and system restoration capability

In EU-SysFlex it is acknowledged that tackling these scarcities will require a holistic solution with system-level thinking. Having a complete suite of system services, across the entire spectrum of technical scarcities will assist with ensuring that the future power system will be more robust to high impact events, more reliable despite increasing the penetration of variable renewable generation and greater levels of demand-side uncertainty and more resilient to emergency situations and contingencies. To continue to provide a secure and resilient power system for consumers, new and innovative system services may be required, to complement the existing suite of ancillary services, as well as a range of technical solutions. Addressing these scarcities via system services is a key objective of Task 3.1 in the EU-SysFlex project.

In this report current system services are catalogued and the need for new system services is assessed taking into account the technical scarcities that could be seen with the transition to a power system with high levels of variable renewable generation, as defined by WP2 in the literature review presented in Deliverable 2.1 (EU-SysFlex Consortium, 2018). It should be noted that an advanced, quantitative assessment of system needs and technical scarcities is on-going in Task 2.4.

An extensive range of system services and products, more than 120, are identified through the use of a state-of-the-art assessment. These products range from existing products to products that are under consideration in various jurisdictions and countries, with the varying stages of development accounted for. The products are first categorised based on the main type of technical scarcity (or scarcities) that they mitigate and then based on the time period over which they operate. Not surprisingly, it is found that, traditionally, focus has been on active power services and frequency control. Indeed when existing system services are examined, they are found to predominately address current challenges associated with frequency control, rather than the future technical scarcities that were identified previously in the EU-SysFlex project in Task 2.1. Figure 1 shows that a considerable number of products exist in the frequency control category in comparison with the other scarcity categories. It should be noted that while Figure 1 is not a comprehensive list, as information to create it was only obtained from the EU-SysFlex consortium partners (see ANNEX I), it succeeds in highlighting some clear trends and some potential gaps in the existing suite of system services.

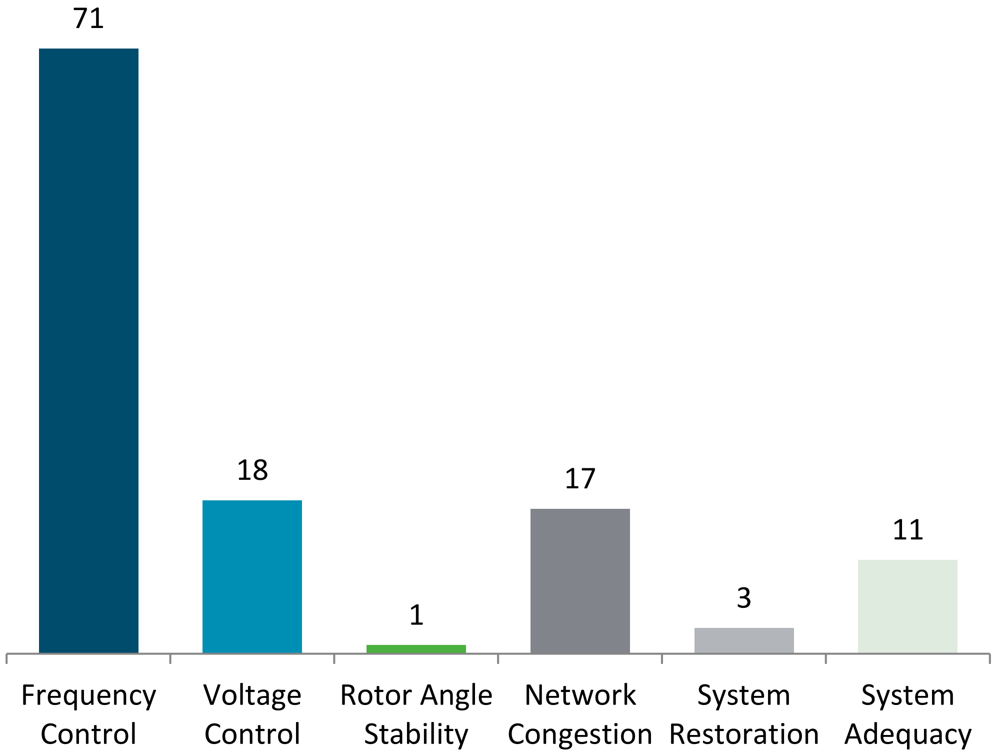

FIGURE 1: MAPPING OF COMPLETE LIST OF ALL PRODUCTS AND SYSTEM SERVICES (OR MARKET- AND GRID CODE- BASED SOLUTIONS) IDENTIFIED (EXISTING SERVICES, NEW SERVICES AND NEW CONCEPTS) WITH THE TECHNICAL SCARCITIES THEY MITIGATE

Consolidating the list of all system services[1] and products from the state-of-the-art assessment reveals a number of generic system services, for which high-level descriptions were provided. Where applicable, an indication of innovation potential is also provided. Potential areas for innovation included enhancement of service specification, specifically in relation to incorporating energy and power, as well as trajectories, into the service requirements. Additionally, concepts such as bundling multiple services into one product and having a "super-

[1] The system services that were identified within the scope of the EU-SysFlex project.

product" are also introduced. It should be mentioned that the reference for innovation potential in this case is the "as is" or the "state-of-the-art" assessment.

Review of the high-level descriptions of the system services reveals clear gaps. In order to address these gaps innovative services are proposed. Such innovative services include Synchronous Inertial Response, Fast Post Fault Active Power Recovery, Dynamic reactive response, Ramping products and Congestion Management products. These services could be utilised in many jurisdictions, based on a case by case analysis, to mitigate technical scarcities that will be assessed by WP2. They could be further developed and enhanced, in conjunction with market design developments, to solve a range of needs. Additionally, these services could be used in parallel with non-market based measures such as network codes or infrastructural investment.

Task 3.1 provides a 'basket' or suite of potential products for system services. These services could be utilised to mitigate technical scarcities and could be further developed and enhanced, in conjunction with market design developments, to solve a range of needs. This 'basket' or suite of generic products is summarised in Table 1.

TABLE 1: BASKET OF GENERIC SYSTEM SERVICES

System Service	Aim	Timeframe
Inertial Response	Minimise RoCoF	Immediate
Fast Response	Slow time to reach nadir/zenith	<2 secs
Frequency Containment Reserve	Contain the frequency	5 secs to 30 sec
Frequency Restoration Reserve	Return frequency to nominal	30 secs to 15 mins
Replacement Reserve	Replace reserves utilised to provide faster products	15 mins to hours
Ramping	Oppose unforeseen sustained divergences, such as unforecasted wind or solar production changes	1 hour, 3 hours, 8 hours
Voltage Control - Steady-State	Voltage control during normal system operation	Long or short timeframe for activation
Dynamic Reactive Power	Voltage control during a system disturbance and mitigation of rotor angle instability	<40 ms
Congestion Management	Manage congestion that occurs as a result of a range of situations	mins to hours

Complementary to the analysis of the potential for new system services, there is a need to examine remuneration mechanisms and explore the need to employ new and innovative market designs. Consequently, this report provides a first indication of potential market arrangements for the procurement of the system services. The four key market organisations considered in this report are Centralised Market, Decentralised Market, Regulated Arrangements and Distributed Market.

The final contribution from the report is an indicative, preliminary mapping of the various system services with potential market frameworks, laying the groundwork for further analysis in Task 3.2. There are multiple market frameworks that could be utilised to procure the basket of system services. At this stage of the process, several market framework options are plausible but dependent on the service, state of the system and available technologies, each market framework will have different advantages and disadvantages.

Throughout this report it should be remembered that EU-SysFlex Task 3.1 is one step in the overall process for identifying, defining and validating system services that may be needed to address the technical challenges in power systems with very high levels of non-synchronous renewable generation. Additional work is required to validate the proposed new services and solutions and to determine their value.

1. INTRODUCTION TO TASK 3.1

1.1 CONTEXT

With the advent of very high levels of variable renewable generation, as well as a move to more decentralised and distributed power electronic interfaced technologies, there are likely to be significant challenges that need to be overcome in relation to the technical, as well as the financial, characteristics of power systems. In the context of the EU-SysFlex project, high levels of renewable generation are defined as being installed capacities of renewables that succeed in meeting at least 50% of the total annual electricity demand. Transitioning from power systems which have traditionally been dominated by large synchronous generating units to systems with high levels of variable non-synchronous renewable technologies has been shown to result in technical challenges for balancing and operating power systems safely and reliably. This is due to the non-synchronous nature of these technologies as well as the variable nature of the underlying resources. Deliverable 2.1 of the EU-SysFlex project (EU-SysFlex Consortium, 2018) has performed a comprehensive review of the literature and identified a number of key technical scarcities associated with integration of variable non-synchronous generation and the associated displacement of conventional synchronous generation. These scarcities, if not mitigated, may impact the security and stability of the power system of the future.

According to Deliverable 2.1 (EU-SysFlex Consortium, 2018) the advent of non-synchronous renewable generation, and the associated displacement of conventional generation, will result in a need for extra resources in order to obtain operating reserve capabilities from non-conventional technologies to ensure there will be sufficient frequency control capabilities across multiple time frames. Displacement of conventional technologies can also lead to a range of instabilities and issues with reactive power control. Similarly, the transition to power systems with high levels of renewable generation results in high levels of variable generation, both at the transmission level, but also embedded in distribution networks and a consequential increase in congestions especially when renewable generation is situated far away from load centres. Addressing these scarcities is a key objective of Task 3.1 in the EU-SysFlex project. Furthermore, displacement of conventional generation could lead to a lack of system restoration capability and a need for additional resources to provide black start services. Similarly, a potential reduction in system adequacy has also been identified as a challenge associated with displacement of conventional generation.

In recent times, there have been many changes to ancillary services markets. These adaptations have mainly been driven by new service providers, new entrants to the market and the drive towards greater cross-border coordination, rather than being driven by the evolving needs of a future power system with very high levels of variable renewable generation. Thus, in order to mitigate the technical scarcities that were identified in Deliverable 2.1 (EU-SysFlex Consortium, 2018) and will be further investigated in WP2, and to continue to provide a secure and resilient power system for consumers, new and innovative system services may be required, to complement the existing suite of ancillary services. In addition, new service providers will need to have a route to market. Thus, in the following pages current system services will be catalogued, the need for new system services and new system service providers will be assessed taking into account the technical scarcities that could be seen with the transition to a power system with high levels of variable renewable generation, and suggestions regarding suitable services to mitigate those scarcities will be provided.

It is possible, however, that these new system services, could not be procured and remunerated in the same manner as current ancillary services. Thus, in conjunction with the analysis of the potential for new system services, there is a need to examine remuneration mechanisms and explore the need to employ new and innovative market designs. Consequently, this report provides a first indication of potential market arrangements for the procurement of the system services. Further, more detailed analysis of market arrangements will be presented in the subsequent tasks in WP3.

The remainder of Chapter 1 outlines the objectives of WP3, more generally, and Task 3.1 specifically. Chapter 2 provides an overview of the approach that was used in this task, while Chapter 3 outlines the technical scarcities that were identified in Deliverable 2.1 (EU-SysFlex Consortium, 2018) which will be further explored in Task 2.4 of EU-SysFlex. Chapter 4 of this report details the system services and presents the results of a gap analysis that was performed to identify whether the range of products covers the entire spectrum of technical needs. Chapter 5 presents potential options for procurement of system services, paving the way for much more detailed analysis in Task 3.2 of EU-SysFlex. Chapter 6 summarises the conclusions reached in this report.

1.2 WP3 OBJECTIVES

Work Package 3 of EU-SysFlex is entitled "Analysis of market design and regulatory options for innovative system service". The main objectives of WP3 are the development of innovations for existing and new system services which goes hand in hand with the analysis of different options for market design. The assessment of product characteristics and corresponding market design will be supported by advanced modelling techniques. In addition, roles and interactions of both regulated and deregulated stakeholders will be examined in the context of the provision of system services. For the different market design options, the regulatory framework is analysed for a selection of relevant countries. Within Work Package 3, generic functional specifications in terms of business use cases are provided for the services tested by the different demonstrators within EU-SysFlex.

1.3 OBJECTIVE OF TASK 3.1 AND RELATIONSHIP WITH OTHER TASKS

The process for identifying, defining and validating innovative system services, and methods to procure them, comprises a number of steps. These steps, as well as the corresponding, relevant tasks in EU-SysFlex, are outlined in Table 2, below. As can be seen, Task 3.1 forms one step in this process and consequently, Task 3.1 should be viewed as such in the context of the wider EU-SysFlex project.

Task 3.1 aims to provide a consolidated overview of innovative products for system services from best practices and from finished and ongoing projects throughout the EU and a qualitative assessment of those system services.

The focus in this task is primarily on system services that support the day-to-day operation of a safe, secure and reliable future power system with increasing penetration levels of variable renewable generating technologies. While it is acknowledged that both system restoration capability and ensuring system adequacy are vitally important for power systems, they are out of scope in this task. It could be argued that developing the correct system services to ensure that there is sufficient capability in the generating portfolio to meet the operational needs of the power system, there will be sufficient amounts of generation capacity installed to ensure system adequacy. Capacity markets, which are out of scope in this task, can also be employed to guarantee generation adequacy. System restoration capability, on the other hand, is provided by only few very specific generating technologies and the requirement to utilise this capability is so infrequent. Consequently, it falls outside the remit of operational decisions and so is out of scope in this task. Indeed, it is more appropriate to grid code mandate system restoration capability rather than via a competitive market arrangement.

Technical specifications of individual product parameters will be provided, enabling a qualitative assessment to ensure that the range of products covers the entire spectrum of technical needs. Detailed simulations and technical analysis are not within the scope of Task 3.1. This work takes place in Task 2.6. In addition, Task 3.1 should provide an indication of relevant product parameters and a preliminary assessment to the extent the products can be procured, activated and settled through market or regulated mechanisms. There are situations when, without detailed analysis, it is not clear whether a given service should be encapsulated as "market product" or "regulatory requirement". In such cases more detailed assessment is necessary, which is beyond the scope of this task, but however, is within the scope of Task 3.2.

TABLE 2: PROCESS FOR IDENTIFYING, DEFINING AND VALIDATING SYSTEM SERVICES THAT MAY BE NEEDED IN THE FUTURE

Steps in Process	Tasks in EU-SysFlex Undertaking this Work
1. Detailed technical studies and analysis to identify the technical scarcities and needs including an assessment of the capabilities of the portfolio of technologies	Task 2.1 (Literature Review), Task 2.2 (Scenario Development), Task 2.3 (Model Development), Task 2.4 (Technical Scarcity Studies)
2. Development of proposals for new services and alternative solutions to mitigate the scarcities and meet the needs identified	**Task 3.1**
3. Further iterations of detailed technical studies and analysis, with information from field tests	Task 2.6 (Review of technical modelling studies)
4. Detailed market design assessment, supported by several quantitative analysis, including valuation of new services and solutions	Task 3.2 (Market Design), Task 3.4 (Market Modelling), Task 2.5 (Evaluation of System Services)

More generally, the discussion in Task 3.1 will feed into the work that will take place in Task 3.2 and Task 3.4, but will also inform the development of the roadmap in WP10. The relationship between Task 3.1 and other tasks in the EU-SysFlex project is graphically depicted in Figure 2. Task 3.1 forms part of the link between the technical studies that take place in Work Package 2 and the market based assessments that form the remainder of Work Package 3.

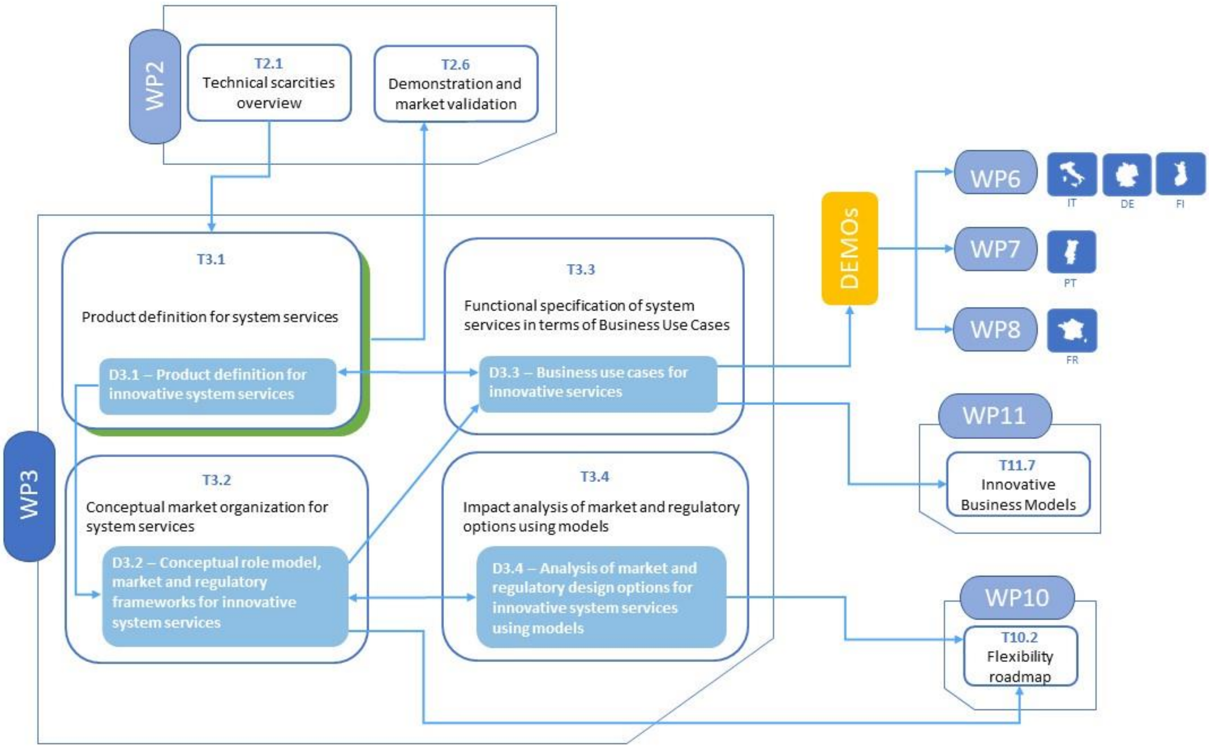

FIGURE 2: RELATIONSHIP BETWEEN WP3 TASKS AND OTHER WORK PACKAGES

In what follows, a **system service** is defined as the physical action, be it the provision of active or reactive power and/or energy, which is needed to mitigate a particular technical scarcity or scarcities. A **product**, on the other hand, is the “option” that is purchased and remunerated, where the service is what is actually delivered and the service defines exactly what is needed once a particular option is called upon. For example, manual frequency restoration reserve is a product, while the service in this case is the provision of active power to restore the system frequency to nominal following a frequency deviation.

2. METHODOLOGY AND APPROACH

2.1 OVERVIEW

As previously mentioned, Task 3.1 was first and foremost, a qualitative task. This has dictated and influenced the approach applied. The main facets of this task required significant information gathering as well as detailed discussions and out-of-the-box thinking. In order to achieve this, it was necessary to employ a number of different approaches. These approaches included:

a) A state-of-the-art assessment of system services, including co-ordination with the demonstration projects
b) Out of the box thinking through the use of a detailed questionnaire
c) Detailed discussions that took place during regular conference calls, but most predominantly during an internal WP3 workshop that occurred on the 5th of December 2018 in Leuven, Belgium, including the perspectives of more than twenty consortium partners (research institutes, universities, consultants, TSOs, DSOs etc.).

Figure 3 gives an overview of the approaches utilised in this task, together with the inputs that are used and the outcomes that are obtained from applying the approaches. The expertise and knowledge of each of the partners in this task was leveraged, not only in gathering information but also in fuelling the discussions that took place during the frequent interactions.

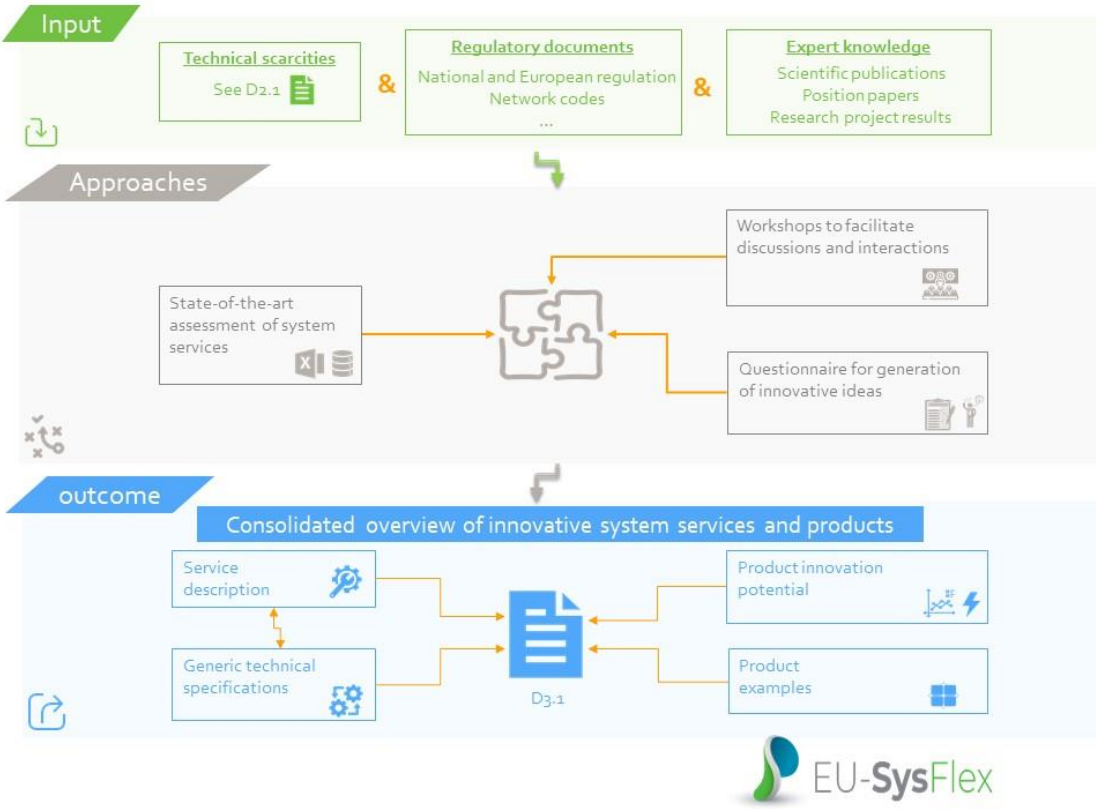

FIGURE 3: OVERVIEW OF THE APPROACHES UTILISED IN TASK 3.1

2.2 STATE-OF-THE ART ASSESSMENT OF SYSTEM SERVICES

In order to collate and assemble an overview of system services and products, an internal database was prepared at the outset of this task. This database was used by the partners to describe services and products which are either existing and/or under consideration in their respective jurisdictions and countries, as well as products which are at varying stages of development. A distinct strength of the EU-SysFlex project is the experience brought by the wide range of partners who are involved, from TSOs and DSOs to research institutions and consultancy firms[2], but also from a large set of countries with different power systems specificities.

The database for describing system services and products was developed based on the DS3 system service products from Ireland and Northern Ireland (SEM Committee, 2013) as well as the consultation document on Project TERRE (ENTSO-E, 2016). The characteristics for describing the services and products are multi-faceted, ranging from technical characteristics through to the type of mechanism that could be used to remunerate their provision. These characteristics are listed in Table 3. As can be seen, not all of these parameters pertain to the technical characteristic of system services; some relate to market arrangements. Consequently, as will be seen in Chapter 3 and Chapter 4, only the crucial technical parameters will be considered in this task, while the remaining parameters will be detailed in Task 3.2.

