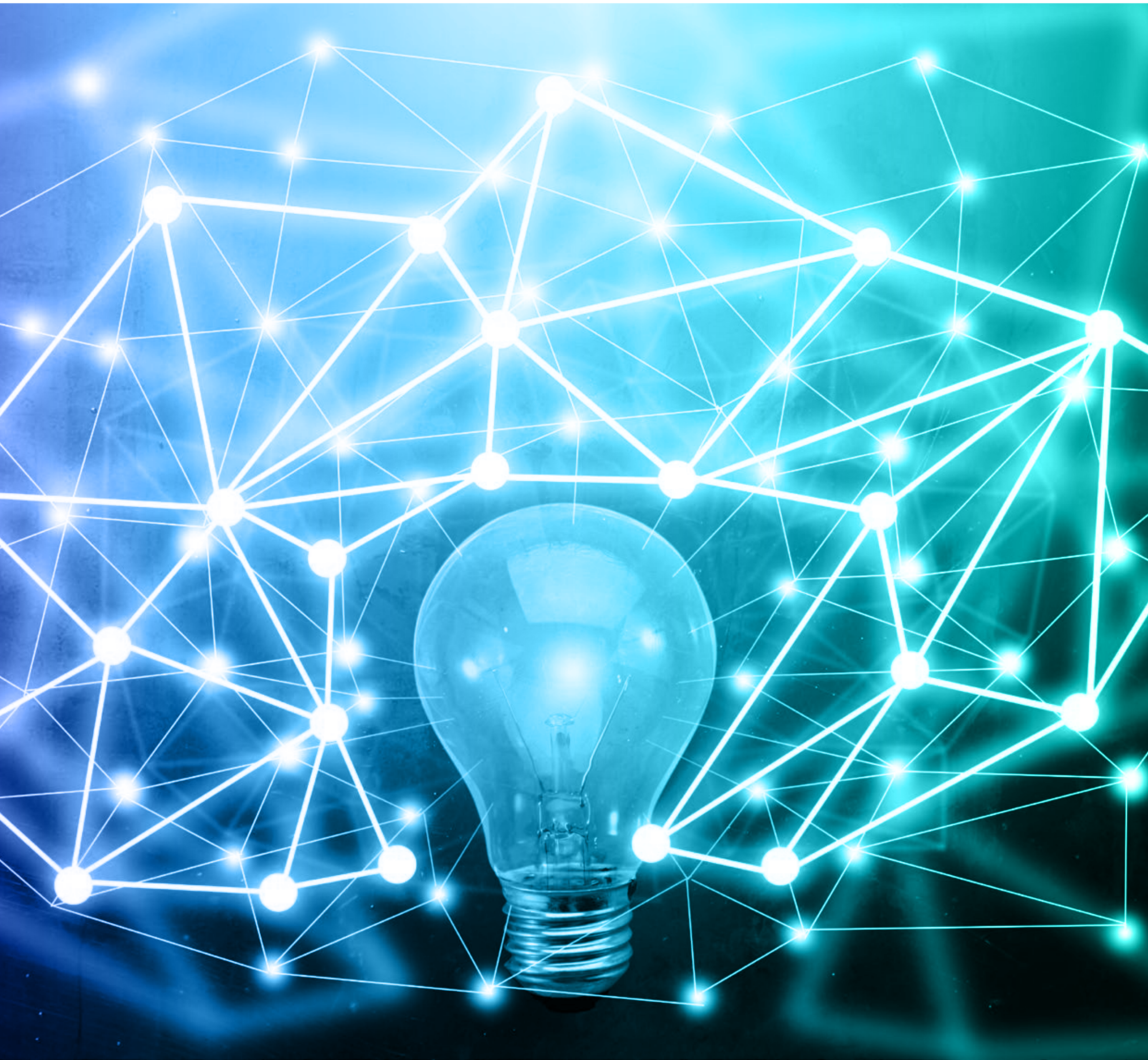
ENTSO-E

Research, Development & Innovation Roadmap 2020–2030



entsoe

About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, represents 42 electricity transmission system operators (TSOs) from 35 countries across Europe. ENTSO-E was registered in European law in 2009 and given legal mandates since then.

Contents

Executive Summary

Calls for decarbonisation, electrification, and digitalisation are reshaping the entire energy system in Europe. Innovation is key to accompany the energy industry through this profound transformation.

In an effort to reach carbon neutrality by 2050, the European Green Deal aims to implement innovative, carbon-neutral energy solutions by energy transition through a mix of linear and disruptive system transformations. As Europe's energy system integrates ever-increasing shares of renewable energy, electrification of end-uses and sectoral integration will play important roles in reaching this target[1,2,3] by placing the electrical grid at the core of an integrated, decarbonised energy system. This calls for Transmission System Operators (TSOs) and Distribution System Operators (DSOs) to fast-track the integration of clean energy solutions into the electrical grid, to develop bold and agile strategies with policy-makers and stakeholders, to fast-track the integration of clean energy solutions.

In this context, and as required by the Clean Energy Package,[4] ENTSO-E has developed a Research, Development, and Innovation Roadmap for 2020–2030 (RDI Roadmap) based on a use-case approach to target challenges which need to be solved before 2030. This RDI Roadmap strives to address challenges to reaching the 2030 goals identified in the ENTSO-E Vision for Market Design and System Operation.[5] It prioritises key RDI activities for power transmission in the coming decade. The RDI Roadmap integrates the opportunities provided by technological trends, the needs of TSOs arising from system operations and market evolution, policy objectives of the European Commission (EC) and inputs from external stakeholders.

THE ENTSO-E R&D&I ROADMAP 2020–2030

Towards a pan-EU energy system with net zero emissions of greenhouse gases in 2050