More than 120 different system services and products were identified and logged in the internal database. A complete list of these services and products is included in ANNEX II of this report. The products were categorised based on the main type of technical scarcity (or scarcities) that they mitigated. In addition, by focussing on the time period that describes a system service or product, the list of products were further categorised. Such a categorisation enabled an assessment of the products to determine if they covered the entire spectrum of technical needs as discussed in D2.1 (EU-SysFlex Consortium, 2018). This gap analysis assessment is discussed in more detail in Chapter 4. It should be noted that there is not always a one to one relationship between a product and a scarcity; some products can mitigate more than one scarcity. Similarly, some scarcities can be mitigated by more than one product.

[2] For more information on the consortium please consult the EU-SysFlex website (http://eu-sysflex.com/consortium/). For more information on the partners involved in WP3, please see ANNEX I.

TABLE 3: KEY PARAMETERS FOR SYSTEM SERVICES WHICH WERE GATHERED FROM THE STATE-OF-THE-ART ASSESSMENT

Parameter	Description	Options/Examples
Type of product	This refers to the high level need for each product	Frequency control, voltage control, congestion management.
Type of event	This relates to the type of event which initiates or requires use of the product to mitigate an issue and the associated scarcity or issue which is resolved due to this product. This will be useful and important information when working with WP2.	Under-frequency following loss of a generator, congestion, system fault, voltage deviation etc.
Scarcity or scarcities that are mitigated	This refers to a specific scarcity or scarcities, that a product can be used to mitigate.	Falling inertia levels, rotor angle instability, congestion etc.
The activation principle	This refers to the manner in which the product is activated.	Inherent response, automatic response or manual activation
Full activation time of the product:	This refers to the period between the event/disturbance and the time the product is fully available/deployed.	2 seconds, 30 second, 90 seconds, 5 minutes, 15 minutes etc.
Required duration of the response	This refers to the time over which the product response must be sustained.	300ms, 10 seconds, 15 minutes, 2 hours, 8 hours etc.
Recovery Period	This refers to the time between the end of the response and the time when the resource can once again provide a response, during which the product is not available. This is usually not applicable for RES and conventional units, may be applied to DR, batteries and other energy limited resources.	10 minutes, 90 minutes, 12 hours etc.
Status of the Product:	This refers to whether the product currently exists, if it is planned for the coming years or whether it is a hypothetical product currently being researched and explored.	No, yes, under trial, an EU-SysFlex demonstration.
Potential procurement options	This refers to the ways in which a product could be procured.	Grid code mandate, market mechanisms, regulated arrangements.
Remuneration Mechanism	How the product is remunerated, if it is an existing product.	Pay-as-bid, pay-as-clear, fixed rate, not remunerated

2.3 QUESTIONNAIRE FOR GENERATION OF INNOVATIVE IDEAS

The aim of the questionnaire was to collect a set of relevant ideas for further detailed discussion during the internal workshop. The questionnaire was created in conjunction with partners from Task 3.2. The goal of the questionnaire was to initiate the discussion on potential characteristics of innovative system services and market architectures, EU-SysFlex Task 3.1 and EU-SysFlex Task 3.2, respectively. The ultimate aim was to utilise the feedback and responses from the questionnaire to fuel the discussion for the workshop.

The questionnaire covered the following subjects:

- Innovative system services and products for (close to) real-time operation of power systems,
- Fundamental steps for product pre-qualification, procurement, activation and settling of system services,
- Cooperation between DSO and TSO to procure and activate these innovative products,
- Novel market-based mechanisms and alternative arrangements for products procurement.

As one of the aims of Task 3.1 and Task 3.2 is to future-proof system service descriptions and market designs to account for future scenarios with very high levels of variable renewable generation, the questionnaire challenged the status quo. The questionnaire was circulated to the sixteen participants of Task 3.1 and Task 3.2. Responses were obtained from fourteen of the participants.

2.4 WORKSHOP TO FACILITIATE DISCUSSIONS AND INTERACTIONS

The questionnaire, available in ANNEX IV of this report, provided the basis for discussion topics and content for the WP3 workshop, which took place in Leuven in December 2018.[3]. The workshop had the following general objectives[4:]

- Specify a comprehensive "basket" of generic products to provide system services,
- Assess the roles and interactions of regulated and deregulated actors for the provision of system services,
- Analyse different options for market design and regulatory frameworks to facilitate innovative system services.

In addition to the general objectives, specific objectives were defined:

- Generate innovative product ideas related to system services,
- Initiate discussions on market design options for different ancillary service products,
- Challenge the product and market design ideas in the context of the EU-SysFlex project,

[3] This workshop was part of work package (WP) 3 activities.
[4] Each objective relates to research tasks in WP3, i.e., 3.1, 3.2 and 3.4, respectively.

- Discuss the interactions between Tasks 3.2 and 3.4,
- Discuss the interaction between WPs 3 and 4.

The workshop approach was built upon the concept of the 'discovery café'5. This is an innovative technique for brainstorming to facilitate discussions and to link ideas within a group. In practice, small sub-groups ware created at multiple tables. Every table discussed a different topic for a set period of time, after which the group rotated to the next table and next topic. Each table had a moderator who recorded all insights. The moderator reported to the entire group at the end of the session. This concept is illustrated in Figure 4.

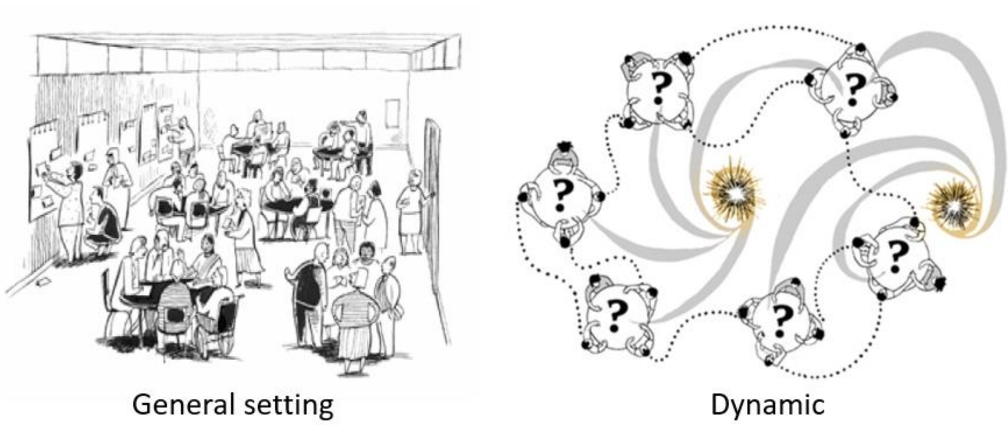

FIGURE 4: WORLD CAFÉ CONCEPT (UPTEST, 2011), (THE WORLD CAFE, 2015)

During the workshop, three break-out sessions were held in the 'discovery café' layout.

- Break-out session 1 focused on the design of a 'super product', covering multiple system needs. Participants were asked to brainstorm on the concept of such a product, on the technical scarcities such a product would cover and on its technical characteristics, while discussing advantages, disadvantages and challenges to be overcome. The "super product" concept is discussed in more detail in Section 4.7.6.

- Break-out session 2 revolved around products and market designs. Four different products were discussed (inertial response, fast frequency response, voltage control and congestion management) in the context of four different market environments (regulated market environment, central market environment, local market environment and peer-to-peer (P2P) market environment). Each of these market environments is discussed in Chapter 5. The participants were asked to set up a list of characteristics of the AS product regarding the procurement and activation of the product, and regarding communication interaction steps between the different market players.

[5] The main purpose of the café was to discover links, observe interactions and discuss ideas, hence the name "discovery café" (The World Cafe, 2015)

- In break-out session 3 participants were asked to contest the findings from the second break-out session from four different perspectives (cross-border interaction, TSO-DSO coordination, data management, and citizen energy communities). Some of the discussion is included in this report in Chapter 5. The remainder of the material will be presented in the report for Task 3.2.

Note that there was also a fourth break-out session. This section focused on how to streamline activities between Tasks 3.2 and 3.4.

3. OVERVIEW OF THE TECHNICAL SCARCITIES

Through a comprehensive review of the literature (EU-SysFlex Consortium, 2018), Task 2.1 of EU-SysFlex identified 6 main categories of technical scarcities, which underpin all of the work that takes place in EU-SysFlex. They will be further investigated through detailed simulation and analysis in WP2. These scarcities and brief summaries are listed in Table 4:

TABLE 4: SUMMARY OF TECHNICAL SCARCITIES FROM EU-SYSFLEX DELIVERABLE 2.1 (EU-SYSFLEX CONSORTIUM, 2018)

Scarcity in System Need	Associated Issues	Why is it Becoming a Scarcity?
Lack of Frequency control	1) Inertia 2) Reserves 3) Ramping	• Reduced amounts of synchronous generation on the system providing inertia and reserve capability means that frequency can vary more quickly in case of power equilibrium incidents and can be less manageable.
Lack of Voltage control	1) Short circuit power 2) Steady state voltage control 3) Dynamic voltage control	• Less synchronous generation available to provide reactive power support. • Reduced short circuit power due to the replacement of synchronous machines and the limited capacity of converters in terms of short-circuit current injection. • Voltage variation effects due to connection of RES in the distribution system.
Rotor angle instability	1) Small signal stability 2) Transient stability	• Less synchronous generation to maintain inertia and stability. Reduction in synchronising torque deteriorates stability margins. • Reduction of transient stability margins due to the displacement of conventional plants. • Introduction of new power oscillation modes. • Reduced damping of existing power oscillations.
Congestion	1) Network hosting capacity 2) RES curtailment 3) Capacity allocation	• Increase in distance between generation and load, and generation variability. • Increased feed-in power (e.g. solar PV plants) and bidirectional power flows noted in distribution networks.
Need for System restoration capability	1) Black-start capability 2) Network reconfiguration 3) Load restoration	• Less black start capable plants on the grid. • Current restoration strategy mainly refers to large synchronous generation.
Reduction in system adequacy	1) Uncertainty of RES generation 2) System interdependencies	• Reduction in load factors and decommissioning of conventional generation driven by penetration of renewables.

3.1 LACK OF FREQUENCY CONTROL

3.1.1 LACK OF SYSTEM INERTIA

System inertia *"characterises the ability of a power system to oppose changes in electric frequency after large and sudden changes in active power production or consumption"* (ESIG, 2019). A potential reduction in system inertia, due to increasing penetration of variable non-synchronous and inverter-based generation resources (e.g., wind, solar, batteries), which do not naturally contribute inertia to the system (ESIG, 2019) and associated displacement of synchronous conventional generation, could lead to two major impacts on system operation: a) large frequency excursion and b) excessive rates of change of frequency (RoCoF).

Following the sudden loss of a generator, interconnector or load, a system with reduced inertia will experience larger magnitudes of frequency excursions. Studies of both the Continental system (EDF R&D Division, 2015) and the Ireland and Northern power system (EirGrid and SONI, 2010) show that situations could arise where the frequency nadir[6] falls and triggers under-frequency load shedding. In some circumstances, it was shown that severe frequency excursions could also result in tripping of under-frequency relays on generation (EirGrid and SONI, 2010). Similarly, according to ESIG (ESIG, 2019), dynamic studies performed recently by ERCOT concluded that the reserve (specifically frequency containment reserve) needed to prevent the system frequency falling below the level that triggers load shedding is dependent on the system inertia.

Falling inertia levels can also result in increased RoCoF following a disturbance. Analysis has shown that the size of contingency that could results in a RoCoF greater than 1Hz/s will decrease as the level of variable renewables increases. As discussed in D2.1 (EU-SysFlex Consortium, 2018), the main issues with high RoCoF is the activation of RoCoF protection settings on generators, loads and other devices, which can lead to greater frequency disturbances.

3.1.2 LACK OF OPERATING RESERVES

Maintaining a stable system frequency is dependent upon controlling the active power balance between generation and demand. With increasing levels of renewables on the power system, it is vital that there is sufficient capability across the power system, and across multiple timeframes to balance active power. The literature has shown that operating reserves are required over timeframes ranging from just a few seconds up to multiple minutes. Indeed, ERCOT found that there is a critical inertia level below which existing frequency response mechanisms are not fast enough to contain the frequency and prevent it from reaching under-frequency load shedding (ESIG, 2019). This concurs with the findings of D2.1 (EU-SysFlex Consortium, 2018), which concludes that inertial response alone will not be sufficient to contain fast frequency deviations in future power systems with high levels of variable renewable generation and fast frequency responses will be essential.

[6] Frequency nadir is one of the boundary conditions for frequency stability analysis. Other conditions are steady-state frequency range and RoCoF. Frequency nadir is the lowest point of the frequency time series.

Another issue noted in the report produced in EU-SysFlex Task 2.1 (EU-SysFlex Consortium, 2018) is that of a voltage dip induced frequency deviation (VDIFD). This phenomenon refers to active power recovery following a voltage disturbance; at high levels of non-synchronous generation a voltage disturbance results in a period of decreased active power output of wind generation in the locality. This sustained period of reduced active power output can result in a supply-demand imbalance and a consequential fall in system frequency.

3.1.3 LACK OF RAMPING RESERVES

In the deliverable from EU-SysFlex Task 2.1 (EU-SysFlex Consortium, 2018), it is noted that many studies have highlighted the need for greater ramping capability in generation portfolios. There are two main drivers of this increased need. Firstly, with the transition to power systems with higher levels of variable RES, there is an increase in intra-hour load following and ramping reserves required due to the variable and uncertain nature of renewable generation. Continued improvements in the accuracy of forecasting are essential in dealing with the uncertainty associated with RES. The variable nature of RES however requires greater ramping capability. Indeed, many renewable integration studies from the United States have indicated that there is an increase in load following (i.e. ramping) requirements as power systems transition to higher levels of variable renewable generation (IEA Wind Task 25, 2009). Similarly, studies of the power system of Continental Europe have demonstrated that there is an increase in the requirement for reserve services due to intra-hour wind variability and uncertainty (ENTSO-E EWIS, 2010).

Secondly, with increasing levels of renewable generation and the associated displacement of conventional generation units, (i.e. gas generators, coal-fired power plants, etc.) there could be a general lack of ramping capability over all the necessary timeframes (NREL, 2013) (NREL, 2016) (EirGrid and SONI, 2010); where ramping capability is the ability to mitigate unforeseen sustained divergences, such as unforecasted wind or solar production changes (Ryan, 2018). Lack of ramping capability is possible even if generation capacity is adequate, necessitating additional resources and new technological solutions. Thus, it is likely that without sufficient ramping capability the system will become increasingly difficult to efficiently and effectively manage variable renewable sources and changes in interconnector flows, while maintaining system security (EirGrid and SONI, 2010).

3.2 LACK OF VOLTAGE CONTROL

The management of voltage on a power system is essential for efficient transmission of electricity. The system voltage is determined by the balance of reactive power production and absorption. Generators have traditionally been a primary source of reactive power, which compensates for the reactive power produced and absorbed by the system load and by the network. In Deliverable 2.1 of EU-SysFlex (EU-SysFlex Consortium, 2018), it is noted that voltage control is becoming more challenging due to the increasing penetration of variable renewable generation and displacement of synchronous generators (which traditionally provided the reactive power required). There is now a greater need to exploit the capability that can be provided by inverter based technologies, such as wind and solar. It has been shown that, without this reactive power capability, used in an efficient manner, system losses would increase, and system security would be compromised (EirGrid and SONI, 2010).

Lack of reactive power capability can manifest itself in the form of voltage ranges being exceeding on grid assets or at grid user connection points. A lack of reactive power is predominately a local phenomenon or local scarcity. However, the management of voltage requires a co-ordinated approach of reactive power control throughout the whole system as deficiencies in a local area at a certain point can have an inordinate impact on other voltages, potentially leading to a system collapse (EirGrid and SONI, 2010).

3.2.1 REDUCTION OF SHORT CIRCUIT POWER

Short circuit power represents the inherent ability of the power system to withstand voltage disturbances. A reduction in short circuit power may lead to non-detection of some faults by certain protection devices, resulting in damage to system assets. Traditionally, this capability has been provided by synchronous generators, however with the displacement of synchronous generation associated with increased penetrations of variable renewable generation, and due to the fact that variable renewable generation resources are typically far away from load centres, this inherent capability is in decline.

3.2.2 LACK OF STEADY STATE VOLTAGE CONTROL

Steady-state voltage control refers to steady-state operation and is concerned with the reactive power management in real-time to account for fluctuations. Depending on the given voltage level (e.g. high voltage, medium voltage, etc.) and the severity and timescale of the fluctuation, a set of reactive power resources may be needed to address it. Maintaining steady voltage profiles is essential for the reliable transmission of electricity and safety of connected devices especially on consumption side (EirGrid and SONI, 2010).

3.2.3 LACK OF DYNAMIC VOLTAGE CONTROL

During a disturbance, voltage stability is strongly influenced by loads in general and in particular by their dynamic behaviour with respect to active and reactive power consumption in response to this disturbance (MIGRATE Consortium, 2016) (Van Custem, 2000). This response is dependent on, amongst others, motor slip adjustments, distribution voltage regulators, tap-changing transformers, thermostats and power electronic control systems in case of PE-interfaced loads (MIGRATE Consortium, 2016) (Van Custem, 2000).

Additionally, as previously mentioned, a voltage dip induced frequency deviation (VDIFD) is another issue that could occur with very high levels of wind generation and refers to active power recovery following a voltage disturbance. A VDIFD event is when a voltage disturbance results in a sustained decrease in the active power output of wind generation in the surrounding area, which subsequently has a negative impact on the system frequency. If not managed, this could result in a significant frequency deviation which leads to load shedding or system collapse.

3.3 ROTOR ANGLE INSTABILITY

Rotor angle stability refers to '*the ability of synchronous machines of a power system to remain in synchronism after being subjected to a disturbance'* (Kundur, 2004). It relates to the ability of each synchronous machine to maintain or restore equilibrium between its electromagnetic and mechanical torque whenever a disturbance occurs.

In steady-state operation, there is equilibrium between the electrical and mechanical torque of a synchronous and hence the machine rotates at a constant speed. However, during disturbances this equilibrium is violated, and therefore there is a consequential acceleration or deceleration of the rotors of the machines. Assuming that one machine may temporarily run faster than another one, the angular position of its rotor in relation to the slower machine will advance, leading to an angular difference (Kundur, 2004). System stability depends on the existence of sufficient synchronising torque and damping torque to reduce this angular difference.

Transient stability is concerned with the ability of a power system to maintain synchronism after a severe disturbance, (EirGrid and SONI, 2010) (MIGRATE Consortium, 2016). At high penetrations of variable renewable generation, the displacement of synchronous generators can reduce the system transient stability margin. Essentially, at high levels of instantaneous penetration of nonsynchronous generation, when there are relatively few conventional (synchronous) units left on the system, the electrical distance between these units is increased. The synchronous torque holding these units together as a single system is therefore weakened, increasing the potential for generators to lose synchronism with the system

3.4 NETWORK CONGESTION

The increase in penetration of non-synchronous renewable generation resources has been shown in the literature in D2.1 (EU-SysFlex Consortium, 2018) to have the potential to cause network congestion and create challenges for transmission and distribution system operators in the form of increased thermal loading and energy losses, and impacting the life cycle asset management (e.g., increasing maintenance costs). Congestions appear when the grid cannot be reinforced in sufficient time, when further grid users are connected or when grid reinforcement is economically not efficient compared to the value of curtailment.

3.5 NEED FOR SYSTEM RESTORATION AND BLACK START CAPABILITY

As power systems transition to higher levels of variable and non-synchronous generation, it is likely that there will be a displacement of the conventional generating units that provide system restoration or black start capability.

It is acknowledged that a black-start generator should have the capability to provide both dynamic frequency and voltage control to alleviate large fluctuations typically expected during system restoration periods (National Grid, 2016). Additionally, a black-start generator should be able to handle instantaneous loading of large demand areas, connection of power islands, etc. progressively leading to whole-system restoration (National Grid, 2016).
With the transition towards a power system with high levels of distributed generation and as more synchronous generators are de-energised, new black-start approaches may need to be developed to ensure that other eligible providers can participate in this process (National Grid, 2017). It could be argued that as black start capability is such a crucial capability and as there are very limited resources that possess this ability, it should be something that is either grid code mandated and/or contracted on a unit by unit basis, not capability that would benefit from being procured via a competitive market. Indeed, the market conditions during system restoration state are greatly different than during normal operations, e.g. there is no freedom to choose provider of electric energy. For these reasons, the assessment and arrangements of such services are out of scope of Task 3.1 in EU-SysFlex. However, exploring the benefit of implementing a competitive tender or an auction to procure black start capability could be considered in Task 3.2.

3.6 REDUCTION IN SYSTEM ADEQUACY

System adequacy refers to the existence of sufficient capacity to meet system demand at all times (Billinton & Allan, 1996). With the transition to power systems with high levels of variable renewable generation the variability and uncertainty associated the non-synchronous renewable resources has an impact on system adequacy, which is compounded by the decommissioning of conventional generating capacity. Capacity markets, or capacity payment mechanisms, is one mitigation option to ensure there is sufficient capacity. It is important to note that it is not enough to have sufficient levels of capacity to meet system demand; the capability and reliability of the portfolio is also crucial to ensure that the technical scarcities are mitigated and the system can be operated reliably and securely. Designing appropriate system services markets is key to this. As the discussion on enhancing market designs falls under the remit of Task 3.2 of EU-SysFlex, it is outside the scope of the work reported in this document; therefore system inadequacy will not be considered further and is included here only for the sake of completeness.

3.7 FROM TECHNICAL SCARCITIES TO SYSTEM SERVICES TO PRODUCT INNOVATION

In order to mitigate the technical scarcities discussed above, the delivery of the necessary services should be supported by the design of the appropriate products and relevant markets. Recent developments in product design have been predominantly focused on the inclusion of new technologies in the provision of existing ancillary services. In future power systems (in the context of EU-SysFlex, power systems in 2030 with more than 50% RES-E) however, for reasons outlined earlier, there may be a requirement for additional innovation in product design or indeed the development of new system services. Innovation in system services should not be considered to only refer to the creation of new products. Innovation can of course be at the level of the products themselves, i.e. in the creation of new products, but innovation can also appear in any step of the process, from changing the parameters of existing products to introducing changes in market organisation or a larger deployment of services already existing in some areas.

Prior to the deregulation of a power system, ancillary services were provided by an integrated utility as part of its normal operations. Back then, these services needed not to be explicitly delineated and monetized (Isenmonger, 2009). The deregulation of power systems brought about changes in many aspects of ancillary services, i.e., how these services are defined, procured, activated and remunerated. More recently, efforts to decarbonize power systems are challenging even more the operational procedures used by system operators to maintain grid reliability.

The main goal of ancillary services is to support the exchange of electricity resulting from competitive wholesale markets with the required degree of quality and safety (Stoft, 2002). Note that during the liberalization process, in Europe, most investments in electricity generation capacity were made on large-scale, fossil-fuelled power generation (Newberry, Pollitt, Ritz, & Strielkowski, 2018). Therefore, operational procedures (including ancillary services) were based on the characteristics of this generation mix. To cope with the advent of non-dispatchable generation, i.e., wind and solar power, system operators are exploring design changes to ancillary services. Non-dispatchable generation, however, is highly uncertain and variable and can result in significant changes in net demand patterns (Villar, Bessa, & Matos, 2018). The increasing uncertainty and variability in power supply and demand observed in many power systems is driving today's needs of system operators (EU-SysFlex Consortium, 2018).

Adaptations to the design of ancillary services seek to enlarge the pool of potential service providers. In recent years, the focus of the research and innovation has been on facilitating non-dispatchable generation, responsive demand and storage capacities to provide these services. For instance, with regard to frequency regulation, studies have shown that different control strategies of wind turbines may be used to provide inertial response and FCR (Kirby, Milligan, & Ela, 2010); (Mokadem, Coutercuisse, Saudemont, Robyns, & Deuse, 2009); (Ramtharan, Jenkins, & Ekanayake, 2007); (MacDowell, Dutta, Richwine, Achilles, & Miller, 2015). For services dealing with voltage control, fault ride-through capability and reactive power support, a number of studies have examined the capabilities of grid-connected solar PV (Milller & Clark, 2010); (Cagnano, Torelli, Alfonzetti, & Tuglie, 2011); (Cagnano, Tuglie, Liserre, & Mastromauro) and energy storage systems (Calderaro, Galdi, Lamberti, & Piccolo, 2015); (Chen, Keyser, Tackett, & Ma, 2011); (Zou, Chen, Xia, He, & Kang, 2015) to provide these services. Moreover, storage and demand response are today active in the provision of FRR in many member states (Smart Energy Demand Coalition, 2017) and likely to play a bigger role as smart active demand and new electrical uses such as electric vehicles are developing.

In the next chapter the list of system services that were identified in the state-of-the art assessment is mapped to the technical scarcities that they mitigate. This enables determination of a set of generic services, as well as providing an indication of where the gaps and limitations of the existing range of products lie and indicates where innovation potential exists. Generic services are high level classifications of system services, where the system services are classified based firstly on the technical scarcity they mitigate and secondly on the timeframe over which they activate. This process is demonstrated in Figure 5. Similarly, the material gathered from the questionnaire (see ANNEX IV of this report) as well as the workshop in Leuven feeds into the discussion on the innovation in system services.

It should be acknowledged, that WP2 of EU-SysFlex has not yet concluded at the time of completion of this report. Therefore the specific analyses, and thus conclusions, in relation to the scale of the technical scarcities and the relative magnitude of the need for each system service are not yet completed. There is no doubt as to the existence of technical scarcities, both in current systems and in future systems, as evidenced by the literature, documented in Task 2.1. However, there is still considerable work to be done in quantifying the scale of the scarcities, the degree to which each service is needed and therefore the volumes of the specific system services that would be required. Thus, Task 3.1 does not make definitive recommendations on the system services and products that are needed in the power systems of the future in each jurisdiction. Instead, Task 3.1 provides a 'basket' or suite of potential products for system services. These services could be utilised to mitigate technical scarcities and could be further developed and enhanced, in conjunction with market design developments, to solve a range of needs. Additionally, these services could be used in parallel with non-market based measures such as network codes or infrastructural investment.

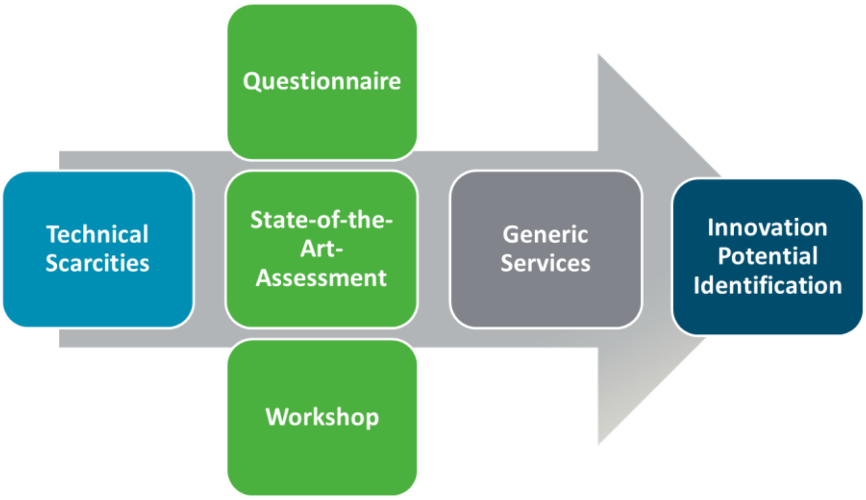

FIGURE 5: OVERVIEW OF STEPS INVOLVED IN GOING FROM TECHNICAL SCARCITIES TO PRODUCT INNOVATION

3.7.1 PARAMETERS IMPORTANT FOR PRODUCT DESIGN

Throughout the work in Task 3.1 a subset of the parameters listed in Table 3 were identified as being necessary to define a service and the associated product from a technical characteristics point of view. These are listed in Table 5. Where applicable, an indication of whether such parameters may affect, or be affected by, regulatory or market settings is provided. These are also the parameters that are being used to define the generic products in Chapter 4 of this report with particular focus on the scarcity which the services mitigate and the timeframe over which the services are activated. Where applicable, additional information pertaining to the activation principle and whether locational information is required is indicated.

TABLE 5: LIST OF SOME CRUCIAL PRODUCT PARAMETERS FOR DESCRIBING GENERIC SYSTEM SERVICES

Parameter	Comments
Technical scarcity	This refers to the high level need for the product. An understanding of the need for a product will influence the type of market structure employed to procure the product.
Type of event	This relates to the type of event which initiates or requires use of the product to mitigate an issue and the associated scarcity or issue which is resolved due to this product. The type of event will also dictate the market structure adopted and specificities of the market design. Specifically the frequency of procurement and the temporal resolution of the market should be linked with the type of product and the type of event that causes the need for a product
Activation principle	This refers to the manner in which the product is activated. If a particular event is likely to be sudden and severe and the product used to mitigate it is likely to be an automatic product that reacts quickly.
Full activation time of the product	This refers to the period between the event or disturbance and the time the product is fully available/deployed.
Geographical location	Location of both service provider and the need for the service. Depending on the service, this information may be vital to include in the market designs.

In designing products, technology neutrality should be a key consideration. There could be a challenge associated with ensuring that emerging service providers are in a position to compete on a level-playing field with conventional service providers. One of the issues in this regard is that new service providers, such as renewables, storage and demand, have different technical characteristics for the parameters listed in Table 5 compared to conventional generation resources. Indeed, it is not possible to replace 1MW of conventional plant with 1 MW of RES or 1 MW of DR etc. In order to foster confidence and certainty for System Operators (SOs) and the wider industry, there will be a need for robust prequalification, demonstrations and pilot projects, as well as detailed power system studies.

Ensuring, or at a minimum encouraging, technology neutrality in system services and in market designs is likely to continue to pose challenges. It was found during Task 3.1 that there currently exist a number of requirements or parameters that may exclude technologies and therefore may hinder technology neutrality. For example, the location and minimum size requirements could specifically hinder distribution connected small-scale generation or demand-side resources from participating. That being said, some systems have begun to amend the rules governing the minimum size of resources that can participate in ancillary services markets (Cappers, Macdonald, & Goldman, 2013). Furthermore, requirements around full activation time and minimum duration of response may impede some resources from entering system services markets, for example those that are energy limited and therefore not in able to sustain a service for the required duration. Similarly, requirements associated with direction and symmetry may preclude certain resources as some technologies favour providing services in one direction over another and so would not qualify to provide services that require symmetry in response (Cappers, Macdonald, & Goldman, 2013). Additionally for certain services and products, controllability by the TSO and/or DSO is a requirement for qualification and the stringent rules around control and telemetry may prevent, for example, some DR resources from participating (Macdonald, Cappers, Callaway, & Kiliccote, 2012).

The need to calculate baselines for demand-side resources (Chuang, 2007) (Cutter, Taylor, Kahrl, & Woo, 2012) is a fundamental challenge to demand response participating in system services markets. Indeed, there are also other very technology specific challenges. Consolidated results of the questionnaire identify the ability of each technology to provide system services, categorising the ability as fully capable, capable but with cost challenges, capable but with technical challenges or not capable. As can be seen from Figure 6, there is a wide range of capability across the variable technologies but the broad consensus from the questionnaire suggests that there is potential for system service provision from a wide range of resources. While these are the general conclusions from the questionnaire, they are indicative only and based on the views and professional experience of the partners from Task 3.1 and Task 3.2, rather than on a detailed assessment of the technical characteristics of the technologies in question. Future technological evolution may result in a change to these findings.

		Frequency Control					Voltage Control			
Technologies	Inertial response	<2	<30	<900	>900	Ramping	Static	Dynamic	Congestion	Short Circuit Current$^{\Delta}$
Conventional thermal generation	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
Wind generation	CC	FC	FC	FC	CC	CC	FC	FC	FC	TC
Solar PV – large scale	CC	CC	CC	CC	CC	CC	FC	FC	FC	TC
Solar PV – residential scale	CC	CC	CC	CC	FC	CC	CC	CC	CC	TC
Demand side – industrial	CC	CC	CC	FC	FC	CC	FC	FC	CC	TC
Demand side – commercial (data centres)	CC	CC	CC	CC	FC	CC	FC	CC	CC	
Demand side – residential	TC	CC	CC	CC	CC	CC	CC	CC	CC	
Flywheels	TC	FC	FC	FC	FC	CC	FC	FC	CC	
HVDC Interconnectors	CC	FC	FC	FC	FC	FC	FC	FC	FC	
Ocean energy devices	CC	FC	FC	CC	CC	FC	FC	FC	FC	
Ultra-capacitors	FC	FC	FC	FC	FC	FC	FC	FC	FC	
Synchronous condensers	FC	CC	CC	CC	CC	CC	FC	FC	CC	FC
Rotational stabilisers	FC	FC	FC	CC	CC	CC	FC	FC	FC	
PV and Storage*	TC	FC	FC	FC	FC	FC	FC	FC	FC	
Demand, Storage and PV*	TC	FC	FC	FC	FC	FC	FC	FC	FC	
Gas turbine and battery storage*	FC	FC	FC	FC	FC	FC	FC	FC	FC	
Batteries		FC	FC	FC	FC	FC	FC	FC		

*Only one entry for each of these technologies
$^{\Delta}$Only one entry for this service

FC	Fully capable	TC	Capable, with technical challenges
CC	Capable, with cost challenges		Not at all capable or no information

FIGURE 6: OVERVIEW OF FINDINGS FROM QUESTIONNAIRE IN RELATION TO THE CAPABILITY OF TECHNOLOGIES

3.7.1 RESILIENCE OF POWER SYSTEMS

Resilience of the power system is important to consider in the design of products for system services and associated markets. Resilience of the power system, as it is being used here, is much more than the ability to withstand and recover quickly from serious events. Resilience is also much more than just reliability. Resilience encapsulates consideration of power quality and adequacy and essentially everything that enables a secure, safe, efficient and reliable power system.

Energy markets, system services and capacity markets all contribute to the overall resilience of the power system. One way to view the difference between "energy", which is the typical view of electricity, and "resilience", is that "energy" is the physical phenomenon from which consumers derive utility, but "resilience" provides the certainty that the consumers will also be able to gain utility from the consumption of electricity, even during a storm or, at a minimum, very soon after.

3.7.2 PUBLIC GOOD CHARACTERISTICS OF ELECTRICITY

Historically, electricity has been considered to be a commodity that was not a necessity and that consumers could be excluded from if they failed to pay their bill. Electricity was also rivalrous in that there were multiple suppliers or that an alternative fuel could be used to heat homes and buildings.

Today, things have vastly changed. In the European Union, access to electricity is considered to be a right and customers should not be disconnected anymore for failing to pay (European Union, 2019). Therefore, electricity is now a non-excludable commodity. Additionally, the resilience of the power system is non-rivalrous; the resilience of the power system for one grid user does not preclude other grid users having a resilient power system; quite the contrary. Either everyone benefits from a resilient power system or no one does. Public lighting, vital medical devices and machines, pumps and safety systems and IT all rely on a resilient power system.

In a resilient power system, through storms and contingencies, the economy still functions and traffic lights work. It is very difficult to live without any electricity. Without electricity for long periods, or even short periods, there can be no clean water (as this relies on pumps) or no gas fired heating (as safety systems are triggered when there is no electrical supply and stop the heating systems). In this context, electricity is now a public good.

System services and associated markets are fundamental to ensuring a resilient power system both now and in the future and, thus, it is vitally important to consider that the non-rivalrous and non-excludable nature of electricity, particularly when designing suitable market arrangements.

4. SYSTEM SERVICES SPECIFICATION

4.1 RESULTS OF THE STATE-OF-THE-ART ASSESSMENT

As discussed earlier, a system service is defined as the physical action, be it the provision of active or reactive power and/or energy, which is needed to mitigate a particular technical scarcity or scarcities. A product, on the other hand, is the “option” that is purchased and remunerated, where the service is what is actually delivered and the service defines exactly what is needed once a particular “option” is called upon.

Over one hundred and twenty different products, or product concepts, were identified during the state-of-the-art assessment. For the complete list, please refer to ANNEX II of this report. These products provided services which varied from those which are legacy services which have been in existence for some time to new and innovative services and concepts at varying stages of development. A number of European Member States are accounted for in the list of products, while additional products and concepts from Australia and the United States of America are also included, as well as the services that will be tested in the demonstration projects as part of EU-SysFlex. That being said however, this list is not exhaustive, but should be at least indicative and representative of the current state-of-play. About 65% of the products for which information was gathered are currently in existence, while the remainder are either service provision or products which are being tested in the demonstrations in EU-SysFlex or are still research concepts.

As part of Task 3.1, the system services and/or products were mapped with the scarcities they mitigate in an attempt to build a complete picture of the available suite of system services and the needs that are not being met. However, it should be noted that there is not always a one to one relationship between the products and the scarcities. Effectively, what this means is that there are some services which can mitigate multiple scarcities and there are scarcities which can be tackled in a number of different ways and with different system services. As expected, the vast majority of the products identified from the state-of-the-art assessment mitigate scarcities associated with frequency control. This can clearly be seen in Figure 7, with about 60% of all products identified falling into the frequency control category. The findings illustrated in Figure 7 concur with the literature review that was performed as part of Task 2.1 and the questionnaire used in this task; that there has been a lot of focus, traditionally, on frequency control services. Traditionally the need for upward response services to manage under-frequency has dominated the suite of system services. However, in recent years more focus has been placed on over-frequency events and consequently on downward reserve services, in conjunction with under-frequency events. In addition, in many countries symmetrical frequency products are now in existence.

Attempts to compare reserve services found that there are huge difficulties associated with comparing definitions (Rebours & Kirschen, 2005). Rebours & Kirschen propose a framework for comparing reserve services focussing on some key characteristics including details on:

- Why a particular type of frequency control is used (e.g. to stabilise and contain the frequency, to bring back or restore the frequency or to restore and replace reserve),

- The timeframe over which the frequency control is activated,
- How the frequency control is achieved (automatically or manually),
- What sources can be used.

The approach that is employed in Task 3.1 aligns closely with the suggested framework by Rebours and Kirschen in that the services are first categorised based on the scarcity that they are used to mitigate (i.e. why a type of frequency control is used) and further categorised based on the full activation time to (i.e. the timeframe over which the frequency control is activated). Furthermore, in the sections that follow, where possible, details relating to how a particular service is activated as well as the type of resources that can be utilised are provided[7].

It should be noted that this categorisation of the products is likely to evolve over time, as the needs of the power system change. Additionally, as alluded to earlier in this report, there is not always a one to one relationship between a product and a scarcity; some products can mitigate more than one scarcity and some products could fall into multiple categories.

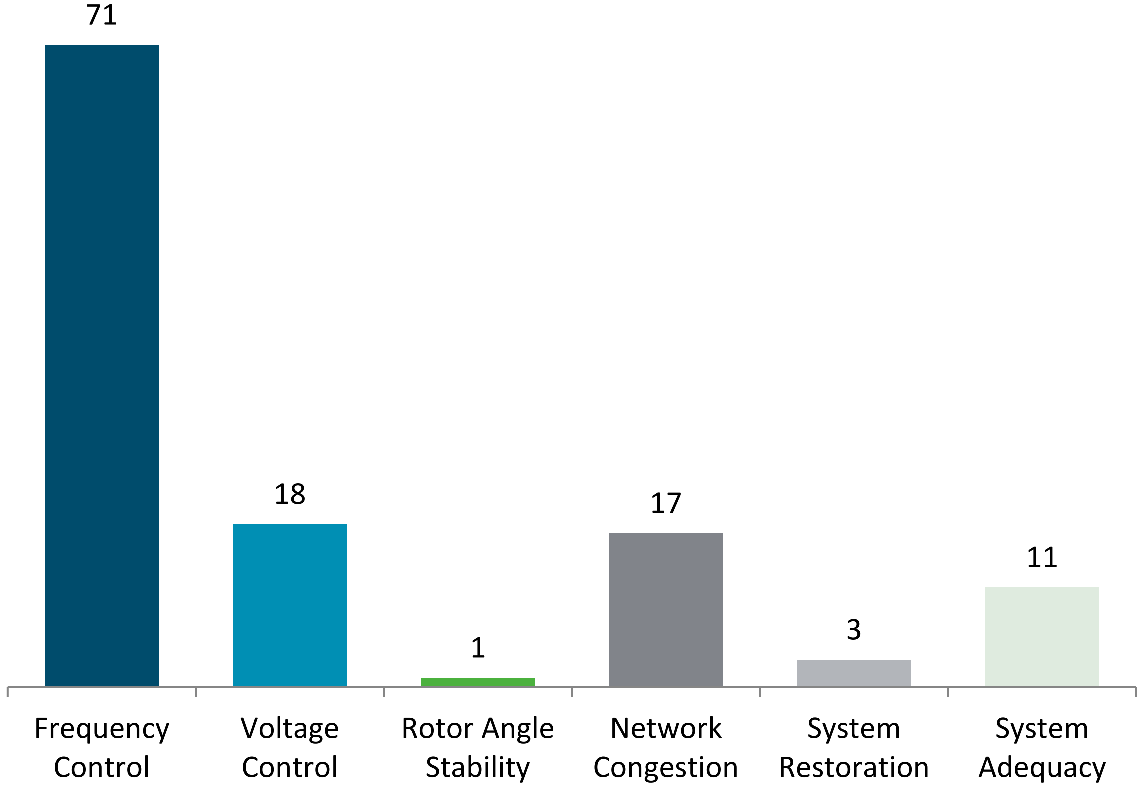

FIGURE 7: MAPPING OF COMPLETE LIST OF ALL SYSTEM SERVICES (OR MARKET- AND GRID CODE- BASED SOLUTIONS) IDENTIFIED (EXISTING SERVICES, NEW SERVICES AND NEW CONCEPTS) WITH THE TECHNICAL SCARCITIES THEY MITIGATE

[7] Not all of the products listed in the database are mentioned at this chapter. This was a result of the fact that some critical information was missing at the time of writing.

By further categorising the products in the frequency control category based on their activation time, another clear trend develops, namely that the bulk of the products fall into the timeframe between 5 seconds and 15 minutes following a disturbance. This is clearly illustrated in Figure 8.

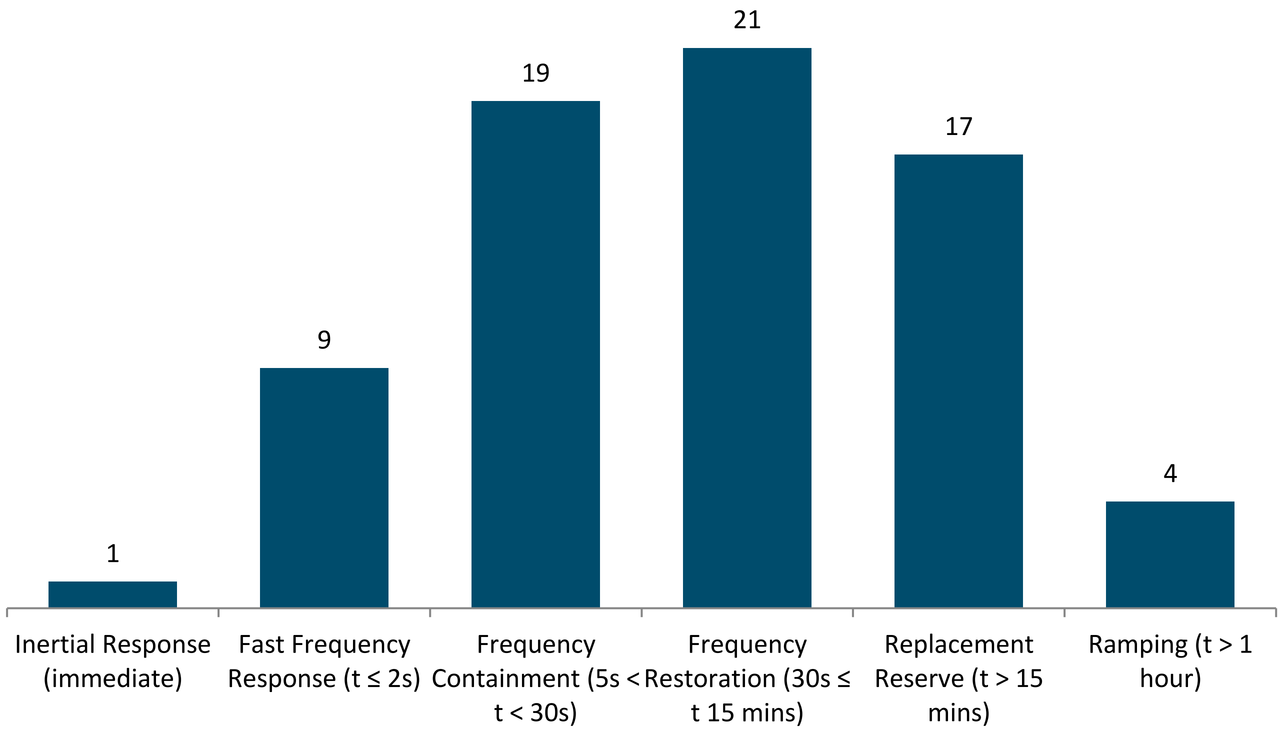

FIGURE 8: CATEGORISATION OF THE COMPLETE LIST OF SYSTEM SERVICES IDENTIFIED (EXISTING SERVICES, NEW SERVICES AND NEW CONCEPTS) IN THE FREQUENCY CONTROL CATEGORY

The next step in the process is to consolidate the list of system services into a suite or basket of services. What follows here is a result of that consolidation process. For each scarcity, a generic, high level description is provided of a service that could be used to mitigate that scarcity, as well as examples of products pertaining to those services. Current experience in relation to each service is indicated and, where relevant, the specificities of the demonstration projects of EU-SysFlex are presented. Where applicable, the commonalities and differences between products in different jurisdictions are discussed. This is important because, while scarcities may be common to some power systems, the strategies (e.g., definition of product and services) to tackle them may not be for reasons due to different generation mixes and operational procedures. Innovation potential and the potential options for changes to current services that could be explored are also presented.

4.2 FREQUENCY CONTROL

TABLE 6: OVERVIEW OF GENERIC SYSTEM SERVICES FOR FREQUENCY CONTROL

Generic System Service	Aim	Timeframe
Inertial Response	Minimise RoCoF	Immediate
Fast Frequency Response (FFR)	Slow time to reach nadir/zenith	<2 secs
Frequency Containment Reserve (FCR)	Contain the frequency	5 secs to 30 secs
Frequency Restoration Reserve (FRR)	Return frequency to nominal	30 secs to 15 mins
Replacement Reserve (RR)	Replace reserves utilised to provide faster products	15 mins to hours

It is recognised that there appears to be a gap between 2 and 5 seconds. Responses faster than 2 seconds can be remunerated via fast frequency response products and faster responses still can also be incentivised (see Section 4.2.2). However, it would seem that there is no incentive for responses that can be activated in the time frame between 2 seconds and 5 seconds. This is something that should be investigated in Task 3.2, in conjunction with information relating to technical scarcities from Work Package 2.

4.2.1 INERTIAL RESPONSE

Service Description: Inertial Response is the response in terms of active power output and synchronising torque that a unit can provide following disturbances. It is available immediately and is typically provided by synchronous generators, synchronous condensers and some synchronous demand loads and is a key determinant of the strength and stability of the power system. The amount of inertial response that can be provided is proportional to the total rotating mass of synchronous generators and turbines and the speed of rotation (Tielens & Van Hertem, 2016).