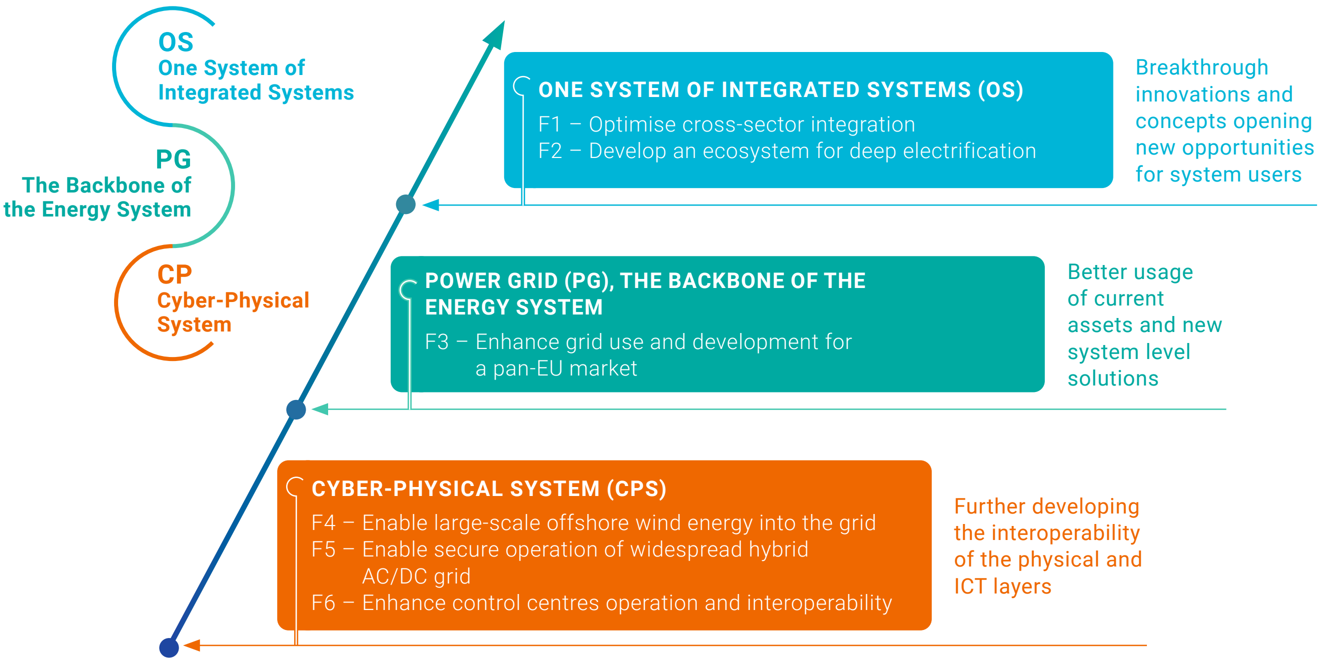


Figure 1: ENTSO-E 3 RDI priority Areas/Clusters and Flagship projects

1 Energy Transitions Commission: http://www.energy-transitions.org/mission-possible
2 European Commission: https://ec.europa.eu/clima/policies/strategies/2050_en
3 ENTSO-E: https://www.entsos-tyndp2020-scenarios.eu/
4 Regulation of the European Parliament and of the Council: 2019/943, Article 30(1)(i).
5 Available at: https://vision2030.entsoe.eu/

Main findings

The RDI Roadmap identifies three major RDI Areas/Clusters, addressed by six Flagship projects:

1. One System of Integrated Systems (OS)

This focuses on market expansion, through electrification sector coupling and integration, TSO-DSO interface, and the coordination of market players.

› **Flagship 1: Optimise cross-sector integration.** To focus on significantly improving efficiency and flexibility as well as the reliability and adequacy of the energy system, this requires that:

(i) Markets for cross-sector integration are developed and coupled,

(ii) System operators and market parties have access to planning and optimisation tools to develop and maintain an integrated system, and

(iii) The creation of an integrated system of governance.

› **Flagship 2: Develop an ecosystem for deep electrification.** To focus on deep electrification of energy end uses, this will require:

(i) A new and comprehensive TSO-DSO interface to provide grid users with the best service,

(ii) New scenarios and modelling techniques, and

(iii) The development of new market concepts and ancillary services to integrate flexible new sources.

2. Power Grid (PG), the Backbone of the Energy System

This implies Increased grid capacity and optimisation as well as large-scale deployment of solutions and services with high Technology Readiness Levels (TRLs).

› **Flagship 3: Enhance grid use and development for a pan-EU market.** Markets and services should ensure both horizontal and vertical integration of energy resources with an eye toward optimisation as new types of services to customers emerge. Tools, algorithms, and control systems need to adapt accordingly to:

(i) Enable enhanced Pan-EU power systems,

(ii) Develop interoperable, integrated, and standardized platforms, and

(iii) Find new approaches to grid design and asset management.

3. Cyber-Physical System (CPS)

This focuses on ensuring the technical soundness of the system in terms of digitalisation and inter-operability, including integration of power electronics and offshore developments.

› **Flagship 4: Enable large-scale offshore wind energy into the grid.** The vast potential of offshore energy sources (e.g. wind) in the North and Baltic Seas is a promising source of renewable energy for Europe. To exploit this potential, offshore grids and related advanced system models are needed, along with suitable new High Voltage Direct Current (HVDC) connections and improvements in the supply chain to scale up delivery. To meet these goals will require:

(i) Thoughtful regulatory guidelines,

(ii) The development of interoperable hardware and software solutions for Direct Current (DC) grids and systems, and

(iii) Consistent attention to developing new HVDC technologies and materials.

› **Flagship 5: Secure operation of widespread hybrid AC/DC grid.** The development of a strongly interconnected power system with high renewables penetration requires the implementation of advanced solutions by TSOs to overcome the technical challenges associated with the management of hybrid Alternating Current (AC)–Direct Current networks. The following solutions are critical:

(i) Hybrid AC/DC power flow and system modelling,

(ii) Control, operation, and protection of hybrid AC/DC grids, and

(iii) Hybrid AC/DC systems to provide ancillary services.

› **Flagship 6: Enhance control centres operation and interoperability.** Due to the coexistence of micro and mega grids, TSOs need new, scalable management tools to cope with increasingly complex systems. Future control centres will rely on improved system monitoring and control capabilities through enhanced information and communications technology (ICT) infrastructure. This requires RDI focusing on:

(i) The interoperability of control centres,

(ii) Enhanced control centre development and wide-area monitoring, and

(iii) The development of guidelines and tools to manage highly complex interoperated systems.

Going Forward

TSOs are strongly committed to deliver on the Flagship projects set forth above. There is already significant activity in certain areas such as deep electrification, enhanced grid use and control centre operations and interoperability. Considering the numerous milestones to be achieved over the next few years, the realisation of this RDI Roadmap will require attention to the effective coordination of resources. TSOs will also have to pay due attention to other constraints such as environmental impacts, permitting procedures, public acceptance, risk of stranded assets etc.

Fulfilling these six Flagships is not only about improving and operating transmission grids; the whole energy value chain will reap benefits from the realisation of these Flagship projects. To fulfil this important mandate, TSOs will step up collaboration with universities, research institutes, equipment manufacturers, DSOs, digital companies, market participants, start-ups and consumers. The European Commission, through its programmes such as Horizon Europe and Connecting Europe Facility, can further support and enhance pan-European collaborations and promote synergies within these Flagship projects. Encouraging a collaborative approach to innovation will enable the effective implementation of this RDI Roadmap and support the delivery of the European Green Deal and its related policies.[6]

6 Related policies include the Smart Sector Integration Strategy, revision of Regulation for Trans-European Network for Energy, Offshore Wind Strategy, etc.

Chapter 1: Introduction

The ENTSO-E Research, Development and Innovation Roadmap 2020–2030 (RDI Roadmap), is a legally-mandated research and innovation planning tool. It targets TSO decision-makers and ecosystems, policymakers, and other stakeholders.

It defines the main research and innovation priorities for the power production and transmission in the coming decade based on technological trends, new operational needs, market developments, and constantly updated input from TSOs and stakeholders. It strives to achieve technical, economical, and socially acceptable solutions for a pan-European electricity transmission system.[7]

Compared to previous editions, the primary developments and improvements in this third RDI Roadmap[8] are:

- **A shift from simply a catalogue of technologies and solutions to a problem-solving approach identifying main challenges and proposed use cases;**
- **Increased focus on TSO core activities and their planning, operational, and management processes;**
- **A reorganisation of innovation areas, now structured around three RDI Clusters and six Flagship projects to enable more focus on system needs and solutions.**
- **A shift towards innovation activities with higher technology readiness levels (TRLs) for the faster deployment and implementation of advanced infrastructures.**

An Implementation Plan will follow this RDI Roadmap to address in more details how RDI activities within each Flagship area will be carried out. With a clear focus on just a few prioritised topics per year, the Implementation Plan represents a crucial step in translating Flagship project ideas into realities.

7 ENTSO-E may revise the objectives stated in the present RDI Roadmap depending on the progress achieved or in case of breakthrough developments.

8 The ENTSO-E RDI Roadmap, 2017–2026, is available at: http://riroadmap.entsoe.eu/

Chapter 2: The electrical power system as enabler for the decarbonisation

With the **European Green Deal**,[9] the European Commission aims to reach zero net greenhouse gas emissions by 2050; this requires a deep decarbonisation of Europe's energy system. This ambitious climate action agenda will accelerate the ongoing transformation and modernisation of the European energy system.

The following structural trends already affect the way the European power system operates:

- New generation patterns due to the advent of variable renewable energy production that must be connected to the system and transported over long distances to end users.
- New load patterns due to the electrification of energy end uses, e.g. fast-charging for electric vehicles, characterised by higher power consumption peaks.
- Decentralisation of energy resources with the connection of numerous small-scale assets to the distribution grid and the related emergence of new grid participants like local energy communities and prosumers.
- Sector coupling of end-use sectors and supply networks via the conversion of electricity by energy carriers and vice-versa.
- Technology development and breakthrough solutions in the IT sector leading to further digitalisation of the energy sector.

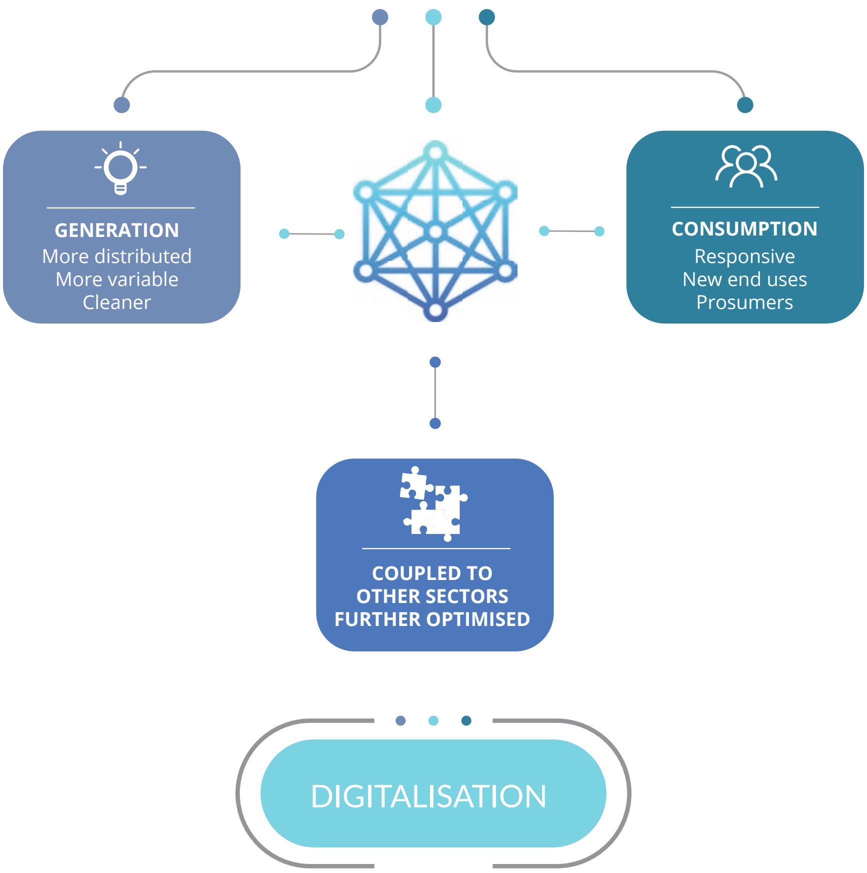


Figure 2: Major trends in power systems, ENTSO-E Vision 2030[10].

9 https://ec.europa.eu/info/publications/communication-european-green-deal_en
10 https://vision2030.entsoe.eu/

These trends raise new challenges for TSOs:

- As a significant share of available resources will be connected to distribution networks,[11] system operations will require new tools to improve forecasting, visibility, and controllability, and new processes and related data exchanges will be needed to coordinate between various actors, most notably with the entities that will manage behind the meter devices (aggregators), and the DSOs.

- The large penetration of power electronics interfaced distributed generation and high voltage direct current (HVDC) transmission systems will result in a hybrid AC / DC power system.[12] This raises issues related to system dynamics such as low system inertia, reduced short circuit contribution from these new resources (compared to synchronous generators), and new types of interaction phenomena.

- The increasing gap between market outcomes and the physical reality of the grid requires measures and technologies that will allow to accelerate investments in the power system.

- The synergy and interdependency between the electricity system and other sectors in terms of flexibility provisions or black-start capabilities require a new, integrated approach to planning, regulation, markets, data exchanges, etc.

- The development of a digital grid capable of meeting the new and changing needs of the Green Deal requires the integration of automation and decision-support tools as well as procedures to manage emerging threats such as cyberattacks.

Overcoming these challenges will require new solutions and radical innovations in system planning, operations, and management.

11 ENTSO-E Vision 2030 assumes that at least 50% of all new renewable energy sources will be connected to distribution networks.

12 ENTSO-E Vision 2030: The ratio of non-synchronous (power electronics) generation to total generation in 2030 will vary from 25% for the Nordic area to around 50% for Continental Europe, the Baltic area, Great Britain, and Ireland.

Chapter 3: Innovation goals and strategy

With radical changes at the corner, bold investment in innovation is vital for TSOs to cost-effectively guarantee supply security and quality of service to grid participants. A massive ramp-up of innovation activity and a suitable portfolio of R&I projects, from small scale pilots to large-scale demonstrations and addressing theoretical, model, and simulated activities, is needed.

A key objective of network innovation should be to deliver transformational change – the implementation of viable business initiatives that incorporate novel methods to scale up and roll out new practices, processes, and technologies.

Optimising assets and practices includes improving power system capabilities, resilience, reliability, safety, and security, and reducing environmental impact. Developing innovative solutions can increase flexibility, transparency, and efficiency of the energy system, making networks more responsive to changes in energy sourses and end-use demands. The Flagships are designed around this approach; they approach problems and goals by gathering energy system stakeholders and assembling the necessary expertise and resources to accomplish each step in the RDI Roadmap.

The six Flagships evolved out of the ENTSO-E RDI Strategy adopted early 2020. This Strategy is structured around three RDI Clusters representing the three primary concerns of future power system evolution.