Current experience: The technical characteristics of inertia are well understood and there is wide experience with utilising inertial response services. The contribution of inertia is an inherent and crucial feature of rotating synchronous generators. Due to electro-mechanical coupling, a generator's rotating mass provides kinetic energy to the grid (or absorbs it from the grid) in case of a frequency deviation (Ulbig, Borsche, & Andersson, 2014). The kinetic energy provided is proportional to the rate of change of frequency (RoCoF) (Kundur, 1994). TSOs have long relied upon the inherent inertial response from synchronous machines for managing power system frequency. Inertia is important for decelerating the RoCoF and allowing more time for active power responses (i.e. the more inertia the system has, the slower the frequency response can be). However, on its own, it is not in a position to contain the frequency of the system.

Even though the technical characteristics of inertia are widely known, there is little experience with the design and procurement of an inertial response product. In Europe, only EirGrid and SONI have defined, procured and currently provide a payment for an inertial response product.

National Grid is currently investigating actions for managing falling inertia levels as they believe it will be a problem in the future. It is, however, unclear at this point in time whether they will tackle the issue by explicitly rewarding the provision of inertia or whether they will mitigate the issue by developing a new frequency response product (National Grid, 2017) and operating the system with lower levels of system inertia. The Nordic TSOs are also looking into solutions for dealing with falling inertia levels using faster frequency reserves (Statnett, FinGrid, Energinet, Svenska Kraftnat, 2018).

Innovation potential: The creation of an inertial response product is an innovation in its own right. This is further discussed in more detail in 4.5.1 below.

Product example: The only case study available is the Synchronous Inertial Response (SIR) introduced in Ireland and Northern Ireland. This is defined as the kinetic energy (at nominal frequency) of a dispatchable synchronous machine multiplied by a factor equal to the ratio of the kinetic energy (KE) (at nominal frequency) to the lowest sustainable MW output at which the unit can operate at while providing reactive power control.

Emulated inertia and synthetic inertia are misnomers. Inertia is a physical property of synchronous units which provides an inherent response to slow the RoCoF, providing time for an active power injection to correct the supply-demand imbalance, but it cannot act to restore power system frequency. In contrast, fast frequency response (and, therefore, emulated and synthetic inertia) is based upon a control system that can be tuned to operate as desired, and can inject active power to correct the imbalance and restore power system frequency. These two services deliver different benefits to the system, and are not directly interchangeable (AEMO, 2017). Fast Frequency Response is discussed next in Section 4.2.2.

4.2.2 FAST FREQUENCY RESPONSE

Service Description: Fast Frequency Response (FFR) refers to a broad range of capabilities and applications (AEMO, 2017) and has a wide range of interpretations based on their applications. It could be defined as "*any type of rapid active power increase or decrease by generation or load, in a timeframe of less than 2 seconds, to correct supply-demand imbalances and assist with managing frequency*" (AEMO, 2017). The service refers to the fast change of active power in the timeframe following inertial response to reduce further deviations of frequency and to further to help delaying the time to reach frequency nadir.

Current experience: Some SOs have already introduced (or are planning to introduce) incentive-based schemes for ensuring sufficient levels of FFR capabilities. EirGrid and SONI and National Grid UK are such examples. ERCOT and New Zealand have a fast demand response service that is essentially a fast frequency response product with a response time of 0.5 seconds and 1 second, respectively (AEMO, 2017). AEMO, the market operator in Australia, is looking at implementing an FFR service (Austrialian Electricity Market Operator, 2017). In other markets, the approach is different- some participants have mandated FFR capability. For example, Hydro-Quebec, Ontario and

Brazil require all wind farms to provide synthetic inertia, with a full response required within 0.5 seconds - 1 second following an event (AEMO, 2017).

EU-SysFlex Demonstration: The French demonstration in WP8 is looking at such a service. In the French demonstration, a wind energy converter will provide emulated inertia. There will be temporarily increases in active power output to the grid following a frequency deviation, by taking energy from the momentum of the wind turbine rotor and converting this to electrical energy. The full activation time is expected to be between 0.5 seconds and 1 second.

Innovation potential: Similar to the inertial response product, an FFR service is novel in its own right. An alternative (and innovative) approach could include 'bundling' FFR with other frequency response products to create a sustained response service, including specified trajectories into the product definition. An additional innovation could be creating products based on grid codes or network codes that incentivise system service providers to go above and beyond the mandatory requirements, such as Fast Post-Fault Active Power Recovery, which will be detailed later in this chapter (see section 4.5.2).

Product examples: Table 7 summarises the types of products that were identified during the state-of-the-art assessment that fall into this 'Fast Frequency Response' category. As can be seen, there are two main scarcities tackled: a) voltage dip inducted frequency deviations (VDIFD) and b) falling system inertia and increased RoCoF.

TABLE 7: SUMMARY OF PRODUCTS IN THE FAST RESPONSE CATEGORY

<table>
<tr><th>Category
(Scarcity Tackled)</th><th>Product Examples from the State of the Art</th><th>Jurisdictions</th></tr>
<tr><td>VDIFD</td><td>Fast Post-Fault Active Power Recovery</td><td>Ireland and Northern Ireland</td></tr>
<tr><td rowspan="7">Falling system inertia,
increased RoCoF,
Frequency deviations</td><td>Fast Frequency Response</td><td>Ireland and Northern Ireland</td></tr>
<tr><td>Enhanced Frequency Response</td><td>United Kingdom</td></tr>
<tr><td>Synthetic inertia</td><td rowspan="3">Under investigation in many jurisdictions</td></tr>
<tr><td>Emulated inertia response</td></tr>
<tr><td>Virtual Inertia</td></tr>
<tr><td>Fast Frequency Response</td><td>Australia</td></tr>
<tr><td>Fast Frequency Response</td><td>ERCOT</td></tr>
</table>

The Fast Frequency Response (FFR) product on the island of Ireland, and Enhanced Frequency Response (EFR) product in Great Britain, are designed to provide a MW response faster than existing Operating Reserve times. Both these services are intended to quickly arrest frequency excursions in the event of a sudden power imbalance. Emulated inertia from wind farms can be considered to be a fast frequency response product. Table 8 compares the various fast frequency response products that were identified in the state-of-the-art assessment. As can be seen, there are many different variations of a fast frequency response product, however, the key parameter that they have in common is the fact that the time to full activation is less than 2 seconds, and in some cases faster responses are either required or incentivised.

Another product which also falls in to this category is Fast Post-Fault Power Recovery (FPFAPR) used on the island of Ireland. This is designed to mitigate the fall in frequency which can be induced by voltage disturbance or voltage dip induced frequency deviation (VDIFD). This service is described in more detail in Section 4.5.2. This type of service is typically needed at very high levels of wind generation. On the island of Ireland, this equates to System Non-Synchronous Penetration (SNSP) levels above 70% and as the current limit on SNSP is 65%, this product has not yet been procured.

TABLE 8: COMPARISON OF PRODUCTS IN THE FAST FREQUENCY RESPONSE CATEGORY

Product Examples	Jurisdictions	Full Activation Time	Required Duration	Providers	Comments
Fast Frequency Response	Ireland & Northern Ireland	2 sec	8 sec	Conventional generators, CH, Biomass, wind farms, batteries, flywheels, PHES, CAES, HVDC ICs, AGUs, DSUs (EirGrid Group, 2017).	There is an incentive for responses faster than 2 seconds. Min and Max provision levels apply.
Enhanced Frequency Response	United Kingdom	1 sec	15 min	Generators, Storage, Aggregated DSR	Providers must be capable of delivering a minimum of 1 MW of response. This may be from a single unit or aggregated from several smaller units. Maximum response of 50MW.
Fast Frequency Response	Australia	Not yet developed.	Not yet developed	Wind providing emulated inertia, wind using pitch control, PV inverter overload, PV set point operation, Batteries, flywheels, supercapacitors, DRS, Aggregators (AEMO, 2017)	In AEMO, FFR is not necessarily a separate service, but rather an alternative way of providing one or more of the frequency services in AEMO (AEMO, 2018).
Fast Frequency Response	ERCOT	0.5 sec	10 min	Load	Load disconnection if frequency drops to 59.7 Hz

4.2.3 OPERATING RESERVE FOR FREQUENCY CONTAINMENT RESERVE

Service Description: This category includes the active power reserves available to contain system frequency after the occurrence of an imbalance. According to the EU Commission (European Commission, 2017), Frequency Containment Reserve (FCR) , in the European Union Internal Electricity Balancing Market, means the active power reserves available for containment of frequency deviations (fluctuations) from nominal system frequency after the occurrence of an imbalance in order to constantly maintain the power balance in the whole synchronously interconnected system. For the purposes of this report, this category has been designated to include operating reserves with an activation time up between 5 and 30 seconds.

Current experience: Evidence of widespread use, as indicated by the large number of products in this category identified in the state-of-the-art assessment (see Table 9). Table 9 compares the various frequency response products that fall into the Frequency Containment Reserve category. There is considerable variation in time to activation between the different products, but they can broadly be categorised into 4 timeframes.

EU-SysFlex Demonstration: The Finnish demonstration will investigate Frequency Containment Reserve. The Portuguese demonstration is utilising a Virtual Power Plant (VPP) to examine the provision of FCR from wind farms. Further information on the details of the demonstrations can be found in the Deliverable for Task 3.3 (EU-SysFlex Consortium, 2018).

Innovation potential:

- Bundling multiple operating reserve products together,
- Including specified trajectories into the product definition,
- Including a dynamic dimensioning of reserve into the requirements,
- Division into upward and downward products.

Product examples:

TABLE 9: SUMMARY OF FREQUENCY PRODUCTS IN THE FREQUENCY CONTAINMENT TIMEFRAME

Category (time to activation)	Product Examples from the State of the Art	Jurisdictions
<5 seconds	Primary Operating Reserve	Ireland & Northern Ireland
Between 5 and 10 seconds	Mandatory Frequency response - Primary Response	United Kingdom
	Mandatory Frequency Response - High frequency response	United Kingdom
	Firm Frequency Response - Primary response	United Kingdom
	Firm Frequency Response - High frequency response	United Kingdom
Between 10 and 15 seconds	Primary Reserve	Spain
	Secondary Operating Reserve	Ireland & Northern Ireland
Between 15 and	Mandatory Frequency response - Secondary response	United Kingdom

30 seconds	Firm Frequency Response - Secondary response	United Kingdom
	Primary Reserve upward - load	Belgium
	Primary Reserve down	Belgium
	R1 symmetrical 100 mHz	Belgium
	Primary Frequency Response	Texas
	Regulation Primaria	Spain
	Regulation Secundaria	Spain
	R1 symmetrical 200 mHz	Belgium
	Frequency Containment Reserves for disturbances	Finland & Sweden
	Frequency Containment Reserve	Poland & CE

Table 10 compares the various frequency response products that fall into the Frequency Containment Reserve category. As can be seen there are many different variations of a Frequency Containment Reserve type product, the key parameter that they have in common is the characteristic that the time to full activation is between 5 seconds and 30 seconds. It is worth noting that the required duration of response varies considerably from jurisdiction to jurisdiction.

What is also noticeable is the wealth of different types of service providers that are qualified or capable of providing Frequency Containment Reserve. For Frequency Containment Reserve, the service providers range from conventional generators to renewable resources and from batteries to industrial loads and residential demand response.

TABLE 10: COMPARISON OF PRODUCTS IN THE FREQUENCY CONTAINMENT CATEGORY

Product Examples	Jurisdictions	Full Activation Time	Required Duration	Service Providers
Primary Operating Reserve	Ireland & Northern Ireland	5 sec	10 sec	Conventional generators, CHP, Biomass, Hydro, wind farms, batteries, flywheels, PHES, CAES, Sync comps, HVDC ICs, AGUs, DSUs (EirGrid Group, 2017).
Mandatory Frequency response - Primary	United Kingdom	10 sec	20 sec	All large power stations connected to the transmission system are obliged to have this capability
Primary Reserve	Spain	15 sec	15 min	Mandatory for all generators
Secondary Operating Reserve	Ireland & Northern Ireland	15 sec	75 sec	Conventional generators, CH, Biomass, Hydro, wind farms, batteries, flywheels, PHES, CAES, Sync comps, HVDC ICs, AGUs, DSUs (EirGrid Group, 2017).
Primary Reserve down	Belgium	30 sec	15 min	Base-load Elia-connected generation and batteries
Primary Reserve upward	Belgium	30 sec	15 min	Large industrial TSO and DSO grid users (via aggregator, including batteries and VPP).
R1 symmetrical 100 & 200 mHz	Belgium	30 sec	15 min	Baseload flexible units
Regulation Primaria	Spain	30 sec	while frequency is outside the range (100 - 200mHz)	Mandatory for all generators
Frequency Containment Reserves for disturbances	Finland & Sweden	30 sec	50% in 5s, 100% in 30s	Producers/consumers, aggregators
Frequency Containment Reserve	Poland	30 sec	Unlimited.	Synchronous power plants
Frequency Containment Reserve	Continental Europe	30 sec	No required for duration, yet specified in SO GL. Likely to be between 15 min and 30 min.	Not specified

4.2.4 OPERATING RESERVE FOR FREQUENCY RESTORATION RESERVE

Service description: According to the European Commission (European Commission, 2017), Frequency Restoration Reserve (FRR) refers to the active power reserves available to restore system frequency to nominal frequency and, for a synchronous area consisting of more than one Load-Frequency Control (LFC) area, to restore power balance to the scheduled value. This category typically includes slower acting reserve products than those in 4.2.3. For the sake of this report, this category of reserve products is seen to include operating reserves with an activation time of the order of minutes, typically between 5 and 15 minutes. It should be noted that Frequency Restoration Reserve can have both automatic and manual activation.

Current experience: Evidence of widespread use, as indicated by the large number of products in this category identified in the state-of-the-art assessment (see Table 11).

EU-SysFlex Demonstration: The Portuguese demonstration is utilising a Virtual Power Plant (VPP) to examine the provision of automatic FRR (aFRR) from wind farms. In addition, the Portuguese FlexHub demonstration, the Finnish demonstration and the Italian demonstration are investigating manual FRR (mFRR). Further information on the details of the demonstrations can be found in the Deliverable for Task 3.3 (EU-SysFlex Consortium, 2018).

Innovation potential:

- Bundling multiple operating reserve products together
- Including specified trajectories into the product definition
- Including a dynamic dimensioning of reserve into the requirements
- Division into upward and downward products

Product examples: Table 11 compares the various frequency response products that fall into the Frequency Restoration Reserve category. There is considerable variation in time to activation between the different products, but they can broadly be categorised into 6 timeframes.

TABLE 11: SUMMARY OF FREQUENCY PRODUCTS IN THE FREQUENCY RESTORATION TIMEFRAME

Category (time to activation)	Product Examples from the State of the Art	Jurisdictions
<90 secs	Tertiary operating reserve 1	Ireland & Northern Ireland
Between 90 and 120 seconds	Automatic Frequency Restoration Reserve	Sweden
Between 120 and 180 seconds	Frequency Containment Reserve for normal operation	Finland
Between 180 and 300 seconds	Tertiary Operating Reserve 2	Ireland & Northern Ireland
	Secondary Reserve	Spain
	Frequency Restoration Reserve	Poland

Between 300 and 450 seconds	aFRR - Frequency Restoration Reserve	Continental Europe
	Secondary Reserve up	Belgium
Between 450 and 900 seconds	Secondary Reserve down	Belgium
	mFRR - manual Frequency Restoration Reserve	Estonia and Continental Europe
	Regulation Terciaria	Spain
	Emergency reserve	Estonia
	mFRR - manual Frequency Restoration Reserve	Finland
	Tertiary Reserve Standard	Belgium
	Tertiary Reserve Flex	Belgium
	Tertiary Reserve with Non-reserved Volumes	Belgium

4.2.5 REPLACEMENT RESERVE

Service description: According to the European Commission (European Commission, 2017), RR refers to the active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including generation reserves. This category typically includes slower acting reserve products, necessary to replace those reserves which have been utilised in the time frame directly following an event. Typically, the reserve products in this category have an activation time longer than 15 minutes.

Current experience: Evidence of widespread use, as indicated by the large number of products in this category identified in the state-of-the-art assessment (see Table 12).

EU-SysFlex Demonstration: The Portuguese FlexHub demonstration, the Italy demonstration and the Finnish demonstration are looking at the provision of active power to provide the RR service. Further information on the details of the demonstrations can be found in the Deliverable for Task 3.3 (EU-SysFlex Consortium, 2018).

Innovation potential:

- Bundling multiple operating reserve products together
- including specified trajectories into the product definition
- including a dynamic dimensioning of reserve into the requirements
- Division into upward and downward products.

Product examples: Table 12 compares the various frequency response products that fall into the Replacement Reserve category. There is considerable variation in time to activation between the different products, but they can broadly be categorised into 4 main timeframes.

TABLE 12: SUMMARY OF FREQUENCY PRODUCTS IN THE REPLACEMENT RESERVE TIME FRAME

Category (time to activation)	Product Examples from the State of the Art	Jurisdictions
<900 seconds	Interruptibility	Spain
	Tertiary Reserve	Spain
Between 900 and 1200 seconds	Replacement Reserve (De-Synchronised)	Ireland & Northern Ireland
	Replacement Reserve (Synchronised	Ireland & Northern Ireland
Between 1200 and 1800 seconds	Replacement Reserves	TERRE
	Deviation Management (Replacement Reserve) (REE)	Spain
	Cross border balancing product (BALIT) (REE)	Spain
	Demand turn up	United Kingdom
Between 1800 and 5400 seconds	BM Start Up	United Kingdom

4.2.6 RAMPING PRODUCTS

Service Description: Ramping is the ability of generation (or demand) to increase or decrease active power output (or consumption) over a specific time horizon for a specific duration in order to maintain supply-demand balance. Ramping reserves oppose unforeseen sustained divergences, such as unforecasted wind or solar production changes (Ryan, 2018). There are two groups within this category: spinning or synchronized services and non-spinning ramping services.

Current experience: TSOs will have specific mechanisms for dealing with system ramping events, but they may not necessarily have distinct products for mitigating sustained deviations. To the best of our knowledge, there is only one system with bespoke ramping products that are used to mitigate technical scarcities associated with unforeseen sustained divergences; the Ireland and Northern Ireland power system. While, other jurisdictions have ramping products, such as CAISO and MISO, these are short time-frame products (usually less than 15 minutes) and the need for them is driven by market design failures rather than technical scarcities or by scarcities on the operating reserve timeframe.

Innovation potential: Potential for a fast ramping product to deal with short-time frame system imbalances caused by high levels of renewables (for example ramp events caused by solar PV variability due to cloud cover) and associated forecasting errors.

Product examples: The new ramping-up service in Ireland and Northern Ireland covers three distinct product time-horizons; one, three and eight hours (see Table 13). Ramping Margin (RM) is defined as the guaranteed margin that a unit provides to the system operator at a point in time for a specific horizon and duration. There are horizons of one, three and eight hours with associated durations of two, five and eight hours respectively. The

Ramping Margin is defined by both the minimum ramp-up and output durations. Thus the Ramping Margin represents the increased MW output that can be delivered by the service horizon time and sustained for the product duration window.

TABLE 13: PRODUCTS IN THE RAMPING CATEGORY

Category (Horizon)	Product Examples from the State of the Art	Jurisdictions
1 hour	Ramping Margin 1 Hour	Ireland & Northern Ireland
3 hours	Ramping Margin 3 Hour	Ireland & Northern Ireland
8 hours	Ramping Margin 8 Hour	Ireland & Northern Ireland

4.3 VOLTAGE CONTROL

As voltage control is a very local phenomena it is crucially important that products addressing this scarcity are both effective and efficient. It should also be noted that prediction of voltage problems day-ahead is difficult especially in meshed grids. There are two broad categories of voltage control system services (see Table 14).

TABLE 14: OVERVIEW OF GENERIC SYSTEM SERVICES FOR VOLTAGE CONTROL

Generic System Service	Aim
Steady State Reactive Power	Voltage control during normal system operation
Dynamic Reactive Power	Voltage control during a system disturbance

4.3.1 STEADY STATE REACTIVE POWER

Service Description: According to European Commission (EU) regulation (European Commission, 2017), Voltage Control refers to the manual or automatic control actions at the generation node, at the end nodes of the AC lines or HVDC systems, on transformers, or other means, designed to maintain the set voltage level or the set value of reactive power. The need for reliable steady-state reactive power (SSRP) control during normal operation is important for the control of system voltages and for the efficient transmission of power around the system. Both synchronous and non-synchronous sources can contribute to this requirement. The need for reactive power varies as demand varies and as the sources of generation vary. Since reactive power is difficult to transmit over long distances (unlike active power), reactive sources are required to be distributed across the system. Thus there is not necessarily a strong link between the need for active power and reactive power from the same sources.

Current experience: Evidence of widespread use and experience, as indicated by the high number of products in Table 15.

EU-SysFlex Demonstration: The German demonstration project will investigate reactive power management by the DSO, for the TSO, while the Italian demonstration will look at voltage support in the MV network as well as voltage control in HV/MV substations. Additionally, the Finnish demo will explore options for implementing a local market for voltage regulation, while the Portuguese demo will similarly investigate a local reactive power market using their FlexHub concept. Further information on the details of the demonstrations can be found in the Deliverable for Task 3.3 (EU-SysFlex Consortium, 2018).

Innovation potential: Permitting demand-side units to provide reactive power services could represent an innovation in steady-state reactive power products. This may require careful design of reactive power products.

Product examples:

TABLE 15: SUMMARY OF STEADY-STATE VOLTAGE PRODUCTS

Category	Product Examples from the State of the Art	Jurisdictions	Comments
Steady-State	Local Voltage Control	Belgium	Local voltage is automatically activated
	Reactive power at EHV/HV interface	EU-SysFlex Demo	Additional material presented in (EU-SysFlex Consortium, 2018)
	Voltage Control in HV/MV substations		
	Local Voltage Support		
	Voltage control	Spain	For renewables, incentives apply to voltage control towards control of cost
	PQ DN flexibility	Concept	Concept introduced in (Silva, et al., 2018)
	Steady-state Reactive Power	Ireland & Northern Ireland	Incentives apply to enhanced delivery
	Centralised Voltage Control	Belgium	Centralized voltage control is manually activated
	Voltage control	Estonia	Centralized voltage control
	Reactive power control	Estonia	Providers include power plants and HVDC links capable of controlling reactive power flow.
	Enhanced Reactive Power Services	United Kingdom	Can be provided by any site that can absorb or inject/generate reactive power, including demand-side providers.
	Obligatory Reactive Power Service	United Kingdom	Obligatory for all grid connected power plants with a capacity greater than 50 MW.

The Steady-state Reactive Power (SSRP) product in Ireland and Northern Ireland is defined for conventional generators as the dispatchable reactive power range in Mvar (Qrange) that can be provided across the full range of active power output (i.e. from minimum generation to maximum generation). For wind farms SSRP is defined as the dispatchable reactive power range in Mvar (Qrange) that can be provided across the active power range from registered capacity down to the higher of 12% of registered capacity or design minimum operating level as defined by the Grid Code for the Ireland and Northern Ireland power system.

The Centralized Voltage Control Service in Belgium requires injection or absorption of reactive power based on a specific set value, as communicated by the TSO, Elia (Elia, 2018). The service provider is expected to react within 5 minutes after reception by Elia of the confirmation message. Once the requested set point value is attained, the service provider must maintain this level until further notice is received. Once a unit is restarted, it may operate at its standard reactive power set value (Elia, 2018).

4.3.2 DYNAMIC REACTIVE POWER PRODUCTS

Service Description: A dynamic reactive response is a reactive power response during disturbances. At high levels of instantaneous penetration of non-synchronous generation there may be relatively few conventional (synchronous) units left on the system and the electrical distance between these units is increased. The synchronous torque holding these units together as a single system is therefore weakened. This can be mitigated by an increase in the dynamic reactive response (DRR) of resources during disturbances. This service is particularly important at high levels of renewable non-synchronous generation.

Current experience: Only one record of such a product exists and that is in Ireland and Northern Ireland. The technical need for DRR is fully recognised and the product has been designed. However, this product is deemed to only be needed at very high levels of wind generation. On the island of Ireland, this equates to System Non-Synchronous Penetration (SNSP) levels above 70% and as the current limit on SNSP is 65%, this product has not yet been procured.

EU-SysFlex Demonstration: The French demonstration in WP8 is looking at such a service by investigating dynamic symmetrical injection of reactive current during low voltage.

Innovation potential: A dynamic reactive power product is an example of a new product and therefore represents an innovation in its own right.

Product examples: Dynamic Reactive Response (DRR) in EirGrid and SONI. This is discussed in more detail in 4.5.3 below. DRR has not yet been procured in Ireland and Northern, as it was only deemed a necessary service at SNSP levels above 70%.

TABLE 16: SUMMARY OF DYNAMIC VOLTAGE PRODUCTS

Category (Type of Voltage Service)	Product Examples from the State of the Art	Jurisdictions
Dynamic	Dynamic Reactive Power	Ireland & Northern Ireland
Dynamic	Dynamic Reactive Current Injection	EU-SysFlex Demo (WP8)

4.4 CONGESTION MANAGEMENT PRODUCT

Service Description: Transmission and distribution constraints often appear in electricity systems. Congestion management relates to managing the ‘traffic’ (flows) on the electricity network and the control actions designed to alleviate the stress on constrained nodes and lines to support power transfers for a set of power transactions (Nappu, Arief, & Bansa, 2014). There are many different approaches for dealing with network congestion, some of which are market-based (e.g. flexibility procurement, dynamic grid tariffs or dynamic connection agreements) as well as network reconfiguration, counter-trading and redispatching. Other approaches could be investment in networks reinforcements and upgrading of regularly constrained lines. However, the long-term costs of conventional measures such as network upgrades, which are typically very expensive, must be compared with the use of service providers to determine the most cost-efficient solution.

Current experience: Widespread experience exists in adapting active power of conventional, large scale generators as part of the re-dispatch process, mainly at transmission level. For that case, regulation is high, meaning that conventional generators must inform the SOs in relation to their re-dispatch potential and the respective opportunity costs in due time. Due to the rise of renewable energies, congestion management is carried out more often at the distribution level as well, primarily as a close-to-real time measure, requested by TSOs or DSOs.

In European zonal markets, congestion is dealt with separately by the TSOs and DSOs. Typically, SOs have access to offers to solve congestion, in some cases as part of the Balancing Market. The value of congestion is location-specific and the development of a uniform product that can be used across a single price zone may prove challenging. It is therefore unsurprising that, as part of the survey undertaken in Task 3.1, no specific congestion management products were identified. However, currently, offers to the MOs by market participants that are typically used for balancing the system are also used for managing congestion in some cases. Indeed, there are a considerable number of existing products for frequency control that can be used today to manage congestion.

Often in today’s wholesale markets, the topology of the network is ignored. For example, a generating unit sells 500MW on the exchange, but the local network can only accommodate 400MW. There then needs to be a mechanism in place to ‘curtail’ part of the volumes sold to allow for secure system operation. At the same time, another participant will need to compensate for the 100MW ‘curtailed’ to ensure supply-demand balance. It is the view of Task 3.1 that consideration of the network is vital in any congestion management mechanism.

Product examples: Though there are very limited numbers of explicit congestion management services, from what can be seen from the assessment undertaken as part of the EU-SysFlex project, resources earmarked for frequency control or voltage control are also being used by some TSOs for congestion management. The following are some examples of services that could be utilised to mitigate or manage congestion:

- **Tertiary Reserve Standard** is a manual service in Elia in Belgium provided within 15 minutes by generation connected at the transmission or distribution grid used to cope with major imbalances and congestion.
- **Tertiary Reserve Flex** is a manual service in Elia in Belgium provided within 15 minutes by load connected at the transmission or distribution grid used to cope with major imbalances and congestion.
- **Tertiary Reserve with non-reserved volumes** is a manual service in Elia in Belgium provided within 15 minutes by generation and load at transmission used to cope with major imbalances and congestion.
- A fast-response product is under development in Estonia and is provisionally called the “congestion management reserve for TSO/DSO – fast” which requires a preparation period of only up to five seconds and is available beginning at 100 kW, whereas its “slow” version requires up to 15 minutes until full delivery and has a minimum size of 1 MW, but can deliver for one hour.
- Another example is the “active power management by DSO for TSO” product of the **German EU-SysFlex demonstrator** which allows the adjustment of schedules day-ahead in 15 minute time intervals, beginning at a size of 100 kW. The **Portuguese EU-SysFlex FlexHub demonstrator** also includes congestion management products for the TSO, which might also be used for restoration reserve: The product is offered to the market operator seven hours before delivery, with a 15 minute time interval and an expected activation time of 5 to 10 minutes.

EU-SysFlex Demonstration: Many of the demonstration projects in EU-SysFlex will investigate congestion management services:

- Active Power management by DSO for TSO (German Demo)
- Reactive Power management by DSO for TSO (German Demo)
- Congestion management (Italian demo)
- Balancing (Italian demo)
- Flexhub P global market (Portuguese Demo)
- Flexhub Q local market (Portuguese Demo)

As can be seen, apart from the bespoke demonstrations that form part of EU-SysFlex, the majority of these products are, at the moment, frequency control products.

Innovation potential: In some power systems, products for congestion management may not exist as such. Thus, the innovation potential lies in the creation of a specific product for congestion management. Any product for congestion management must, by necessity, include pertinent information relating to location. Arrangements for congestion management (and redispatch) are part of a wider set of arrangements relating to network connection, network access and network charging, and these factors need to be considered in defining such arrangements.

Thus, the innovation potential in the area of congestion management lies either in the amendment of existing products for frequency control, incorporating, by necessity, locational aspects or in designing Congestion Management products that are bespoke and uniquely different from frequency control products to address different needs for the process of Congestion Management

4.5 DESCRIPTIONS OF NEW POTENTIAL SYSTEM SERVICES

In what follows, the newly implemented products as well as innovative product ideas, as identified in the previous sections, are described. These include Synchronous Inertial Response (SIR) and Fast Post Fault Active Power Recovery (FPFAPR). While it could be argued that SIR is not a new service, it is already in existence in Ireland, it is an example of a novel service that could potentially be adopted and used more widely in other jurisdictions.

From the discussion above, it can be noticed there are no bespoke existing specific products to mitigate rotor angle instability and congestion management. Of course, other active power and reactive power services can be employed and other mechanisms could be used to manage the scarcities. However, new products, a Dynamic Reactive Response (DRR) product and a Congestion Management product are also defined to mitigate these scarcities. A DRR product has already been developed in Ireland and Northern Ireland, but it has not yet been procured, as it is only deemed a necessary service at SNSP levels above 70%. It should be noted that service requirements similar to the DRR product exist in network codes. Thus, DRR represents an example of defining a product in order to incentivise response that goes above and beyond grid code requirements. Similarly, Fast Post Fault Active Power Recovery has been developed but not yet procured.

4.5.1 SYNCHRONOUS INERTIAL RESPONSE

Synchronous Inertia Response (SIR), as mentioned above in 4.2.1, is defined as the kinetic energy (at nominal frequency) of a dispatchable synchronous generator, dispatchable synchronous condenser or dispatchable synchronous demand load multiplied by the SIR Factor (SIRF). The SIRF of a synchronous generator is the ratio of the kinetic energy (KE) (at nominal frequency) to the lowest sustainable MW output at which the unit can operate at while providing reactive power control. It is based on the commissioned design capability of the plant as determined through appropriate testing procedures. The SIRF has a minimum threshold of 15 seconds and a maximum threshold of 45 seconds. The SIRF for a synchronous condenser or a synchronous demand load that can provide reactive power control is set at 45 seconds. The SIR Volume is calculated by the following formula:

$$SIR_{volume} = KE_{stored} \times (SIRF - 15) \times Unit\ Status$$

$$SIRF = \frac{Stored\ Kinetic\ Energy\ (MWs^2)}{Minimum\ Generation\ (MW)}$$

$$Stored\ Kinetic\ Energy = \ H\ \times MVA\ rating$$

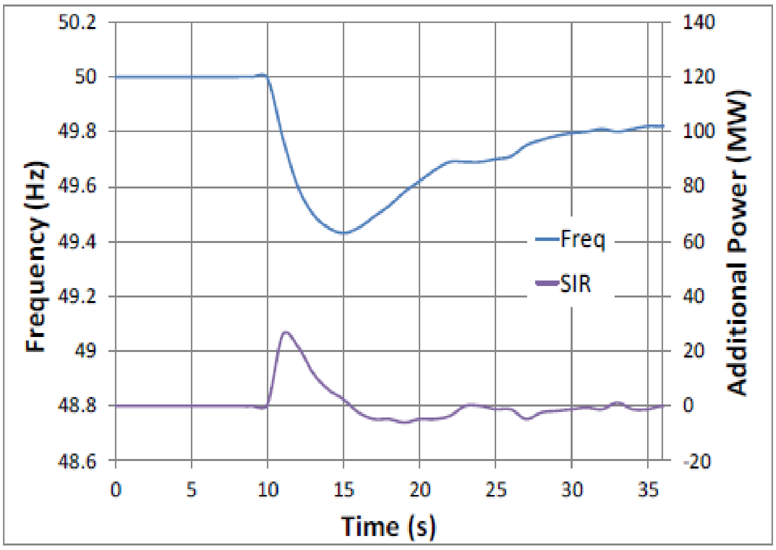

FIGURE 9: ILLUSTRATION OF SIR (EIRGRID AND SONI, 2014)

Through the introduction of this SIRF factor (that is capped at 45 seconds), the SIR product does not simply reward kinetic energy delivered, rather it places additional value on providers able to deliver kinetic energy at low output levels. This provides for an incentive for conventional generators to reduce their minimum stable generation with the highest level of payments available for synchronous condensers (that are in a position to provide inertia at effectively 0MW output).

It should be noted that this specific product was designed to meet the needs of the Ireland and Northern Ireland Power System. Consequently, it may not be directly translatable for implementation in other systems; modifications may be required.

Qualified Technologies: Conventional, centrally dispatched synchronous generators including coal, CCGTs, OCGTs, Waste-to-Energy, CHP, biomass, hydro, peat as well as pumped hydro units, compressed air energy storage and synchronous compensators.

Required Technical Characteristics: Moment of inertia, MVA rating of the unit, stored kinetic energy, minimum generation of the unit, available volume.

4.5.2 FAST POST FAULT ACTIVE POWER RECOVERY

Fast Post-Fault Active Power Recovery is an example of innovation potential in the area of frequency response as identified in section 4.2.2. On the island of Ireland, the Fast Post-Fault Active Power Recovery (FPFAPR) service is deemed to be necessary only at System Non-Synchronous Penetration (SNSP) levels above 70%. As the current limit for SNSP on the Ireland and Northern Ireland power system is 65%, this product has not yet been procured. In other power system, the need for this service may not be as critical as it is for Ireland and Northern Ireland: a case by case analysis would be required.

Units that can recover their MW output quickly following a voltage disturbance (including transmission faults) can mitigate the impact of such disturbances on the system frequency. If a large number of generators do not recover their MW output following a transmission fault, a significant power imbalance can occur, giving rise to a severe frequency transient. The FPFAPR service provides a positive contribution to system security. FPFAPR is defined as having been provided when, for any fault disturbance that is cleared within 900 ms, a plant that is exporting active power to the system recovers its active power to at least 90% of its pre-fault value within 250 ms of the voltage recovering to at least 90% of its pre-fault value (see Figure 10). The service provider must remain connected to the system for at least 15 minutes following the fault. The FPFAPR volume in a settlement period is based on MW output during that period.

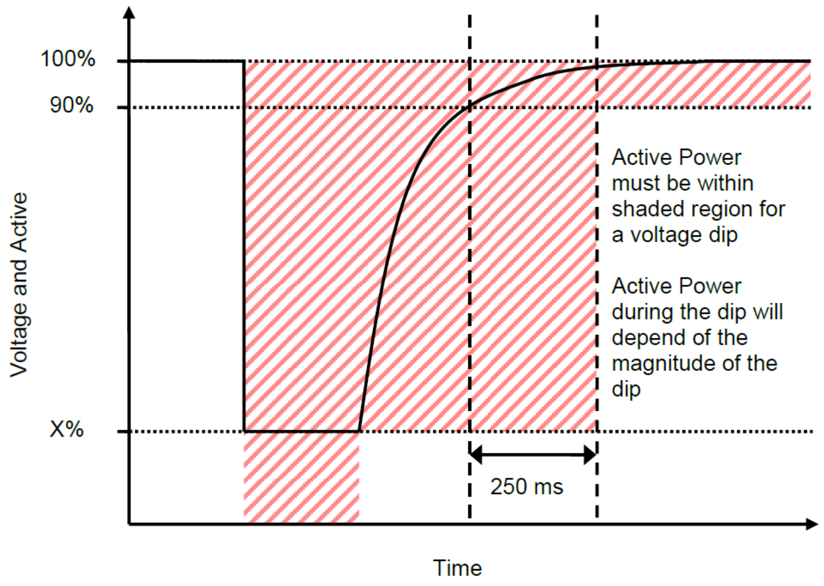

FIGURE 10: FAST POST-FAULT ACTIVE POWER RECOVERY RESPONSE (EIRGRID AND SONI, 2014)

Qualified Technologies: Conventional, centrally dispatched synchronous generators including coal, CCGTs, OCGTs, Waste-to-Energy, CHP, biomass, hydro, peat as well as pumped hydro units, compressed air energy storage, synchronous compensators, batteries, wind turbines, HVDC VSC interconnectors.

4.5.3 DYNAMIC REACTIVE RESPONSE

The DRR service was identified above in section 4.3.2 as a potential innovative product. The DRR product in Ireland and Northern Ireland, illustrated in Figure 11 is defined as the ability of a unit when connected to deliver a reactive current response for voltage dips in excess of 30% that would achieve at least a reactive power in MVAr of 31% of the registered capacity at nominal voltage. The reactive current response must be supplied with a Rise Time no greater than 40 ms and a Settling Time no greater than 300 ms. The volume is based on the unit's registered capacity when connected and capable of providing the required response.

Qualified Technologies: Conventional, centrally dispatched synchronous generators including coal, CCGTs, OCGTs, Waste-to-Energy, CHP, biomass, hydro, peat as well as pumped hydro units, compressed air energy storage, synchronous compensators, wind generators, solid-state batteries, DV VSC interconnection.

Required Technical Characteristics:

- Available volume/MVAr capability, MVA rating of the unit

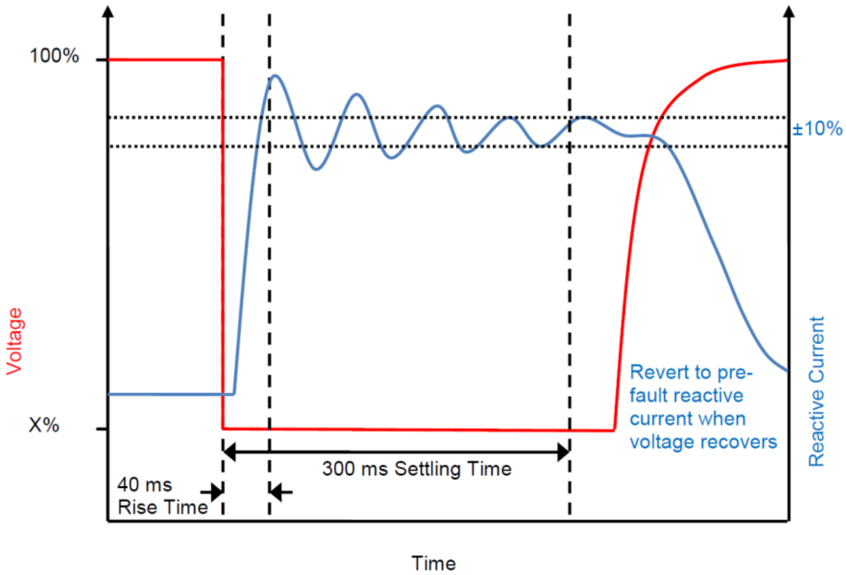

FIGURE 11: DYNAMIC REACTIVE RESPONSE (EIRGRID AND SONI, 2014)

4.5.4 CONGESTION MANAGEMENT PRODUCTS

One way of viewing Congestion Management products (specifically those that are needed for unforeseen situations and need to be activated in a short time-frame (see Table 17)) is that they are special cases of frequency control products, with specific locational aspects. However, there are also situations where congestion is forecastable so that the flexibility selection before and behind the congested assets is a planned process with coordination among SOs. In such a planned process, congestions might also be solved by flexibilities that typically cannot be activated fast enough to qualify for frequency control products.

Similar to frequency control, it was suggested in section 4.4 that perhaps a spectrum of congestion management–related products may be the most ideal approach as the timeframes over which congestion management is required can vary considerably. This potential spectrum of products is outlined in Table 17. Overtime, as the transition to a power system with increasing levels of variable renewables continues and the penetration level of renewables on the distribution network increases, it is easy to see how the need for a congestion product increases and how events that once used to be considered infrequent become part of normal operation. In addition, the availability of flexibility for congestion management purposes might increase with the gradual uptake of the market (driven by system needs), supporting short-term liquidity and resulting in higher procurement of products closer to real-time.

TABLE 17: HIGH-LEVEL OVERVIEW OF POTENTIAL CONGESTION MANAGEMENT PRODUCTS

	Long-term product	Slow Product	Fast Product
Brief Description	Congestion product with long lead time for dealing with regular or permanent congestion	Congestion product for dealing with predictable/forecastable congestion	Emergency congestion management product
Product type	Capacity product and energy product	Capacity product and/or energy product	Capacity product and/or energy product
Event/Situation resulting in need for product/ Origin of congestion	Used to mitigate structural congestion, relied upon as part of the planning process, used as an alternative to network upgrades - changes in demand levels, increased RES penetration.	Used to deal with congestions caused by high-levels of variable renewable generation output. Used to minimise curtailment.	Used to mitigate congestions that are caused by faults and associated remedial actions
System situation type	Normal operation (remedial actions)	Normal operation with high levels of variable renewable generation (remedial actions)	Post-fault/post-contingency
Frequency of occurrence	High/ Happens almost permanently	Medium	Rare
Predictability	Highly predictable	Somewhat predictable or forecastable	Largely unpredictable
Activation Time	Within long-term thermal limits	Not of utmost importance as activation is part of a planned process where	On the order of a few minutes as the time is related to thermal line limits (duration of

		congestion is forecasted.	Temporary Admissible Transmission Loading).
Procurement Timeframe	In line with grid investment horizon	Operational planning timeframe	Close to real-time
Related Balancing Product[8]	RR or perhaps something similar to capacity adequacy procurement	mFRR	aFRR or perhaps faster frequency response products

Perhaps products for congestion management could be differentiated by capacity products and energy products. Irrespective of the timeframe, an energy product is needed to activate congestion management. It could be associated with a capacity product which guarantees the availability of the service. Energy products might be procured from real-time, intraday, day-ahead or even further ahead in case of forecasted congestion problems. In general, products procured closer-to-real time could be energy products while long-term products might be structured as capacity products where the optionality is kept to activate the product when getting closer to real-time.

The frequency of occurrence of the congestion might also impact the decision to have a capacity or an energy product. It should be noted that, for some post-fault remedial actions that do not happen, very often, a capacity product might be a better option, or alternatively, synergies should be found with frequency products (the same product delivering different services) to guarantee that the market is sufficiently liquid.

The market framework of a congestion product could be essentially the same as those used for frequency control products, with some key differences. Firstly, contrary to frequency control products which are only deployed by the TSO, congestion products could be used by both the TSO and DSO. Secondly, if the need for activation of a product is driven by or triggered by congestion, locational information will be required. In contrast to products addressing frequency deviations, congestion products must include local characteristics so that grid operators can assess their physical impact on the congestion.

Another potential requirement may be that these products should be able to be procured day-ahead so that they can be integrated into existing re-dispatch processes and into the coordination process between TSOs and DSOs. Additionally, when including flexibilities with “storage” (electrical, thermal, product, etc.) limitations into re-dispatch processes, their potential shifting time (the phenomena is also addressed as “rebound effect” or “recovery conditions”) must be addressed in the product description so that its activation does not lead to a following counteraction within the congestion timeframe. Since such a timeframe can last for several hours and cannot always be compensated by other resources due to its locational nature, flexibilities might also be selected depending on their maximum shifting time.

[8] This relation only indicates one option of designing congestion management products. Further design options are indicated in the text.

Other differences between congestion management products, such as the minimum size, preparation periods, maximum delivery time and procurement mechanisms also apply to products addressing other scarcities and are not specific to congestion management products. Indeed, this description of products to mitigate congestion management may be considered to be similar to the super-product concept, which is discussed in more detail in Section 4.7.6.Another key difference between frequency control products and the slower acting Congestion Management products would be the proof of provision. Slow Congestion Management could be based on schedules (due to longer possible preparation times and the possibility to forecast activation), whereas for frequency control the last metered point before activation would be sufficient. Furthermore, the Long-Term Congestion Management product could be required in situations where there is forecasted or anticipated congestion, situations when system operators would have a number of mitigation options at their disposal. Consequently, such a Long-Term Congestion Management product would be very different to frequency control products as the requirement and activation of said product would be based on forecasts rather than on coincidence for fast congestion management products.

The ability to implement a fast congestion management product is contingent on the widespread deployment of advanced metering technologies, capable of providing close to real time data, and other advanced SCADA systems. This is to ensure that the most up-to-date network data is available and that locational conditions are observable. However, it is acknowledged that there is a considerable expense associated with this.

Effectively, it can be deduced that there are both similarities and differences between frequency control and congestion management products and further development and assessment is required. Some of this development will continue in Task 3.2, particularly in relation to aligning products and procurement processes. It is also important to consider the potential to utilise service providers that may not qualify to offer slow frequency control products, but may be well placed to over congestion management services.

Qualified Technologies: All technologies capable of adapting their active power output or consumption via an external signal from the system operator (or an aggregator in between) could be capable of providing congestion management services. Effectively, technologies which are qualified to provide frequency response services could also provide congestion management services, as defined here.

Required Technical Characteristics: As mentioned above, congestion products can be viewed as being similar to frequency control products in that both address active power deviations. Thus, as a starting point to developing congestion management products, it can be seen that the product characteristics are similar to those for frequency control products, however, locational information is also vitally important. Additionally, energy limited service providers (i.e DSM and storage) would need to provide futher information relating to their shifting times and other storage characteristics.

4.6 SUMMARY OF THE SUITE OF SYSTEM SERVICES

By combining the newly proposed innovative system services from section 4.5 with the list of generic system services discussed in Sections 4.2, 4.3 and 4.4, the previously identified gaps in the suite if system services are filled. The new, as of yet unprocured, system services are illustrated in Figure 12 with dashed blocks, while the existing consolidated services are illustrated using solid blocks.

Table **18** provides an overview of the generic system services. As can be seen, in the FCR category there are 4 generic service identified, based on the ful time to activation. Similarly, there are 6 generic services in the FRR category and 4 in the RR category.