RDI Clusters Overview

RDI Cluster 1: One System of Integrated Systems (OS)

Breakthrough innovations and concepts opening new opportunities for system users

TSOs need to go beyond the boundaries of their core activities to prepare system operations ready for the challenges ahead. Decentralised generation and increased electrification require TSOs to adapt and support a market expansion with a focus on 'One-System of Integrated Systems' centred around optimised cross-sectoral integration. Digital technology, updated the roles and responsibilities of various actors, and the coordinated use of the new potential for flexibility and infrastructure optimisation will all facilitate this expansion of the TSO role. Electrification of transport, heating, and cooling are key elements that will create new markets and require new ways of modelling future generation and load profiles in the industrial, tertiary, and residential sectors. Coordination between TSOs, DSOs, market participants, and customers must go beyond mere integration of markets and operations and expand into proactive planning.

This RDI Cluster is organised in two Flagships described in detail in Chapter 4:

- **Flagship 1: Optimise cross-sector integration.**
- **Flagship 2: Develop an ecosystem for deep electrification.**

RDI Cluster 2: Power Grid (PG), the Backbone of the Energy System

Better usage of current assets and new system level solutions

Future market integration requires increased grid capacity, optimisation, and integration of new technologies. As a mid-term goal, the transmission grid will have to transport higher volumes of renewable electricity over long distances; hence, embedding controllable devices and control systems in the cross-border infrastructure will ensure that resource management can be optimised. Activities in this field should focus on no-regret technologies and processes with high TRLs that can deliver high benefits with low upfront costs. Innovation should also be introduced to non-technological matters via collaboration through regional and pan-European sandboxes or pilot regulatory schemes. Further digitalisation of markets and power flow controls with appropriate time and location granularity (observability and controllability) needs to be ensured, and new asset management approaches should be implemented to achieve Green Deal targets.

This RDI Cluster includes the following Flagship:

- **Flagship 3: Enhance grid use and development for a pan-EU market**.

RDI Cluster 3: Cyber-Physical System (CPS)

Further developing the interoperability of the physical and ICT layers

Large penetration of power electronics, further digitalisation, and stronger connectivity require TSOs to take further actions to ensure the technical soundness of the cyber-physical power systems. System resilience, security, stability, and restoration after a black-out are and must remain the primary mandate of TSOs. In the short term – by 2025 – securing the interoperability of grid components, both hardware and software, is a high-priority task. HVDC and offshore developments will require multi-terminal use and much more substantial infrastructure for HVDC converters and cables. New open standards and interoperable technologies will be needed to manage real time operations; this will require more computer-human interaction skills while preserving business competencies.

This RDI Cluster is organised into three Flagships:

- **Flagship 4: Enable large-scale offshore wind energy into the grid**
- **Flagship 5: Ensure secure operation of widespread hybrid AC/DC grid**
- **Flagship 6: Enhance control centres operation and interoperability**

Chapter 4: Flagships and milestones

This chapter presents six RDI high-level use cases – **Flagships** – to support the transformation of Europe's energy system.

A schematic representation is used for each Flagship, as shown in **Figure 3.** The related RDI topics are reported in separate sectors delimited by straight lines while the innovation path and related milestone progress takes place over a 10-year time period. This timeline is further divided into three areas with different greyscale colours, starting from the year 2020 (dark grey) to the year 2030 (light grey), with an intermediate time step centred around the year 2025. The milestones are positioned from bottom left to upper right along this time axis. Some milestone cross different sectors indicating the interdependency between RDI Topics and/or time areas. Also, some milestones are connected to each other with arrows to represent evolutionary or subsequent steps between them.

The RDI Roadmap counts more than 80 milestones to be achieved in coordination by numerous stakeholders in the coming decade. As it is shown in **Figure 4**, a significant number of these milestones are expected to be achieved before 2025 which reflects the ambition to quickly deploy high TRL solutions (5–8) to deliver the long-term vision of a decarbonised electricity system.

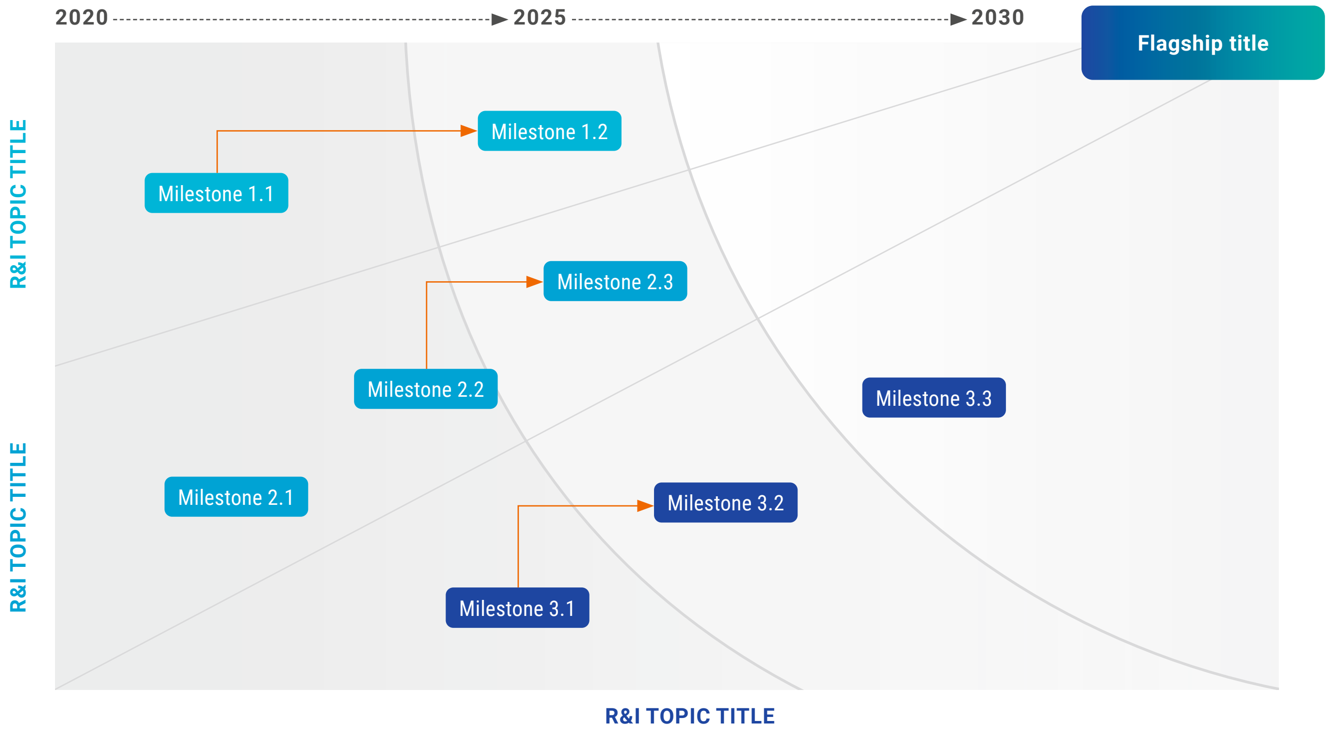


Figure 3: Explanatory scheme of a Flagship

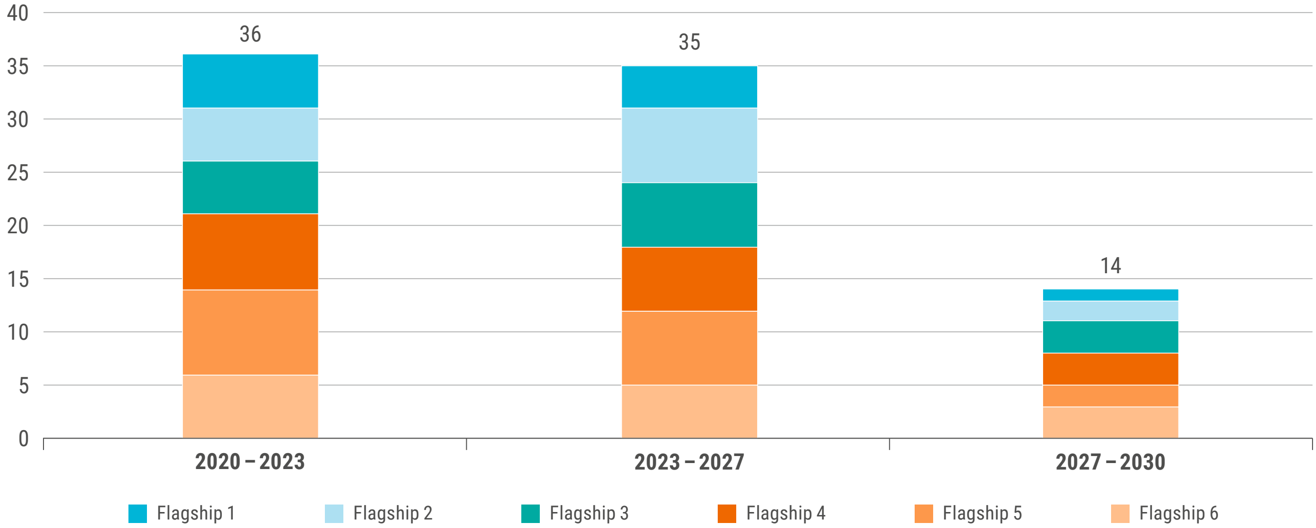


Figure 4: Achievement milestones within the timeline.

RDI Cluster 1: One-System of Integrated Systems (OS)

Flagship 1: Optimise cross-sector integration

Cross-sector integration of the different energy carriers and networks (electricity, gas, heating and cooling, and transport) is an indispensable to plan for the decarbonising Europe's energy system. Pooling of the respective storage features and optimising flexibility will increase the system's overall efficiency, reliability, and adequacy.

Optimised cross-sector integration cannot be accomplished overnight. Through a coordinated, step-by-step innovation process and a large-scale deployment of technologies – such as heat pumps, the smart charging of electric vehicles, power-to-gas solutions etc. – system operators will be able to define and implement innovative approaches and solutions for optimized joint operations, as well as to develop and validate scenarios, tools, and ITC platforms to deploy cross-sector integrations at the systems level.

The first step of this process is the evolution of current market structures with the development of **new market architecture concepts** for the deployment of suitable market **platforms for the newly integrated energy system**.

Using different integrated **scenarios** developed with consideration of the whole energy system and a **pan-EU cross-sector energy system model** by means of specific **demo pilots on how to operate the integrated energy system**, TSOs should evaluate different integration paths. This will allow TSOs to assess the effect of the proposed solutions and to obtain the necessary feedback from the various field sectors in order to steadily advance towards a final *"system of systems"* target. The next required steps would be the development of **optimisation tools and strategies for operating the integrated energy system** as well as **planning tools to enable sector-coupling investments**.

An integrated energy system also requires an effective governance. Hence, the **definition of new roles and responsibilities** for TSOs is pivotal as parallel markets develop. The rules and the associated r**egulatory framework for the integrated energy system** need to be modified or in many cases reshaped – e.g. remuneration schemes for the different grid services provisions. Important innovation steps to reach the optimized cross-sector integration include, among others things, the availability and application of **standards for interoperability and data exchange between sectors**.