TABLE 18: BREAKDOWN OF THE BASKET OF GENERIC SYSTEM SERVICES

System Service	Aim	Time to full activation
Inertial Response	Minimise RoCoF	Immediate
Fast Response	Slow time to reach nadir/zenith	<2 secs
	To manage voltage dip induced frequency deviations	<250 ms
Frequency Containment Reserve (FCR)	Contain the frequency	< 5 secs
		5 to 10 secs
		10 to 15 seconds
		15 to 30 seconds
Frequency Restoration Reserve (FRR and mFRR)	Return frequency to nominal	30 to 90 secs
		90 to 120 secs
		120 to 180 secs
		180 to 300 secs
		300 to 450 secs
		450 to 900 secs
Replacement Reserve (RR)	Replace reserves utilised to provide faster products	<900 secs
		900 to 1200 secs
		1200 to 1800 secs
		>5400 secs
Ramping	Oppose unforeseen sustained divergences, such as unforecasted wind or solar production changes	1 hour
		3 hours
		8 hours
Voltage Control - Steady-State	Voltage control during normal system operation	Long or short timeframe for activation
Dynamic Reactive Power	Voltage control during a system disturbance and mitigation of rotor angle instability	<40ms
Congestion Management	Manage congestion that occurs unpredictably as a result of a fault	Could be similar aFRR
	Manage congestion that occurs predictably due to high-levels of RES	Could be similar to mFRR

	Manage congestion as an alternative to network investment	Could be similar to mFRR or RR

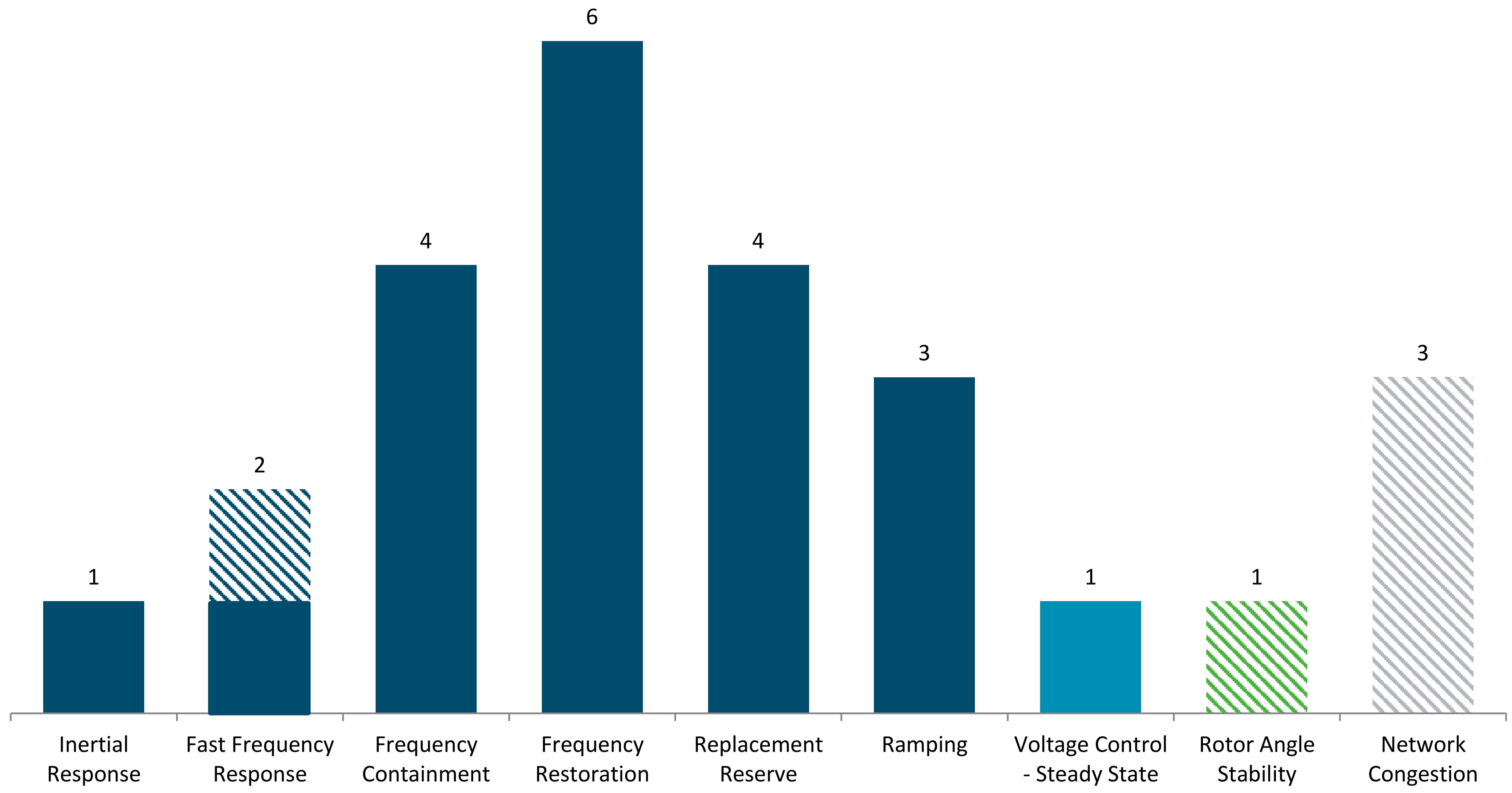

FIGURE 12: SUITE OF SYSTEM SERVICES COVERING THE RANGE OF TECHNICAL SCARCITIES

4.7 OTHER AREAS FOR INNOVATION IN PRODUCT DESIGN

Please note that the discussion on suggested innovation potential that follows here is not exhaustive.

4.7.1 INCLUDING DYNAMIC DIMENSIONING OF RESERVE REQUIREMENTS

As system and grid conditions change from day-to-day (e.g. demand, planned outages, renewable forecasts, etc.), the need for active power reserve changes as well. Therefore there is value in dynamic reserve sizing, i.e. changing the amount of needed and contracted reserves on a daily basis (or weekly / monthly basis) instead of on a yearly basis or having a fixed value.

This is an area that is receiving a lot of interest both in the research (Sprey, Schultheis, & Moser, 2017); (De Vos, et al., 2019) and also in the industry (Elia, 2017) as it offers the potential for cost-savings as well as increased reliability.

4.7.2 ENERGY AND POWER CONSIDERATIONS

Future work could examine the merits of considering not only power requirements in service specifications, but also energy requirements. This is linked to Section 4.7.3.

For services such as FFR, it is necessary that the energy provided (blue area in Figure 13) is greater than the loss of energy from the system (i.e. energy drawn down) in the time frame after the FFR timeframe (green area in Figure 13). Including such requirements in the service specifications assists the TSOs with ensuring that resource providers are assisting with mitigating technical scarcities and not inadvertently exacerbating the issue they set out to rectify.

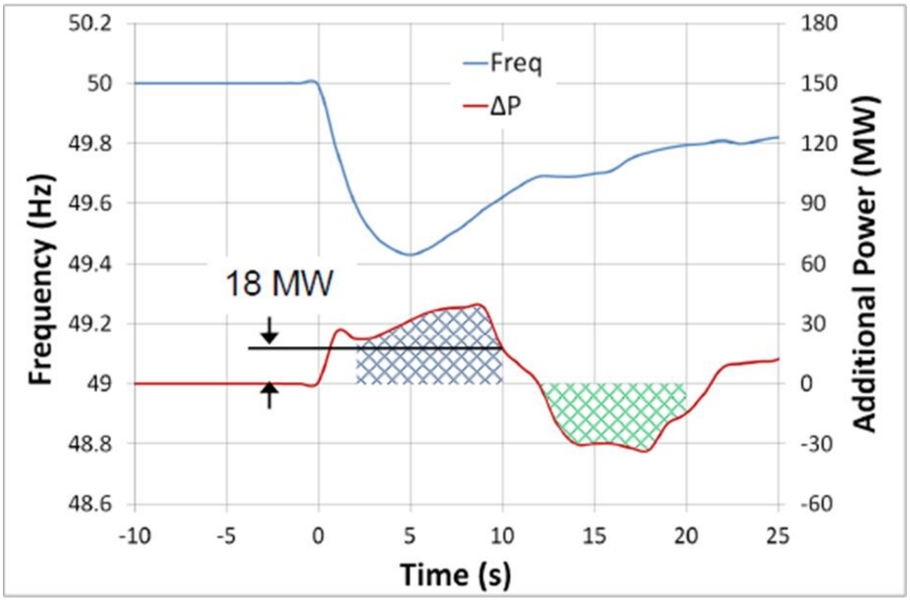

FIGURE 13: EXAMPLE FAST FREQUENCY RESPONSE PROVISION (EIRGRID AND SONI, 2014)

4.7.3 BUILDING SPECIFIED TIMELINES INTO THE REQUIREMENTS

In addition to specifying the time to full activation, it may be beneficial to include details relating to the trajectory or timelines associated with each service. Rebours and Kirschen provide a visualisation of the timing requirements for different frequency control services (Rebours & Kirschen, 2005). There are many ways to meet the requirements of service provision. This type of visualisation may enable new technologies, or indeed aggregations of service providers, to demonstrate their ability to provide services. Such timelines may also be considered for incorporation into service requirements to procure faster responses (see Figure 14 where the bold lines illustrate the minimal service requirements under normal system operating conditions, while the dashed lines illustrate an alternative trajectory for meeting the service requirements under more difficult system operating conditions (Rebours & Kirschen, 2005)).

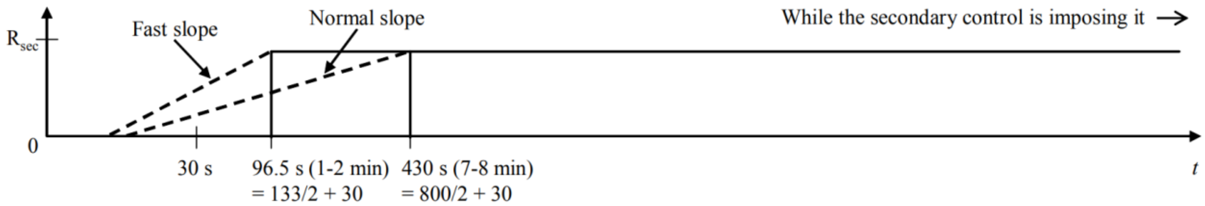

FIGURE 14: TIMELINE FOR SECONDARY RESERVE RTE (REBOURS & KIRSCHEN, 2005)

For example, in EirGrid and SONI the FFR service time period is from 2 to 10 seconds, however, if service providers can reach the FFR volume faster than 2 seconds they will receive a higher tariff.

4.7.4 BUNDLING MULTIPLE OPERATING RESERVE PRODUCTS TOGETHER

Multiple Operating Reserve Products may be bundled together. For example, in the EirGrid and SONI volume capped arrangements, providing units are required to provide 5 frequency services (FFR, POR, SOR, TOR1 and TOR2) and all to the same contracted volume level. The aim of this bundling of services is to provide an element of revenue certainty to new system service providers, thereby enabling entry of new technologies. This would in turn enable provision of services from some of the most cost effective technologies which are capable of meeting the technical requirements.

4.7.5 AGGREGATION OF OUTPUTS TO PROVIDE COMPLIANT RESPONSES

Another manner in which it may be beneficial to enhance product design is to utilise a portfolio-based approach allowing aggregation of different non-compliant resources (because of energy or power constraints) to get a compliant response. This would entail that pre-qualification could be done at the level of the service provision, rather than at the level of the individual devices.

4.7.6 INTRODUCTION TO THE MOTIVATION FOR A SUPER-PRODUCT

As part of the brainstorming sessions, and, in line with the spirit of innovation in System Services product definition and market design, two concepts were developed that mean a departure from the current standard product definitions and way of procurement of System Services. Currently, there are clearly defined products. A provider would need to meet the product requirements in full to be able to provide a specific product – anything less than the strict definitions (for example in terms of speed of response when it comes to frequency response) would mean the provider would be completely excluded. At the same time, a provider that can 'beat' the product definition would neither be rewarded for, nor incentivised to provide such enhanced capability. Our two approaches for re-defining products and procurement are aimed at helping reveal and incentivise such undiscovered capability.

This can be done in two ways:

a) Provider-defined capabilities with TSOs and DSOs choosing the best mix (the 'supermarket' approach): Any attempt to define a common dimension for standard products may inevitably result in a large number of products. This is a direct result of the nature and complexity of system services, and the large numbers of products that exist in the different markets support this view. With a small number of products some providers would be excluded as a result of not meeting a predefined set of criteria. These providers could still be in a position to offer a valuable service and in some cases even help to meet the overall SOs' requirements, potentially even at lower cost. One attractive alternative to SO defined standard products is allowing providers to declare their own capabilities to meet an overall System Services requirement set out by TSOs and DSOs. As providers have very different capabilities and do not conform to one set of standard parameters, it makes sense to be less prescriptive. This could also encourage 'non-standard' providers (demand side resources, pumped storage, compressed air storage and batteries) to compete on an equal footing. Should there then be a need for the determination of a price for some form of granular, standard products (to aid transparency and provide for a price signal), such products could be defined ex-post and be informed by provider capabilities, rather than the other way around – with providers trying to fit into pre-defined structures. This approach has been named the 'supermarket' approach. It is similar to the SOs going into a supermarket without knowing what exact products they want to buy, and shopping around depending on availability, offers and system needs.

b) The 'superproduct' approach: System services providers can typically do more than one of the current standard system services. An obvious example is the provision of different types of frequency response. There is then some scope for defining a very broad 'superproduct' and allowing market participants/portfolios to procure and deliver relevant volumes to TSOs and DSOs through a single provider or an aggregation of providers. Again the pricing for individual sub-products within the 'superproduct' will need to be considered. An example of a superproduct is the FFR-TOR2 procurement that will take place in Ireland and Northern Ireland. This FFR-TOR2 is aimed solely at single providers. It is proposed, however, to allow for aggregators to pull together capabilities from different providers. There is then a similarity with the 'supermarket approach' – by widening the definition of the services needed, there is the potential for more efficient outcomes and discovery of further potential among the different providers. In this second approach, however, the responsibility for such discovery is passed on to aggregators.

5. MARKET ASSESSMENT

5.1 OVERVIEW OF POSSIBLE MARKET ORGANISATIONS

Innovative system services, as presented in the previous chapter, will be used by system operators to mitigate the technical scarcities associated with operating power systems with high levels of variable non-synchronous generation. Dependent on the system services, the processes required to prequalify, procure, activate and settle the products will necessarily differ. The process can be organised according to different market organisations. The roles and responsibilities of both regulated and non-regulated actors will also be different, depending on the market organisation. Indeed, the interactions and corresponding information exchange will also vary.

Although in most countries, DER units can provide some system services, there is still a wide heterogeneity in products and rules across countries (Ramos, Six, & Rivero, 2014); (Gerard, Rivero, & Six, 2016). The results of this task concur with this. Moreover, there is little interaction between system operators in the processes of acquiring these flexibility-based services from the distribution grid (Gerard, Rivero Puente, & Six, 2018). Today, in most cases, the TSO contracts directly resources connected to the distribution grid. In addition, local markets where flexibility-based services could be procured are not yet a reality (Ramos, Six, & Rivero, 2014).

Within EU-SysFlex, four different market structures are assessed. This section is intended to introduce and discuss these possible market structures that are applicable to system services' procurement. These market structures are:

- Centralised market,
- Decentralised market,
- Regulated organisation,
- Distributed market.

In the following section, the general concepts of market organisations, examined within EU-SysFlex, are introduced. High level overviews of each market structure are provided below. Challenges associated with implementing system services and associated markets are touched upon, while topics for future work in Task 3.2 are also indicated. An indicative, preliminary mapping of the various system services with potential market frameworks is provided, laying the groundwork for further analysis in Task 3.2.

5.1.1 CENTRALIZED MARKET ORGANISATION

A centralised market organisation is a market structure that consists of having all flexibility bids and offers optimised from a system perspective in once central marketplace. In the context of system services, this means that all resources from both the distribution grid and the transmission grid will be procured or even jointly optimised within a central marketplace. Buyers and sellers in effect, transact via the central marketplace and not with each other (see Figure 15). The central marketplace could be operated by the TSO, by TSO and DSO or by an independent market operator (MO). The current most frequent utilisation of a centralised market model today is the procurement of system services by the TSO.

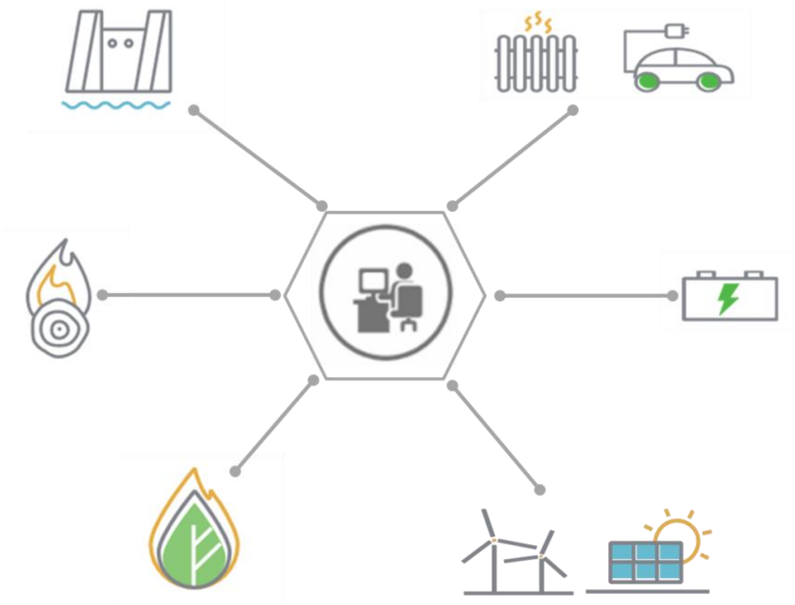

FIGURE 15: REPRESENTATION OF A CENTRALISED MARKET

5.1.2 DECENTRALISED MARKET ORGANISATION

A decentralised market is a market structure that enables TSOs and DSOs to create separate marketplaces where resources from the distribution and transmission grid are procured or even optimised separately. A decentralized market could be defined as a market competing with another market at a different level, for the same service. For example a market at DSO level could compete with a market at TSO level. Resources from the distribution grid are offered first to the decentralised market, on which the DSO has priority to use local resources for local issues. After this first market clearing, the remaining unused bids are transferred by the local market operator (and possibly filtered or aggregated) to the higher market. Therefore, there are two (or could be many) market operators, at least one at the lower level and another one at the higher level (see Figure 16).

For clarity, it must be noted that it is possible to have several decentralized markets organized bottom-up along the grid structure. For simplicity reasons, in this document only two levels (low/high) are defined. A decentralized market could be utilised for mitigating local issues, for instance for procuring a congestion management product or for voltage control products.

For a decentralised market, it is critically important to ensure that there is a sufficient level of liquidity and to limit market power.

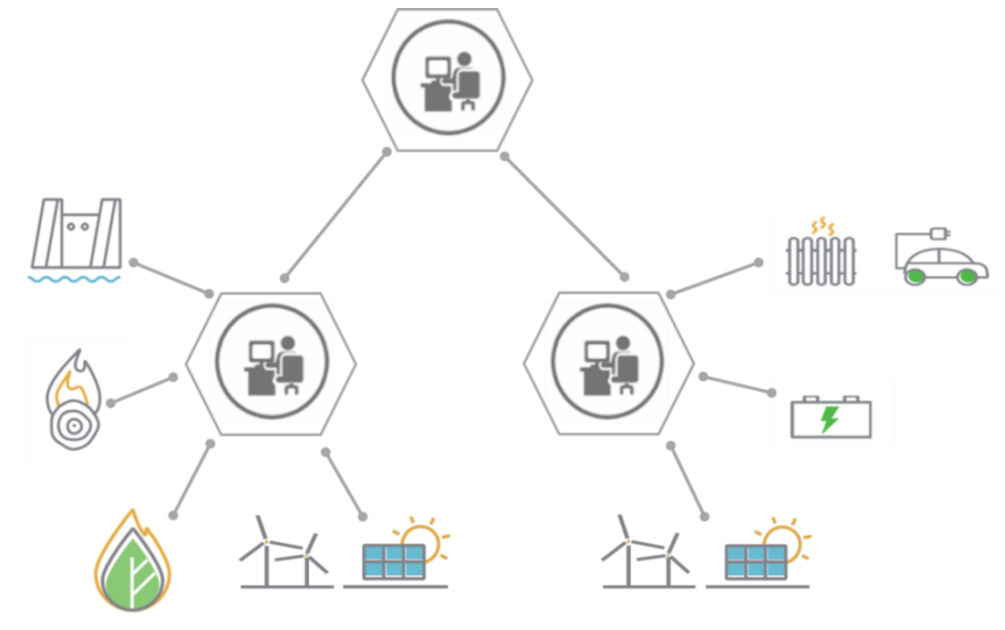

FIGURE 16: REPRESENTATION OF DECENTRALISED MARKETS

5.1.3 REGULATED ARRANGEMENTS[9]

The regulated organisation is simply defined by the absence of a market: the regulator regulates the price for the service. This may be done in a number of ways, including via regulated tariffs, in which included services may be either Grid Code mandated or non-Grid Code mandated. Regulated arrangements may also, for example, include competition(s) for fixed volumes of services in which tenderers submit bids but where the price paid for the service is ultimately limited by a regulatory cap.

Regulated arrangements may be put in place on either an interim or a longer term basis. When a new service is procured for the first time, regulated arrangements may help in providing an initial degree of investor certainty. For example, EirGrid and SONI, the TSOs for the Ireland and Northern Ireland power systems respectively, have implemented regulated arrangements for system services procurement for a defined period with the possibility of moving to competitive auctions in the future. In this case, arrangements have been implemented both for new services not defined in the grid code and for services that have historically been grid code mandated. This was done to encourage behavioural changes, with the ultimate aim of increasing the flexibility of the generating portfolio. Existing units have been incentivised to go above and beyond their grid code obligations and it has provided a signal of future flexibility requirements to investors. As the regulated arrangements are open to all technologies to provide services (where they are technically capable of doing so), non-conventional units including wind turbines and demand side units are now providing services such as reserve for the first time. As regulated tariffs may be subject to change, such arrangements alone are unlikely to provide sufficient investor

[9] Please note that this section refers to regulated tariffs only, not regulation. There could be an aspect of regulation in all market structures.

certainty for investment in new-build units. Other regulated arrangements may be more appropriate in this case. For example, volume limited competitions where a fixed price will be paid for the delivered services for a set period of time to successful bidders and where a lead time for construction is incorporated into the arrangements may be more suitable.

5.1.4 DISTRIBUTED MARKET ORGANISATION

In a distributed market there can be a high number of potential buyers and service providers, often referred to as peers. A peer can be anyone owning or operating an asset or group of assets. All potential active agents in the market can be seen as peers. In a distributed market all peers cooperate with what they have available for trading services (Sousa, et al., 2019). The market price is defined as, or as the result of, the clearing, when existing; in the other cases, an index can be established on bilateral trades' prices.

The advent and rise of Blockchain technology and cryptocurrency have created more opportunities for distributed markets to operate. Through such technology and media, buyers and sellers are afforded a sense of security and trust in transactions without the need for a central exchange/marketplace to monitor and affirm the transactions. Distributed markets can allow for transparency between parties, especially if all parties share mutually agreed upon data and information in the transaction.

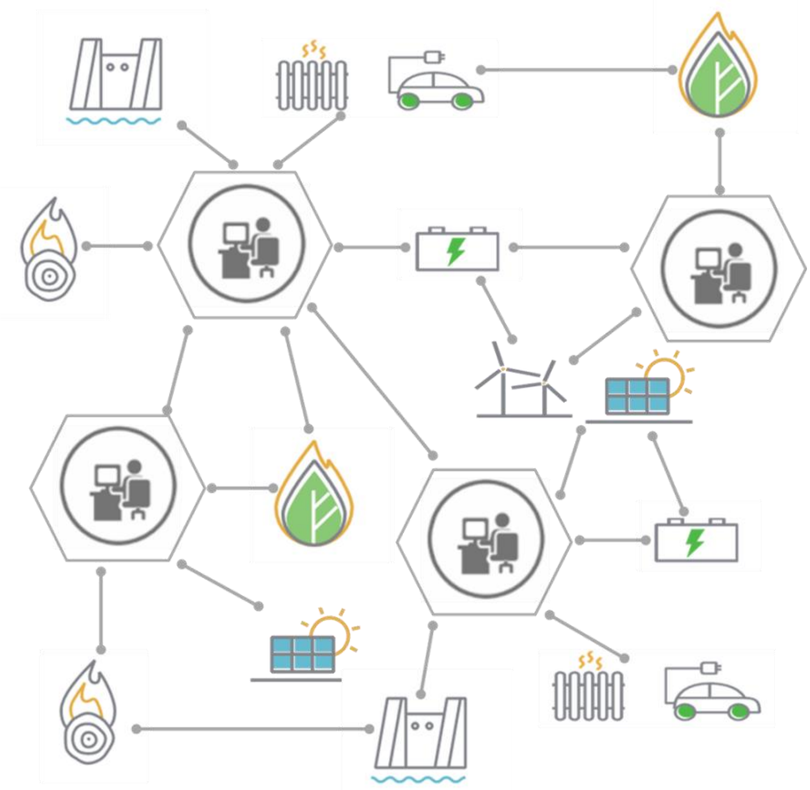

FIGURE 17: REPRESENTION OF A DISTRIBUTED MARKET

5.2 CHALLENGES FOR DESIGNING MARKET ARRANGEMENTS FOR SYSTEM SERVICES

From review of the literature, the results of the questionnaire and the workshop discussions, it is evident that there are a number of challenges that may arise when considering the design of market arrangements for system services in a future power system with very high levels of non-synchronous variable renewable generation. Task 3.1 intends to identify some potential barriers and challenges and to highlight areas of interest for consideration in future work as part of Task 3.2. The assessment within EU-SysFlex (the questionnaire and the workshop) highlighted some important challenges, driven by this transition to a power system with high levels of non-synchronous variable renewable generation. To discuss the challenges associated with designing market arrangements, it is first important to consider the context.

5.2.1 CONTEXT FOR DESIGNING SYSTEM SERVICES MARKETS

Historically, power systems were comprised of large fossil fuel, and hydro, driven synchronous generators (Ulbig, Borsche, & Andersson, 2014). These generators were primarily used to produce electrical energy. However, these generators were also in a position to provide a number of services that are vital for the operation of an AC power system. Utilities ensured that the power plants that were built had sufficient capability to ensure safe and secure operation of the power system. This capability was either as a result of the inherent characteristics of synchronous generators and the laws of physics pertaining to electromagnetism. When utilities were unbundled, the capability of the portfolio was, in effect, a by-product of investing in a generator and ensured that the resilience of the power system was maintained.

In addition, generators were subjected to grid code standards. These grid codes ensured that there was sufficient capability in the generating portfolio to meeting a range of possible issues on the power system. The capability was seen as being provided at the opportunity cost of providing energy. This led to the creation of ancillary services and in some cases capacity markets to offset any losses of revenue incurred in the energy market. The revenue from ancillary service markets was, and still is, typically, a small portion of the overall revenue earned by generators, in comparison with the revenues possible in the energy market. Traditionally, and indeed, when markets were first introduced, remuneration based on marginal pricing of electricity was sufficient to cover the costs of the generator.

With the transition to a power system with greater levels of non-synchronous variable renewable generation, such as wind and solar, it is acknowledged that there will be a downward trend in, or suppression of, the energy market prices (Felder, 2011) and therefore there is potential for the erosion of traditional revenue streams. This is a result of the fact that non-synchronous variable renewable generation are effectively zero or close to zero marginal cost technologies.

Furthermore, the associated displacement of traditional synchronous generation will reveal technical scarcities (as outlined above in Chapter 2 and in the deliverable for Task 2.1 (EU-SysFlex Consortium, 2018)) that will require not only new system services but also provision of new and existing system services from new technologies. Thus, with energy market prices falling, there is a risk that energy markets alone may not provide the right level of revenue certainty or the right signals needed to stimulate investment in new technologies thereby ensuring there is sufficient capability to ensure a secure and resilient future power system (World Energy Council, 2016). Consequentially, and as discussed at the workshop, it will be vital that these new technologies have a route to market and certainty in relation to revenue streams to ensure the appropriate level of investment in capability to ensure that the technical scarcities are addressed. There may be a need to first introduce regulated payments to stimulate investment offering surety to new technology providers, as a step towards competitive markets or competitive auctions or to offer payments to incentivise behaviour that goes above and beyond the requirements outlined in European and national network codes.

5.2.2 THE CORRECT NUMBER OF SERVICES AND THE CORRECT LEVEL OF PAYMENTS

It was agreed during the workshop discussions that the creation of efficient markets for system services could be challenging given the amount of existing and potential new products. It is important that the market designs lead to efficient and effective payment for the correct volume of vital system services. If the right payments are not available there is a risk of insufficient revenue and therefore a knock on effect for investment. It is also vital when designing remuneration mechanisms that sufficient revenue is available for service providers whilst also minimising costs to the end consumer. Since the market defines a market price for each accepted bid that is hence used to settle the remuneration of market parties, a minimum level of competition is required to guarantee that the market price reveals the real cost of the product and is not artificially established. In any way, competition authorities are entitled to cope with market power concerns by lack of liquidity. For this matter, also managing potential gaming situations must be taken into consideration.

5.2.3 WHAT MARKET ARRANGEMENT IS MOST APPROPRIATE?

It is widely acknowledged in the assessment within this task (the questionnaire and the workshop) that the technical scarcities could be tackled by market-based approaches or by non-market approaches, or a combination of the two. Certain scarcities may be best tackled by market-based approaches, while regulation or grid code mandates may be more appropriate for mitigating other scarcities. In the case where grid code requirements already impose some obligations on service provision (for instance on reactive power provision), it is important to assess if there is additional benefit or incentive to be gained through the introduction of a remuneration mechanism. A Regulated Arrangement structure for procurement could be put in place to support grid code requirements where it is deemed that competition would not be sufficient to run a market-based procurement. A Regulated Arrangement could be beneficial in encouraging investment and return on investment certainty to compensate for the cost of the investment. Additionally, a Regulated Arrangement structure is beneficial for encouraging the investment in technologies for which the ability to deliver the service is mandatory (defined by connection requirements). However, providing a sound remuneration is not a static exercise.

TABLE 19: PRELIMINARY MAPPING OF SYSTEM SERVICES WITH MARKET FRAMEWOKRS

System Services	Technical Scarcity	Market Frameworks	Comments
Synchronous Inertial Response	Falling inertia levels, increased RoCoF	Central market Regulated arrangements	As synchronous inertial response is an inherent characteristic of synchronous machines, the procurement of inertia may not be technological neutral. It seems highly sensible that the procurement of inertial response is centralised. This could be via centralised market, as described above or with regulated arrangements.
Frequency Control Services (FFR, FCR, FRR, RR, Ramping)	Lack of Frequency control	Central market Regulated arrangements (Could also use decentralised and distributed market when linked with congestion management products)	As control of frequency is a phenomenon that takes place at the level of the synchronous power system or synchronous area, the management of frequency control should be centralised. Therefore, it seems highly sensible that the procurement of the products to manage frequency is also centralised. This could be via centralised market, as described above or with regulated arrangements. Interactions with the procurement of other active power flexibility products, e.g. for congestion management, must be taken into account.
Steady state voltage control	Lack of Voltage control	Central market Regulated arrangements Decentralised market Distributed market	Unlike frequency, voltage is a local issue and therefore it could be valuable to have a local procurement of voltage control. All market frameworks seem plausible for voltage control type products at this stage in the process.
Congestion management products	Congestion	Central market Regulated arrangements Decentralised market Distributed market	Congestion management covers a lot of different issues from cross-border congestions to local or nodal congestions and different procurement solutions could be adopted. All market frameworks that are suitable for frequency control services seem plausible for congestion management products at this stage in the process.
Dynamic Reactive Response	Lack of Voltage control, rotor angle instability	Central market Regulated arrangements Decentralised market Distributed market	All market frameworks seem plausible for voltage control type products at this stage in the process.

5.2.4 NEED FOR CAREFUL COORDINATION

When flexibilities from the distribution and transmission grid are allowed to participate in a central marketplace, system operators should endeavour to guarantee that both grid constraints from transmission and distribution grid are properly taken into account. The design of markets will need to define the allocation rules of flexibility to the buyers, taking into account the minimisation of costs. In developing centralised markets for congestion management, the roles and responsibilities of DSOs and TSOs must carefully be designed. TSO-DSO coordination will be vital in future power systems to ensure that a) their roles and responsibilities are respected, b) they meet their obligations and objectives and c) barriers to new technologies and new service providers are broken down. Effective co-ordination between TSOs and DSOs will be crucial for ensuring a cost-effective, reliable and resilient power system.

When designing decentralised markets, due consideration must be given to the geographical areas, the voltage levels and the system operators involved in order to efficiently match system services bids and offers. Coordination between various markets should be a key consideration when designing decentralised markets in order to ensure maximum economic efficiency, system and grid security.

In relation to co-ordination between TSO and DSO, there is potential for strides to be made in allowing cost-efficient use of system service providers, on both the transmission and distribution networks, thereby sustainably guaranteeing safe and secure operation of the power system. If, for example, a frequency product is procured using a system service provider in the DSO grid, at a minimum the DSO must be informed with sufficient forward planning. This is necessary to keep the distribution network free of congestion and prevent real time actions by the DSO which could reduce the effectiveness of the frequency product activation. In addition to the need to ensure that the activation of services by different system operators does not lead to counteractions, exploitation of synergies between DSOs and TSOs should be a key consideration to minimize the total costs of flexibility procurement. For example, measures or actions that solve congestions at distribution level might also have a positive impact at transmission level. These mutual benefits should be exploited to increase the total social welfare.

In some countries, there are more than one DSO between high and low voltage; therefore, in addition to greater levels of co-ordination between TSO and DSO, DSO-DSO coordination must be taken into account. Indeed co-ordination and co-operation between TSOs, DSOs and aggregators etc. is critical to well-functioning market frameworks.

5.2.5 CHALLENGES WITH CONGESTION MANAGEMENT

Careful consideration must be given to the design of markets for congestion management products to ensure that sufficient locational information is submitted in the bids. In addition, this information must be carefully utilised and algorithms for selecting bids should consider whether activation of certain bids could cause additional constraints or more congestion. A concept is being trialled in one of the Portuguese demos in EU-SysFlex, where a traffic light system indicates if activation of a particular service causes congestion. A similar topic of discussion that arises when dealing with congestion management: conflicting objectives. This discussion is related to the prospect of using of frequency control products to manage congestion. If the DSO requires activation of a particular service provider to manage, for example, congestion on a distribution feeder but at the same time the TSO seeks to activate a different service provider to mitigate a frequency imbalance which would exacerbate the original congestion on the distribution network, how should such a conflict be resolved? It could be argued that the answer depends on which action results in the greatest overall increase in system benefit or societal welfare. This is far from an easy debate to resolve and is only raised here as a potential roadblock to implementing a congestion management product.

In general, when it comes to congestion, the type of product and the type of timeframe for procurement will depend on multiple factors. Among these factors are the link between the frequency control products in the same market, the frequency of occurrence of the congestion, the liquidity of the different markets, the opportunity costs of grid reinforcement or forced curtailment and effective co-ordination between TSOs, between DSOs and between TSOs and DSOs.

Additionally, implementation of such a market-clearing algorithm with detail representation of the transmission and distribution network is challenging, not only from the point of view of designing such a complex market-clearing algorithm, but also if one considers the amount of real-time information that is required from the transmission and distribution networks. An alternative is the development of marketplaces where the system operators select the appropriate flexibilities for their needs so that the marketplace does not contain grid-related data. In any case, observability of the distribution network in real-time is an issue and results in an increased reliance on the availability of smart meters and SCADA systems.

For technical scarcities that are locational in nature, i.e. congestion and voltage issues, there could be challenges associated with low levels of competition. The lower the voltage level of congestion, the smaller the amount of possible resources that could be available and therefore the smaller the market and the higher the prices. Therefore, the locational nature of some phenomenon creates a need to capture this locational nature in market arrangements. Furthermore, if capability from a lower voltage level is used at a higher voltage level, it must be ensured that activation of this capability does not cause congestions at the lower voltage level. Another challenge is the forecast of exact power flows in meshed grids on a certain line or node e.g. day-ahead. This is because small variations in generation or load could have a high impact on the overall power flows in the network and the congestions on certain lines or nodes could be quite sensitive to changes in power flow

5.2.1 CHALLENGES WITH DATA, TRANSPARENCY AND PROTOCOLS

Additional hurdle with future market designs is the issues associated with transparency of data and the potential for gaming and market manipulation. There is a risk that service providers may be in a position to manipulate or fabricate a situation in which there is congestion on part of the network, thereby creating a need for their services to be activated. Such situations would need to be monitored closely and suggests that there is a need for regulatory involvement in congestion management processes and/or design of markets.

Future work on market designs should consider the merits, both economic and technical, of the various potential solutions. This means that there should be an assessment of the economic efficiency of each option relative to other solutions. This analysis should consider transaction costs, overall society benefit and the necessary incentives to encourage the “right” behaviour and to increase the security of supply. Due consideration should also be given to the roles and responsibilities of the various actors and participants.

Moving towards making full use of the potential of the demand side response for the provision of system services will also continue to be a challenge, and the focus should be placed on revealing this potential. The communications protocols may be an additional challenge, and could end up dictating or limiting the product definitions.

6. CONCLUSIONS

This report provided an overview of the context of the EU-SysFlex project and, more specifically, the key objectives of WP3 and Task 3.1. The work of EU-SysFlex Task 3.1 was summarised, detailing the findings of the state-of-the-art assessment, the questionnaire and the workshop discussions. The process involved in going from technical scarcities to system services and product innovation has also been outlined.

A broad range of system services and products, more than 120, were identified through the use of a state-of-the-art assessment. These products ranged from existing products to products that are under consideration in various jurisdictions and countries, with the varying stages of development accounted for. The products were first categorised based on the main type of technical scarcity (or scarcities) that they mitigated and then based on the time period over which they operate. Not surprisingly, it was found that, traditionally, focus has been on active power and frequency control. It was also noted that, in the existing suite of products, there is huge variety across Europe with a wide range of parameter specifications. This indicates that there may be need for further alignment of products. An effort has been made in this report to consolidate the list of all system services and products from the state-of-the-art assessment and to propose a number of possible generic system services to facilitate meaningful comparison and discussion.

Review of the high-level generic system services descriptions culminated in a basket of system services and revealed some key insights. Firstly, it was found that the existing suite of products predominately addresses current challenges, rather than the future technical scarcities that were identified in EU-SysFlex Task 2.1 and as a result there are some clear gaps. Secondly, it was concluded from the assessment within this task (the questionnaire and the workshop) that the transition to a power system with high levels of variable, non-synchronous renewable generation results in the need, at least in some synchronous areas, for an evolution in system services to encourage and implement faster services and responses. This move towards faster responses might preclude certain technologies from providing such services. For large systems that are less subject to instability, this need assessment requires deeper studies.

New innovative services were then proposed to fill the gaps previously identified. Such innovative services include, Synchronous Inertial Response, Fast Post Fault Active Power Recovery, Dynamic reactive response, Ramping products and Congestion Management products.

Throughout this Task, it has become evidently clear that there is consensus around the specifications for products that are used to mitigate technical scarcities associated with frequency. However, when it comes to challenges such as Congestion Management it is noted that there is still significant work to be completed on determining what the most optimal approach would be. Potential innovations are suggested here, but considerable development is needed. Guidance is required from ENTSO-E, EDSO and regulatory bodies. Indeed, this is very topical at present and an area of on-going discussion and development.

While there have been many recent evolutions in system services, these have mainly focused on the technologies that could provide the services, with less emphasis on the specifications. Future developments in system services could consider enhancing the service specifications by incorporating requirements for energy, as well as power or by building specific timelines into the service definitions and requirements. Fundamental new approaches such as the superproduct and supermarket idea that are presented in this report could completely change the way we approach product development for system services.

It is not sufficient to discuss system services without also touching upon potential market structures that are applicable to system services' procurement. Indeed, for certain services, such as Congestion Management, it has proved difficult to discuss a service without identifying the market design at all. Consequently, market designs for system services are introduced and discussed in this report. The descriptions of the market arrangements provided here require additional discussion and fine-tuning; this will continue in Task 3.2. The four key market organisations considered were Centralised Market, Decentralised Market, Regulated Arrangements and Distributed Market. There are a number of challenges that may arise when considering system services in a future power system with very high levels of non-synchronous variable renewable generation. The challenges identified include falling energy market prices and the fact that energy prices alone may not be sufficient to stimulate investment in new technologies with the required capabilities. The need for greater TSO-DSO coordination was also identified.

The final contribution from the report is an indicative, preliminary mapping of the various system services with potential market frameworks, laying the groundwork for further analysis in Task 3.2. There are multiple market frameworks that could be utilised to procure the basket of system services. At this stage of the process, all market frameworks are plausible options for the majority of the system services, with the exception of synchronous inertial response and frequency control services. The reason these services differ is that the underlying need for them occurs at the system level, ruling out the potential to implement distributed or decentralised markets.

A topic discussed during this task relates to the potential need to introduce regulated arrangements (or simply more regulation in general) for certain products. The need to have an element of regulation is a result of the fact that some system services are so crucial to the secure, prudent and reliable operation of the power system. Therefore, some argue that the procurement of such services should not be left to market forces. This, however, is in conflict with the vision of solving power system challenges via market-based mechanisms. This suggests that there is a need to carefully assess the merits of employing market-based solutions to overcome the technical scarcities challenges at system level against more regulated solutions.

7. COPYRIGHT

Changes in this document will be notified and approved by the PMB. This document will be approved by the PMB.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under EC-GA No 773505.

8. BIBLIOGRAPHY

21st Century Power Partnership. (2015). *Power System of the Future.* Retrieved from https://www.nrel.gov/docs/fy15osti/62611.pdf

AEMO. (2017). *Fast Frequency Response in the NEM.* Retrieved from AEMO: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/FFR-Working-Paper---Final.pdf

AEMO. (2018, March). *Power System Requirements.* Retrieved from AEMO: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf

Austrialian Electricity Market Operator. (2017). Fast Frequency Response in the NEM. Retrieved from https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/FFR-Working-Paper---Final.pdf

Billinton, R., & Allan, R. (1996). *Reliability Evaluation of Power Systems* (2nd ed.). Plenum.

Cagnano, A., Torelli, F., Alfonzetti, F., & Tuglie, E. (2011). Can PV plants provide a reactive power ancillary service?A treat offered by an online controller. *Renewable Energy, 36*.

Cagnano, A., Tuglie, E. D., Liserre, M., & Mastromauro, R. A. (n.d.). Online optimal reactive power control strategy of PV inverters. *IEEE Transactions on Industrial Electronics, 58*.

Calderaro, V., Galdi, V., Lamberti, F., & Piccolo, A. (2015). Co-located storage systems with renewable energy sources for voltage support in distribution networks. *IEEE Power and Energy Society General Meeting*.

California ISO. (2017, September). Discussion on flexible ramping product: Market Surveillance Committee Meeting. Retrieved from https://www.caiso.com/Documents/Discussion_FlexibleRampingProduct.pdf

Cappers, P., Macdonald, J., & Goldman, C. (2013). *Market and Policy Barriers for Demand Response Providing Ancillary Services in US Markets.* US Department of Energy.

Chen, Y., Keyser, M., Tackett, M. H., & Ma, X. (2011). Incorporating short-term stored energy resources into Midwest ISO energy and ancillary service market. *IEEE Transactions on Power Systems, 26*.

Chuang, A. (2007). Demand-side Integration for System Reliability. *Chuang, Advisor. "Demand-side Integration for System Reliability." 2007 IEEE Lausanne Power Tech (2007): 1617-1622.*, 1617-1622.

Cutter, E., Taylor, A., Kahrl, F., & Woo, C. K. (2012). Beyond DR – Maximizing the Value of Responsive Load Limits of the Current DR Paradigms. *ACEEE Summer Study on Energy Efficiency in Buildings*, 77-88.

De Vos, K., Stevens, N., Devolder, O., Papavasiliou, A., Hebb, B., & Matthys-Donnadieu, J. (2019). Dynamic dimensioning approach for operating reserves: Proof of concept in Belgium. *Energy Policy*, 272-285.

EDF R&D Division. (2015). *Technical and Economic Analysis of the European Electricity System with 60% RES.* Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/201406_report_renewables_integration_europe.pdf

EDSO. (2019). *TSO-DSO Report: An Integrated Approach to Active System Management.* Retrieved from https://www.edsoforsmartgrids.eu/wp-content/uploads/2019/04/TSO-DSO_ASM_2019_190304.pdf

EirGrid and SONI. (2010). *All Island TSO Facilitation of Renewables Studies.* Retrieved from http://www.eirgridgroup.com/site-files/library/EirGrid/Facilitation-of-Renewables-Report.pdf

EirGrid and SONI. (2014). *DS3 System Services: Portfolio Capability Analysis.* Retrieved from http://www.eirgrid.ie/site-files/library/EirGrid/DS3-System-Services-Portfolio-Capability-Analysis.pdf

EirGrid Group. (2017, December 13). *DS3 System Services Proven Technology List.* Retrieved from EirGrid Group - DS3 System Services: http://www.eirgridgroup.com/site-files/library/EirGrid/DS3-System-Services-Proven-Technology-Types.pdf

Elia. (2017). *DYNAMIC DIMENSIONING OF THE FRR NEEDS*. Retrieved from Elia: https://www.elia.be/en/users-group/Working-Group_Balancing/Projects-and-Publications/Dynamic-dimensioning-of-FRR-needs

Elia. (2018). *Study on the future design of the ancillary service of voltage and reactive power control.* Retrieved from http://www.elia.be/~/media/files/Elia/publications-2/Public-Consultation/2018/20181107_Study-Report-post-consultation-no-TC.pdf

ENTSO-E. (2016). *Explanatory note DA FB CC methodology for Core CCR.* Retrieved from https://consultations.entsoe.eu/markets/core-da-ccm/user_uploads/explanatory-note-for-core-da-fb-cc-public-consultation_fv.pdf

ENTSO-E. (2017). *Manually Activated Reserves Initiative*. Retrieved from ENTSO-E: https://www.entsoe.eu/network_codes/eb/mari/

ENTSO-E. (2018, November). *TERRE*. Retrieved from ENTSO-E: https://www.entsoe.eu/network_codes/eb/terre/

ENTSO-E EWIS. (2010, March 31). *European Wind Integration Study - Towards a successful integration of large scale wind power into European electricity grids - Final report.* Retrieved from http://www.wind-integration.eu/downloads/library/EWIS_Final_Report.pdf

ENTSO-E. (n.d.). *PICASSO*. Retrieved from ENTSO-E: https://www.entsoe.eu/network_codes/eb/picasso/

ESIG. (2019, March 12). *Implementation of Inertia Monitoring in ERCOT – What's It All About?* Retrieved from Energy Systems Integration Group: https://www.esig.energy/implementation-of-inertia-monitoring-in-ercot-whats-it-all-about/

European Commission. (2017). *COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation.* Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:32017R1485

European Union. (2019). *Access to and use of energy services*. Retrieved from European Union: https://europa.eu/youreurope/citizens/consumers/energy-supply/access-use-energy-services/index_en.htm

EU-SysFlex Consortium. (2018). *State-of-the-Art Literature Review of System Scarcities at High Levels of Renewable Generation: Deliverable 2.1.* Retrieved from http://eu-sysflex.com/wp-content/uploads/2018/12/D2.1_State-of-the-Art_Literature_Review_of_System_Scarcities_at_High_Levels_of_Renewable_Generation_V1.pdf

EU-SysFlex Consortium. (2018). *T3.3 Business Use Cases for Innovative System Services.* Retrieved from http://eu-sysflex.com/wp-content/uploads/2019/03/D3.3_Business-Use-Cases-for-Innovative-System-Services.pdf

Felder, F. A. (2011). Examining Electricity Price Suppression Due to Renewable Resources and Other Grid Investments. *The Electricity Journal, 24*(4). doi:https://doi.org/10.1016/j.tej.2011.04.001.