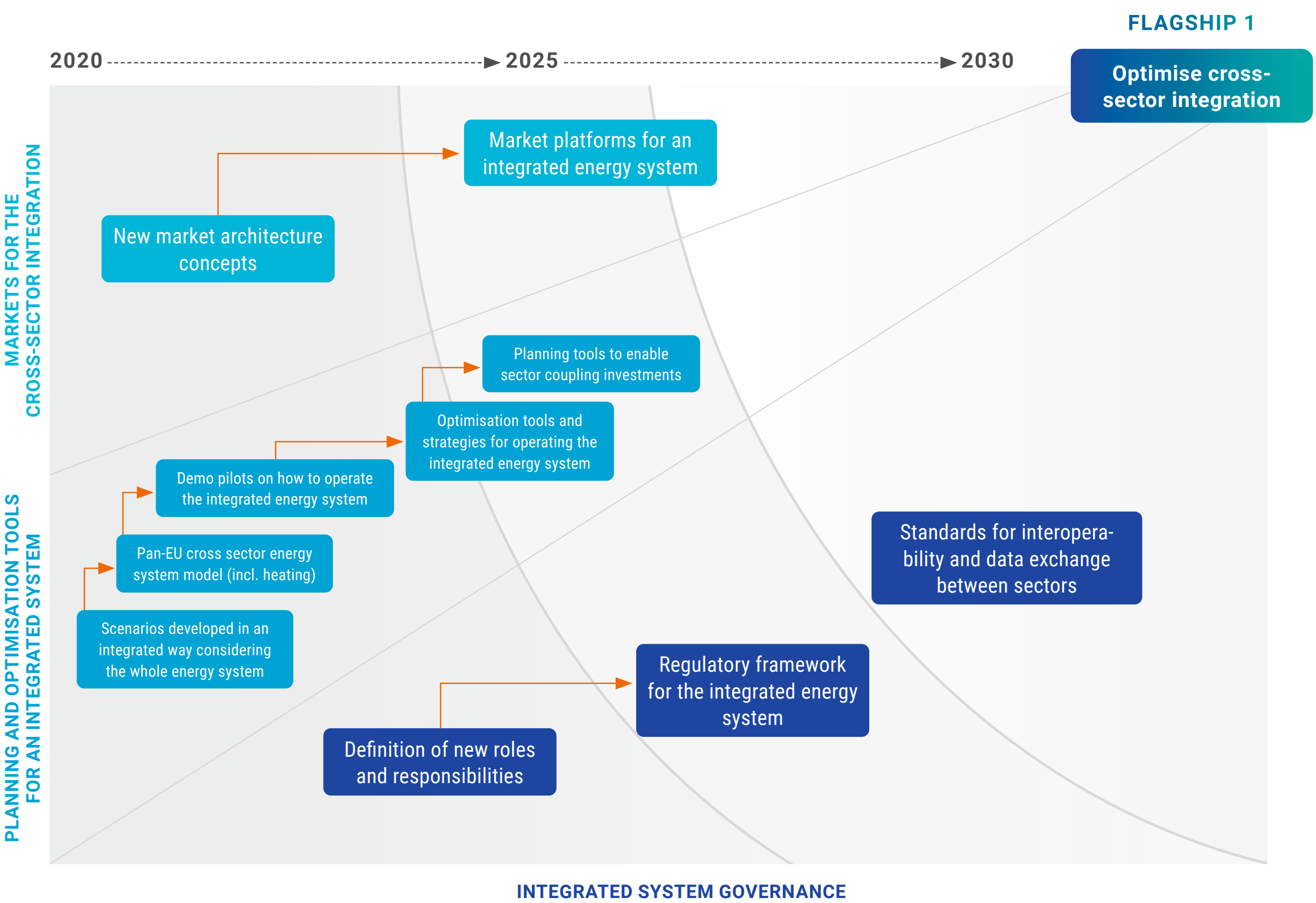


Figure 5: Flagship 1: Optimise cross-sector integration

Flagship 2: Develop an ecosystem for deep electrification

The increasing electrification of the energy system will involve an increasing penetration of various renewable energy source (RES) connections and an increasing need for source flexibility. An assessment of **regulatory requirements for distributed flexibilities** by system operators (TSOs and DSOs) is therefore needed, as is the establishment of enhanced coordination schemes fostering the involvement of stakeholders and final users. Coordination efforts must address ancillary services able to unlock all the available flexibility within the energy system and based **on market-driven TSO–DSO–Prosumer** considerations.

Enhanced TSO–DSO interactions for optimal power flow and system security, along with suitable market platforms, will allow smaller resources connected at the distribution level to participate in energy and ancillary services markets. Moreover, taking into account from the outset physical grid models directly implemented into market models and related processes will help guarantee system security. **Enhanced TSO–DSO interactions in joint system planning** will take into account synergy created through a harmonised planning of transmission and distribution networks.

A deep electrification strategy should be based on improved scenarios with a clear **assessment of electrification potential in residential, services, industry, heating and cooling, and transportation**, including an analysis of new load patterns as shown by a quantification of grid expansion as well as of flexibility potential in those sectors.

Improved Cost-Benefit-Analyses (CBAs) assessing deep electrification scenarios and Cross Border Cost Allocation regulations for pan-European investments are needed to guide new development plans and investments and supplement **high RES penetration scenario analyses in relation to security of supply and flexibility needs**.

During the overall process of system modernisation it is important to foster the engagement of stakeholders and end-users to raise awareness of the evolution of the energy system and the benefits associated with improved grid solutions and infrastructures. TSOs will need to develop **public acceptance analyses and solutions** for this purpose. In concert with Flagship 1, a **cross-sector energy system restoration assessment** will validate assumptions and identify challenges originating out of deep electrification scenarios.

Deep electrification also requires a new market design and additional ancillary services suitable to the new resources. In this respect, an **assessment of the value of peer-to-peer transactions for energy** and an **assessment of the flexibility potential provided by sector coupling**, e.g. power to gas solutions, are essential steps. They will help to identify **new business models for service providers and customers interaction**, develop **market mechanisms for system security and adequacy**, and to ensure the **efficient utilisation of flexibility and demand-side response**.

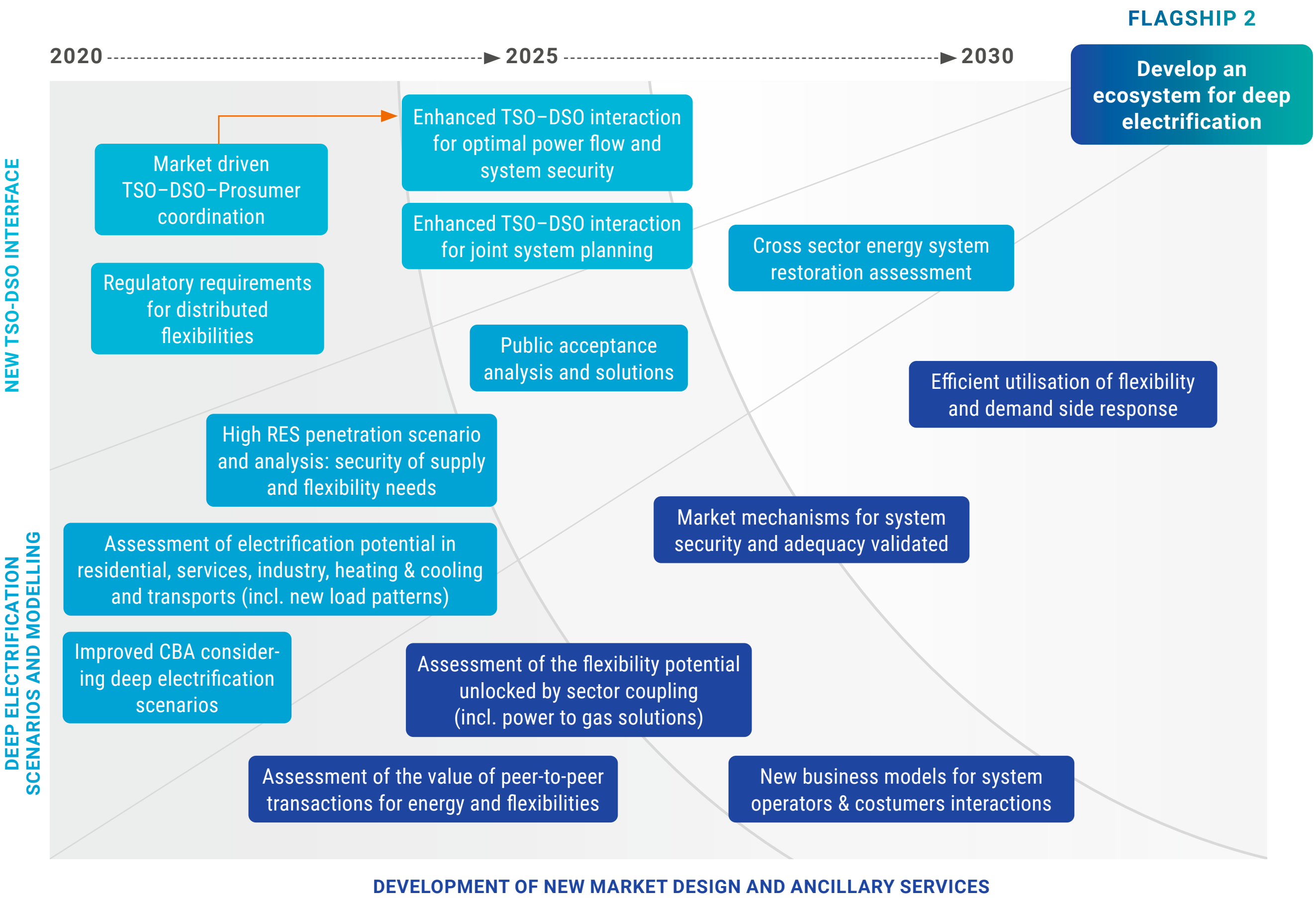


Figure 6: Flagship 2: Develop an ecosystem for deep electrification

RDI Cluster 2: Power Grid (PG), the Backbone of the Energy System

Flagship 3: Enhance grid use and development for a pan-EU market

The European electricity system will play an increasingly important role in the EU economy and innovative energy-dependent technologies, so suitable platforms are needed for the development of a pan-EU energy market. Energy markets and services should ensure that both the horizontal and vertical integration of resources are optimized, and customer can see new types of services emerge. This requires the development and validation of new tools, algorithms, and control systems.