Gerard, H., Rivero Puente, E. I., & Six, D. (2018). Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework. *Utilities Policy, 50*, 40-48. doi:https://doi.org/10.1016/j.jup.2017.09.011

Gerard, H., Rivero, E., & Six, D. (2016). Basic Schemes for TSO-DSO Co-ordination and Ancillary Services Provision. *Technical Report Number D1.3 SmartNet project*.

IEA Wind Task 25. (2009). *Design and operation of power systems with large amounts of wind power - Final report Phase One 2006-08.* Retrieved from http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2493.pdf

Isenmonger, A. G. (2009). The evolving design of RTO ancillary service markets. *Energy Policy, 37*, 150-157. doi:https://doi.org/10.1016/j.enpol.2008.06.033

Kirby, B., Milligan, M., & Ela, E. (2010). *Providing minute-to-minute regulation from wind plants.* Retrieved from www.nrel.gov/docs/fy11osti/48971.pdf

Kundur, P. (1994). *Power System Stability and Control.* New York: McGraw-Hill.

Kundur, P. (2004). Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. *IEEE Transactions on Power Systems*.

Macdonald, J., Cappers, P., Callaway, D. S., & Kiliccote, S. (2012). Demand response providing ancillary services: A comparison of opportunities and challenges in US wholesale markets. *Grid-Interop*.

MacDowell, J., Dutta, S., Richwine, M., Achilles, S., & Miller, N. (2015). Serving the future: advanced wind generation technology supports ancillary services. *IEEE Power Energy Magazine, 13*.

MIGRATE Consortium. (2016). *Massive InteGRATion of Power Electronic Devices - Deliverable D1.1 Report on system issues.* Retrieved from https://www.h2020-migrate.eu/_Resources/Persistent/9bf78fc978e534f6393afb1f8510db86e56a1177/MIGRATE_D1.1_final_TenneT.pdf

Milller, N., & Clark, K. (2010). Advanced controls enable wind plants to provide ancillary services. *IEEE Power and Energy Society General Meeting*.

Mokadem, M. E., Coutercuisse, V., Saudemont, C., Robyns, B., & Deuse, J. (2009). Experimental study of variable speed wind generator contribution to primary frequency control. *Renewable Energy, 34*.

Nappu, M. B., Arief, A., & Bansa, R. C. (2014). Transmission management for congested power system: A review of concepts, technical challenges and development of a new methodology. *Renewable and Sustainable Energy Reviews*. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032114004237

National Grid. (2016). *System Operability Framework.*

National Grid. (2017, June). *System Needs and Product Strategy.* Retrieved from National Grid: https://www.nationalgrideso.com/document/84261/download

National Grid. (2017). *Systems Needs and Product Strategy.*

Newberry, D., Pollitt, M., Ritz, R., & Strielkowski, R. (2018). Market design for a high-renewables European electricity system. *Renewable and Sustainable Energy Reviews, 91*, 695-707. doi:https://doi.irg/10/gdq9x4

NREL. (2013). *Western Wind and Solar Intergration Study Phase 2: Executive Summary.* Retrieved from https://www.nrel.gov/docs/fy13osti/58798.pdf

NREL. (2016). *Eastern Renewable Generation Integration Study.* Retrieved from https://www.nrel.gov/docs/fy16osti/64472.pdf

Ramos, A., Six, D., & Rivero, E. (2014). Evaluation of Current Market Architectures and Regulatory Frameworks and the Role of DSOs. *Technical Report Number D1.2 EvolvDSO Project*.

Ramtharan, G., Jenkins, N., & Ekanayake, J. (2007). Frequency support from doubly fed induction generator wind turbines. *IET Renewable Power Generation*.

Rebours, Y., & Kirschen, D. (2005). *A Survery of Definitions and Specifications of Reserve Services.* University of Manchester. Retrieved from https://labs.ece.uw.edu/real/Library/Reports/Survey_of_Reserve_Services.pdf

Ryan, J. (2018, May). Power Production and Reserve Scheduling in Unit Commitment Models. *PhD Thesis*. University College Dublin.

SEM Committee. (2013). *DS3 System Services Technical Definitions - Decision Paper.* Retrieved from https://www.semcommittee.com/sites/semcommittee.com/files/media-files/SEM-13-098%20%20DS3%20System%20Services%20Technical%20Definitions%20Decision%20Paper%20-%20FINAL_1.pdf

Silva, J., Sumaili, J., Bessa, R. J., Seca, L., Matos, M., & Miranda, V. (2018). The challenges of estimating the impact of distributed energy resources flexibility on the TSO/DSO boundary node operating points. *Computers & Operations Research, 96*, 294-304.

Smart Energy Demand Coalition. (2017). *Explicit Demand Response in Europe - Mapping the Market.*

Sousa, T., Soares, T., Pinson, P., Moret, F., Baroche, T., & Sorin, E. (2019). Peer-to-peer and community-based markets: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 367-378. doi:https://doi.org/10.1016/j.rser.2019.01.036.

Sprey, J. D., Schultheis, P., & Moser, A. (2017). Dynamic dimensioning of balancing reserve. *14th International Conference on the European Energy Market.* Dresden.

Statnett, FinGrid, Energinet, Svenska Kraftnat. (2018). *The Way Forward - Solutions for a changing Nordic power system.* Retrieved from https://www.fingrid.fi/globalassets/dokumentit/fi/tiedotteet/sahkomarkkinat/2018/the-way-forward---solutions-for-a-changing-nordic-power-system.pdf

Stoft, S. (2002). *Power System Economics: Designing Markets for Electricity.* Piscataway, NJ: IEEE Press; Wiley-Interscience.

The World Cafe. (2015). Retrieved from https://mejorimagen.eu/the-world-cafe.html

Tielens, P., & Van Hertem, D. (2016). The relevance of inertia in power systems. *Renewable and Sustainable Energy Reviews*.

Ulbig, A., Borsche, T. S., & Andersson, G. (2014). Impact of Low Rotational Inertia on Power System Stability and Operation. *IFAC Proceedings Volumes, 47*(9), 7290-7297.

UpTest. (2011). Retrieved from https://uptest.wordpress.com/2011/08/07/open-space-ahora-soy-un-nuevo-facilitador-oficial/

US Department of Energy. (2018, March). *Annual U.S. Transmission Data Review.* Retrieved from https://www.energy.gov/sites/prod/files/2018/03/f49/2018%20Transmission%20Data%20Review%20FINAL.pdf

Van Custem, T. (2000). Voltage Instability: Phenomenon, countermeasures and analysis methods. *IEEE Proceedings*.

Villar, J., Bessa, R., & Matos, M. (2018). Flexibility products and markets: literature review. *Electric Power Systems Research, 154*, 329-340.

World Energy Council. (2016). Variable Renewables Integration in Electricity Systems: How to Get it Right. *World Energy Perspectives: Renewables Integration 2016*. Retrieved from https://www.worldenergy.org/wp-content/uploads/2016/09/Variable-Renewables-Integration-in-Electricity-Systems-2016-How-to-get-it-right-_-Full-Report-1.pdf

Zou, P., Chen, Q., Xia, Q., He, G., & Kang, C. (2015). Evaluating the contribution of energy storages to support large-scale renewable generation in joint energy and ancillary service markets. *IEEE Transactions on Sustainable Energy, 99*.

GLOSSARY

Nadir	Lowest point that the system frequency reaches following a disturbance
Zenith	Highest point that the system frequency reaches following a disturbance

ANNEX I. OVERVIEW OF PARTICIPANTS IN THE QUESTIONNAIRE AND WORKSHOP

Name of the partner	Role
AST	TSO
EDF	Generation and retail
EDP	DSO
EirGrid	Task leader. TSO
Elering	TSO
Imperial	Research Institute/ University
INESC TEC	Research Institute/ University
innogy	DSO
KU Leuven	Research Institute/ University
NCNR	Research Institute/ University
Poyry	Consultant
PSE	TSO
RSE	Research Institute/ University
SONI	TSO
UCD	Research Institute/ University
UTartu	Research Institute/ University
VITO	Work Package Leader. Research Institute/ University
VTT	Research Institute/ University

ANNEX II. LIST OF SERVICES IDENTIFIED USING THE STATE-OF-THE-ART-ASSESSMENT

Primary Operating Reserve
Secondary Operating Reserve
Tertiary Operating Reserve 1
Tertiary Operating Reserve 2
Replacement Reserve (De-Synchronised)
Replacement Reserve (Synchronised)
Steady-state Reactive Power
Synchronous Inertial Response
Ramping Margin 1 Hour
Ramping Margin 3 Hour
Ramping Margin 8 Hour
Fast Frequency Response
Dynamic Reactive Response
Fast Post-Fault Active Power Recovery
Active Power management by DSO for TSO
Reactive Power management by DSO for TSO
Assurement of free DSO grid capacity for all frequency reserve products
Virtual Inertia
Network Capacity Market
Inverted connected devices setting and maintaining frequency
Fast Frequency Response (AEMO)
Primary Reserve upward - load
Primary Reserve down
R1 symmetrical 100m HZ
R1 symmetrical 200m HZ
R1 200m Hz RTE
Secondary Reserve up
Secondary Reserve down
Tertiary Reserve Standard
Tertiary Reserve Flex
Tertiary Reserve with Non-reserved volumes
Local Voltage Control
Centralised Voltage Control
Strategic Generation Reserve
Strategic Demand Reserve
Fast Frequency Reponse 1(ERCOT)
Fast Frequency Reponse 2(ERCOT)
Primary Frequeny Response (ERCOT)
Contingency Reserve Service
Supplemental Reseve Service
Up and Down regulating service
PQ maps of the available DN flexibillity
DSO voltage-led load management
PQ DN flexibillity
mFRR - manual Frequency Restoration Reserve
Emergency reserve
Voltage control
Reactive power control
Congestion management reserve for TSO/DSO - fast
Congestion management reserve for TSO/DSO - slow
Flexible grid connection
aFRR - automatic Frequency Restoration Reserve
FCR - Frequency Containment Reserve
FRR - Frequency Restoration Reserve
RR - Replacement Reserves
Variable Generation Smoothing
Capacity Firming
FCR-N - Frequency Containment Reserves for normal operation
FCR-D - Frequency Containment Reserves for disturbances
FRRm - manual Frequency Restoration Reserve
Local market for voltage regulation
All-Island Capacity Auction
Black Start - All-Island
FCR - Frequency Containment Reserve (Poland)
FRR - Frequency Restoration Reserve(Poland)
RR - Replacement Reserves (Poland)
Emulated inertia response/Sythentic inertia
Voltage Support in MV Network (Italian demo)
Voltage Control in HV/MV substations (Italian demo)
Congestion management (Italian demo)
Balancing (Italian demo)
Active power management for mFRR, RR and Congestion services
Load following reserve
Peak Shaving
Energy Arbitrage
Automatic Generation Control
Nodal Voltage Controller
Ramp-rate control (WP8)
Peak shaving (WP8)
Local Voltage Support (WP8)
Regulation Primaria (Spain)
Regulation Secundaria (Spain)
Regulation Terciaria (Spain)
FCR-N - Frequency Containment Reserves for normal operation (Sweden)
FCR-D - Frequency Containment Reserves for disturbances (Sweden)
aFRR - automatic Frequency Restoration Reserve (Sweden)
Fast ramping product / 15 minute ramping product
Regulation
Flexible connection capacity 1
Flexible connection capacity 2

Black start (Belgium)
Firm Frequency Response - Primary response
Firm Frequency Response - Secondary response
Firm Frequency Response - High frequency response
Enhanced Frequency Response
Mandatory Frequency response - Primary Response
Mandatory Frequency response - Secondary response
Mandatory Frequency response - High frequency response
Enhanced Reactive Power Services
Obligatory Reactive Power Service
Black Start - National Grid
BM Start Up
Demand side response (NG)
Demand turn up - National Grid
Fast Reserve
Intertrip services
Short Term Operating Reserve
Super SEL
Primary Reserve (REE)
Secondary Reserve (REE)
Tertiary Reserve (REE)
Deviation Management (Replacement Reserve) (REE)
Additional Upwards Reserve (REE)
Cross border balancing product (BALIT) (REE)
Voltage control (REE)
Interruptibility (REE)
Technical restrictions (Congestion management) (REE)
Flexhub dynamic model
Flexhub P global market
Flexhub Q local market
VPP aFRR
VPP RR

ANNEX III. LIST OF SYSTEM SERVICESCHARACTERISTICS FROM TEMPLATE COMPILED BY PARTNERS IN TASK 3.1

Name	Abbreviation	Description of product	Type of Product	Type of Event	Issues resolved/ Technical Scarcity Addressed	Activation Principle	Preparation Period	Full Activation Time	Maximum Delivery Time	Required duration
			whether the product is a frequency response service, a dispatchable service, a congestion management product etc.	the type of event which triggers or requires use of the product to mitigate an issue	the issues and technical scarcities which are mitigated or resolved by the product	The manner in which the product is triggered.	The time between the event/disturbance occurring and the product activation. For congestion management: time between detection of forecasted congestion and delivery of adjusted schedules or potential of activation (for reactive power)	The period between the start time of the activation of the product and the time the product is fully available. This is particularly relevant for the fast response products.	The time at which the product response ends	The time over which the product response must be sustained

Locational product?	Country/Region	Recovery Period	Other Specific Requirements for Technologies	Symmetry and Direction	Existing?	Current Remuneration Mechanism	Other procurement options
whether the product is a locational product or a system-wide product	the country or region where this product is utilised or where there is potential for its use	the time between the end of the response and the time when the resource can once again provide a response, during which the product is not available. This characteristic may be important for energy limited technologies (DR, batteries etc.)		Is the product symmetrical? Is it an upward product or a downward product?	whether the product currently exists in a system and market or is planned for the coming years or whether it is a hypothetical project that is currently being researched and explored. This allows us to consider a whole range of different products, providing the option to explore more innovative products.	the type of remuneration mechanism if the product is currently in existence	whether the product could be procured as a result of a) a grid code mandate, b) market mechanisms, c) regulated tariffs or d) other mechanisms

Compensation Methodology	Minimum size	Maximum Size	Who the product is procured by	Who benefits from the product	Providers	If procured, over what time frame?	Mechanisms for demonstrating capability	Proof of Provision	Aggregation
€/MW €/MWh €/MW/annum	the minimum size of the bid or volume required	the maximum size of the bid or volume required	whether the product is procured by TSO, DSO or BSP etc.	whether the product is for the benefit of the TSO or DSO	the technologies that are capable of providing this product	whether the product is procured day-ahead, intra-day, hourly, weekly, yearly etc.	what are the mechanisms for illustrating that the product can be provided by various technologies	how availability and delivery of the resource is monitored	whether or not aggregation of resources can be considered

ANNEX IV. QUESTIONNAIRE AS CIRCULATED TO PARTNERS IN TASK 3.1 AND TASK 3.2

1) In your opinion, in general, what will be the 5 most critical technical scarcities or system needs in future power systems with high levels of variable renewable generation?

   Please indicate what you consider to be high levels of variable renewable generation.

2) Of the technical scarcities and needs you have discussed in Q1), please:
   a) Prioritise the technical scarcities and needs. Also, arrange the timeframe options according to the expected relevancy.

   Note that full activation time (FAT) refers to the time the unit takes to reach 100% provision of the offered volume.

   For example, from 1 to 5 (1 for the lowest priority and 5 for the highest)

   (5) Frequency control

   [FAT: (5) x < 30 sec; (4) 30 sec > x < 5 min; (3) 5 min > x < 15 min; (2) 15 min > x < 30 min; (1) x > 30 min]

   i. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   ii. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m

   iii. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   iv. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   v. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   b) For the following, please put an "x" in the technical scarcity that, in your opinion, should not be tackled by a market-based mechanism. Please provide reasons for not tackling a certain technical scarcity via a market-based mechanism:

   Note that full activation time (FAT) refers to the time the unit takes to reach 100% provision of the offered volume.

   i. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   ii. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   iii. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   iv. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

   v. ____ [FAT: ( ) x < 30 s; ( ) 30 s > x < 5 m; ( ) 5 m > x < 15 m; ( ) x > 15 m]

3) Assuming that, all things being equal, any technological challenges have been resolved, please describe in detail what you foresee as the key challenges for the future of system services as a whole. Please also suggest potential mitigation measures.

4) For each of the scarcities thought to be tackled best by a market-based mechanism (Q2), what do you foresee could fundamentally hinder the market from effectively matching supply and demand? e.g., high entry barriers like forbidding resource aggregation and setting the minimum bid size too high; discouraging (temporal) arbitrage between markets.

5) Please list 3-5 future active and reactive capabilities that you would like to see developed.

Future Capabilities	
Active	Reactive
	e.g., inverter modulates absorption and delivery

Considering the technical scarcities or system needs you have already identified in Q1) above, please now map the future capabilities with the needs that they could tackle.

Uses of Future Capabilities for the listed active/reactive needs	
Active	Reactive
	e.g., use inverters for reactive power management and voltage control

6) Based on the list of existing services that have been identified in the product template (available here) and considering the needs you have already identified in Q1), please describe more innovative aspects for providing or describing one or more of these products. For example, could a parameter of a particular product be amended slightly such that it could be made to be technology neutral and thus new technologies could also provide it? Please give an example.
Could a service be subdivided into an upward and downward product as well as a symmetrical service, such that technologies are not excluded? Please give an example.

Could the activation time of the product be amended such that most technologies are incentivised to provide faster responses, but are still within their capabilities? Please give an example.

7) Please identify which system services (existing) you think could, based on technical capability, be provided by each of the following technologies. Please mark the appropriate box in the table, mapping the technology with the service/services it might be possible to provide and note the extent to which the technical capability exists (e.g. fully capable (FC), capable with cost challenges (CC), capable with technical challenges (TC), or not capable (NC)).

a) Inertial response
b) Frequency control / active power response < 2 seconds
c) Frequency control/ active power response < 30 seconds
d) Frequency control/ active power response < 15 minutes
e) Frequency control / active power response > 15 minutes
f) Ramping
g) Voltage control - static
h) Voltage control - dynamic
i) Congestion Management
j) Other. Please state _______________

Technologies	**Services**	**a)**	**b)**	**c)**	**d)**	**e)**	**f)**	**g)**	**h)**	**i)**	**j)**
	Conventional thermal generation										
	Wind generation										
	Solar PV – large scale										
	Solar PV – residential scale										
	Demand side – industrial										
	Demand side – commercial (including data centres)										
	Demand side – residential										
	Flywheels										
	Virtual power plants										
	HVDC Interconnectors										
	Ocean energy devices										
	Ultra-capacitors										
	Synchronous condensers										
	Rotational stabilisers										
	Hybrid site 1 (Please describe below)										
	Hybrid site 2 (Please describe below)										
	Hybrid site 3 (Please describe below)										
	Other										

If you have identified a hybrid site, please describe:

In the case of that a technology is not capable (‘NC’) of providing the service, please explain why.

8) For each technical scarcity, in your opinion, is there merit in replacing the centralised procurement approach currently used for system services? Why? What arrangements do you propose as an alternative?

Firstly, please explain what you understand by a centralised approach.

- Frequency Control
- Reactive Power Management and Voltage Control
- Rotor Angle Stability
- Congestion Management
- Technical Scarcity i
- Technical Scarcity ii
- Technical Scarcity iii
- Technical Scarcity iv
- Technical Scarcity v

9) Do you see merit in not having standard products (i.e. the providers define their capabilities and the TSOs/central body chooses based on the optimal combination of the different providers)? Please explain why.

For which services would you recommend the use of non-standard products? Why?

Please explain what you understand by ‘standard products’.

One potential avenue for identifying new system services is to think about current grid code requirements, or other mandatory services, and identify those that might elicit greater performance or compliance if there were some kind of incentive or remuneration mechanism in place.

Alternatively, you may have other concepts or ideas that you would like to explore.

Please describe new or innovative services that could mitigate one or more of the technical scarcities identified in Task 2.1 (please include technical details such as the timeframe over which the service might operate, the activation principle, trigger, the duration of the service, the direction of the service, etc.). If you have additional supporting details, please also provide.

10) How would you foresee these new or innovative services that you have described in Question 9 above interacting with existing products and services? Co-exist or replace? Are there any restrictions?

What is the benefit that these products bring over and above an existing product?

11) How would you foresee these new or innovative services that you have described in Q10) above interacting with the wholesale energy market? Are there any restrictions? Are there any challenges?

12) For the new services you have described in Q10)), what technologies could provide them? As before, please mark the appropriate box in the table, mapping the technology with the service/services it might be possible to provide and note the extent to which the technical capability exists (e.g. fully capable (FC), capable with cost challenges (CC), capable with technical challenges (TC), or not capable (NC)).

	New Services	I.	II.	III.
Technologies	Conventional thermal plants			
	Pumped storage			
	Hydro Plants			
	Wind			
	Batteries			
	Solar PV – large scale			
	Solar PV – residential scale			
	Demand side – industrial			
	Demand side – commercial (including data centres)			
	Demand side – residential			
	Flywheels			
	Virtual power plants			
	HVDC Interconnectors			
	Ocean energy devices			
	Ultra-capacitors			
	Synchronous condensers			
	Rotational stabilisers			
	Hybrid site 1 (Please describe below)			
	Hybrid site 2 (Please describe below)			
	Hybrid site 3 (Please describe below)			
	Other			

In the case of non-energy service providers (i.e. technologies that don't /can't participate in wholesale energy markets, but can provide crucial system services), how might they be incentivised to provide system services?

13) What are the specific requirements of the service(s) you have identified in Q10) that might exclude a technology? Please refer to specific parameters.

14) For the new services you have described in Q10) above, how do you value the service provided? How would the price (if any) for the system service be determined? How do you determine the quantity of this service that would need to be procured? How might the price include an incentive for greater performance?

15) For the new services you have described in Q10) above, please suggest how they might be monitored. Are there novel ways we should consider for monitoring performance?

What particular features or parameters of the service should be monitored?

What are the restrictions for monitoring this service?

How could the performance monitoring of the service be linked with the remuneration and settlement of the product delivery?

16) For each service identified in Q10), list and describe (in broad terms) potential hindering conditions or situations for its provision. Consider possible limitations at each phase (pre-qualification, procurement, activation and settlement). Bear in mind that hindering conditions may arise from technological needs, market organization requirements or regulatory approaches.

17) For services assumed to be tackled by an organized market (discrete or continuous), what type of complex bids could accommodate the time dependent nature of some market participants? That is, what sort of complex bids could help include the limitations of providing units. How can such complex bids be accommodated in current European markets where dispatch/balancing is primarily based on simple balancing energy bids? For instance, to allow the inclusion of technologies that are flexible in time, but limited in energy (like storage and DR).

18) For each service identified in Q10), please explain how the location of the service providing resource(s) impacts the effectiveness of the service. Also, consider discussing the feasibility for the service to be "Collected" at a distribution grid node (e.g., primary substation) and "Forwarded" to the transmission grid by the DSO.

19) For each service identified in Q10), what are the critical cooperation and coordination steps in respect to operation and market mechanisms that relevant network operators (DSO and TSO) should take to ensure the provision of the service? Would it be possible (or necessary) to have cross-border market?

20) For each of the services described in Q10) what configuration would be suitable? Highlight or complete with the requested information.

Service name:

Scarcity being tackled:

Providing technologies and location: e.g., PV inverters at MV (grid operated by DSO)

Pre-qualification phase: Provide a high-level description of the steps involved (incl. potential schedule)

Procurement phase: Provide a high-level description of the steps involved (incl. potential schedule)

Remuneration

What pricing approach would you suggest for the remuneration of the service?

What concepts would you remunerate?

Activation phase: Provide a high-level description of the steps involved (incl. potential schedule)

Settlement phase: Provide a high-level description of the steps involved (incl. potential schedule)

21) How could we revamp existing procurement mechanisms to incentivise greater or enhanced performance from service providers?

22) Is there any important information we have forgotten to ask about?

23) Please provide references to documents/articles, as well as hyperlinks that complement your vision of novel market architectures for system services.