The availability of **improved, self-refining renewable power forecasts**, as well as the deployment of **innovative solutions** like **digital twins and AI-based coordination of controllable power flow devices** allow for advanced power system operations evolving towards less human interaction and increased automatisation.

New approaches exploiting the **coordinated planning of highly controllable power grids, including HVDC**, are needed. **Collaborative ICT platforms for mass deployment of ancillary services** must be provided by a large number of distributed energy sources for development and validation. The proper development of **ICT requirements and standards to collect data for flexibility markets** will enable enhanced ancillary services management. Properly developed and promulgated standards will allow different actors to exchange information across different systems, thereby paving the way for **interoperable data hubs interconnecting main grid actor infrastructures** and a **pan-EU coordination of energy platforms**.

Besides this systemic innovation effort, TSOs must devote resources to innovative grid design and solutions as well as **new asset management approaches**. Novel methods for grid monitoring through the use of sensors, the Internet of things, satellites, and advanced robotics (i.e. drones) can be combined with big data and applied machine learning for a predictive asset management. TSOs can address environmental concerns through the application of **eco-design and lifecycle management** of power system assets to the final goal to reach a **circular economy approach to planning and**

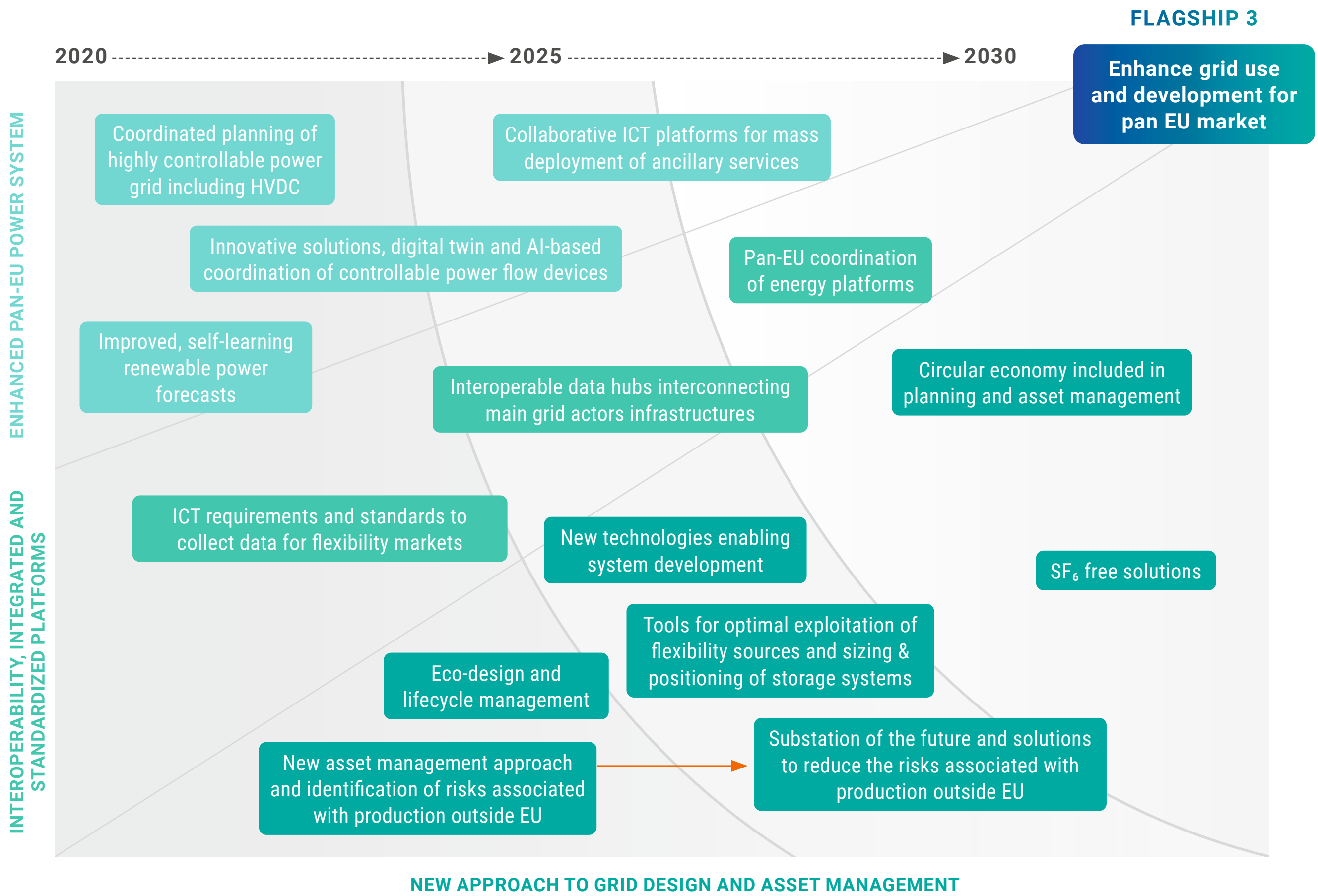


Figure 7: Flagship 3: Enhance grid use and development for pan EU market

asset management. As part of this eco-friendly approach, a major achievement is the consistent use of advanced and sustainable materials for transmission grid components and equipment – in particular, the use of an **SF_6 free solution** for circuit breaker insulation and of organic fluids as alternatives to mineral oil in transformers.

By 2025, TSOs will develop a portfolio of **new technologies for system development** and new **tools for the optimal exploitation of flexibility sources along with the sizing and positioning of storage systems** to cope with the needs and demands of a high proportion of variable RES system. Extended system digitalisation and the exploitation of advanced ICT solutions will make it possible to develop the so-called **'substation of the future'**, i.e. a digitally enabled and eco-friendly substation for advanced control and automation of power systems with high level of inverter-based components. However, it is important to identify and foster viable **solutions to reduce risks associated with production outside Europe**, to avoid EU dependence for key technologies and strategic components.

RDI Cluster 3: Cyber Physical System (CPS)

Flagship 4: Enable large-scale offshore wind energy into the grid

Offshore wind power plants, especially in the North and Baltic Sea, could supply Europe with massive amounts of affordable renewable energy. This resource could be even larger and become available in the other seas surrounding Europe depending on the future development of floating offshore wind technology. Integrating these resources into the continental power system requires the development of offshore grids based on HVDC connections. Considering the challenges associated with their deployment, several intermediate innovation milestones must be achieved first. For example, suitable regulatory guidelines need to be developed starting with an update of the current **regulatory framework definitions** and **implementation**. TSOs need to draft clear **definitions of offshore wind ancillary services** – for example, temporary frequency responses and power oscillation damping for single and clustered wind farm and power system stability enhancement assessments for offshore wind power.

The **standardisation of HVDC model and replicas** considering HVDC equipment from different vendors and the development of **pan-EU standard HVDC modelling tools** represent major achievements in large-scale offshore wind energy system integration. A major step forward is to define the **requirements for multi-vendor converter capabilities at the DC connection point**. These **defined and evaluated protocols for a multi-vendor "plug and play" approach** allow different technology providers to propose solutions and products. **Medium voltage DC multi-vendor and multi-terminal demonstrators** represent an intermediate step for assessing relevant field tests and the validity of the developed models, standards, and protocols. These are mandatory for the effective deployment of full-scale demonstrators. This innovation, alongside the development of **HVDC interoperable grid forming converters**, enables the attainment of the longer-term target of multi-vendor and **multi-terminal HVDC full scale demonstrators**.

Simultaneously, core HVDC technologies need to develop a means for integrating wind energy resources from remote geographical areas and harsh environments; in particular, this includes field testing of innovative **HVDC insulations and circuit breakers**. This innovation effort should be complemented by the **development of HV components and sub-systems designed for extreme environmental conditions, HVDC cables and components standardisation**, and the development and deployment of suitable methodologies to ensure **reliability of HVDC equipment and asset management**. Since large-scale offshore wind power plants are often located in remote areas, the **remote monitoring and maintenance of equipment** must be significantly improved by incorporating innovative technological solutions such as robotic technologies for data collection and maintenance in inhospitable locations.

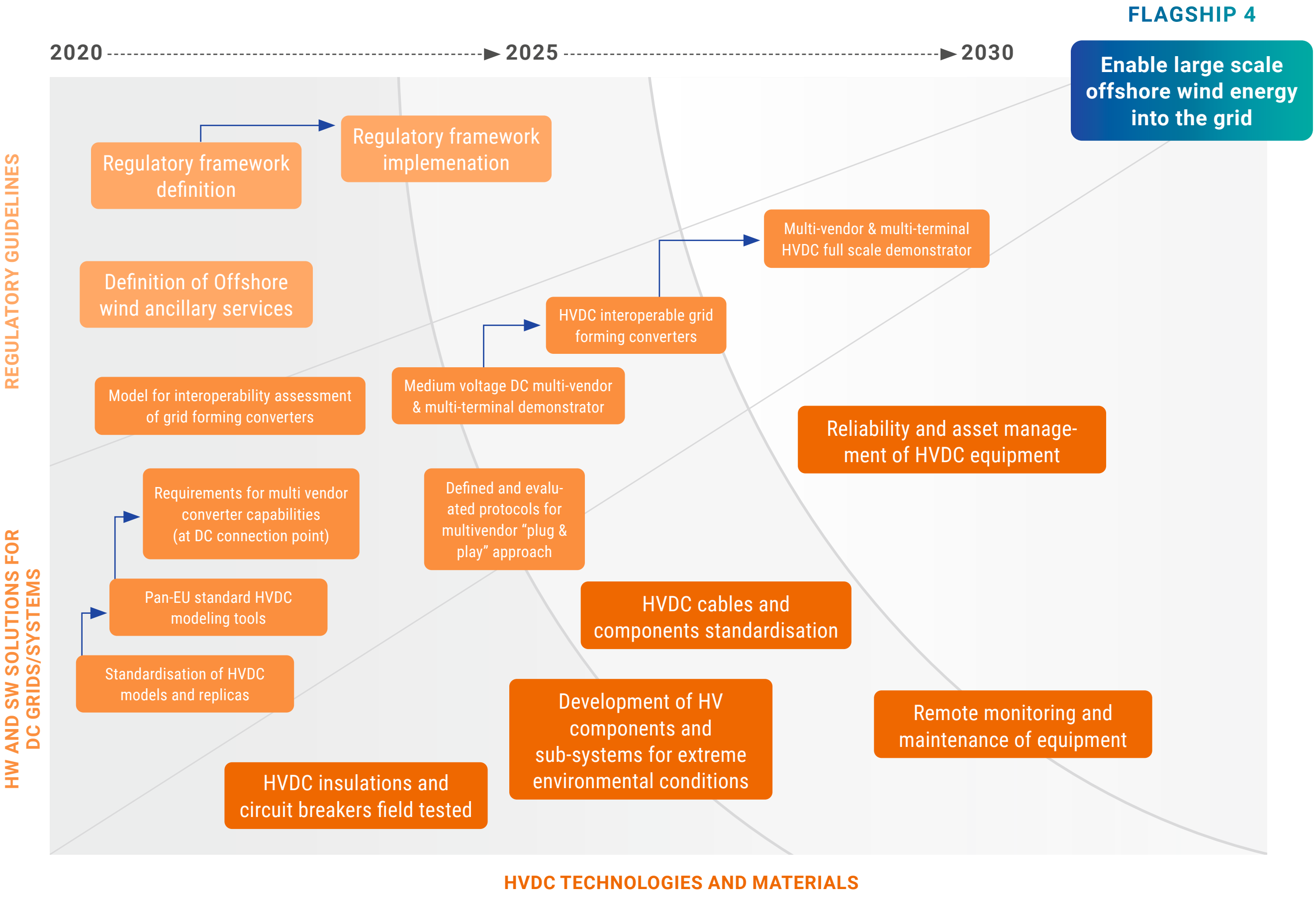


Figure 8: Flagship 4: Enable large scale offshore wind energy into the grid

Flagship 5: Enable secure operation of widespread hybrid AC/DC grid

The extensive deployment of DC links and of hybrid AC/DC grids is an innovation challenge that requires implementation of advanced solutions and methods.

AC/DC system modelling and consolidated procedures for **power quality monitoring and maintenance of hybrid AC/DC systems** will pave the way for the **assessment and validation of meshed DC grids**. In a longer term this, together with the availability of accurate, intrinsic grid parameters estimates, will lead to the **development of meshed DC grids**.

As for the control and protection of hybrid AC/DC grids, key technological aspects to be addressed in the short-term include **assessments of the interactions between AC and DC parts of the system** and **inertia management by grid forming converters**.[13] Correspondingly, at the systems level, **fast system frequency change identification tools** have to be developed and validated, together with real-time RoCoF estimates, to facilitate support system control and management, and the deployment of Fast Frequency Response services by fast acting power electronics-based generators.

The evolution towards hybrid AC/DC grids also requires an update of the tools used for power system operation and control. This includes development and validation of **new protection schemes** and the **upgrade of power flow control tools to include DC grids**. In this **context controllability, stability, and reliability assessments** of the hybrid AC/DC system are of paramount importance. One of the final goals is to provide TSOs with new optimisation techniques to exploit the best new functionalities of hybrid systems.

Before 2025, consolidated and validated **network codes and guidelines updated with requirements for the DC side of grid forming converters** are needed. An accurate **DC faults propagation assessment** is crucial in order to understand and manage how faults within the DC part of the grid affect AC parts and vice-versa. The innovation activity within this Flagship will define a new regulatory framework supporting to fully exploit the new **ancillary services of grid forming converters**, such as synthetic inertia response and fast frequency primary reserves. At system level, restoration after a blackout is a fundamental challenge that must be fully addressed. A **restoration plan of the pan-European system** which considers all the new threats and available technologies, must first be developed and validated by means of small pilot projects, before being scaled up.

13 An important capability with an essential role due to the increasing number of inverter-interfaced generators and the AC/DC converters of the hybrid grids

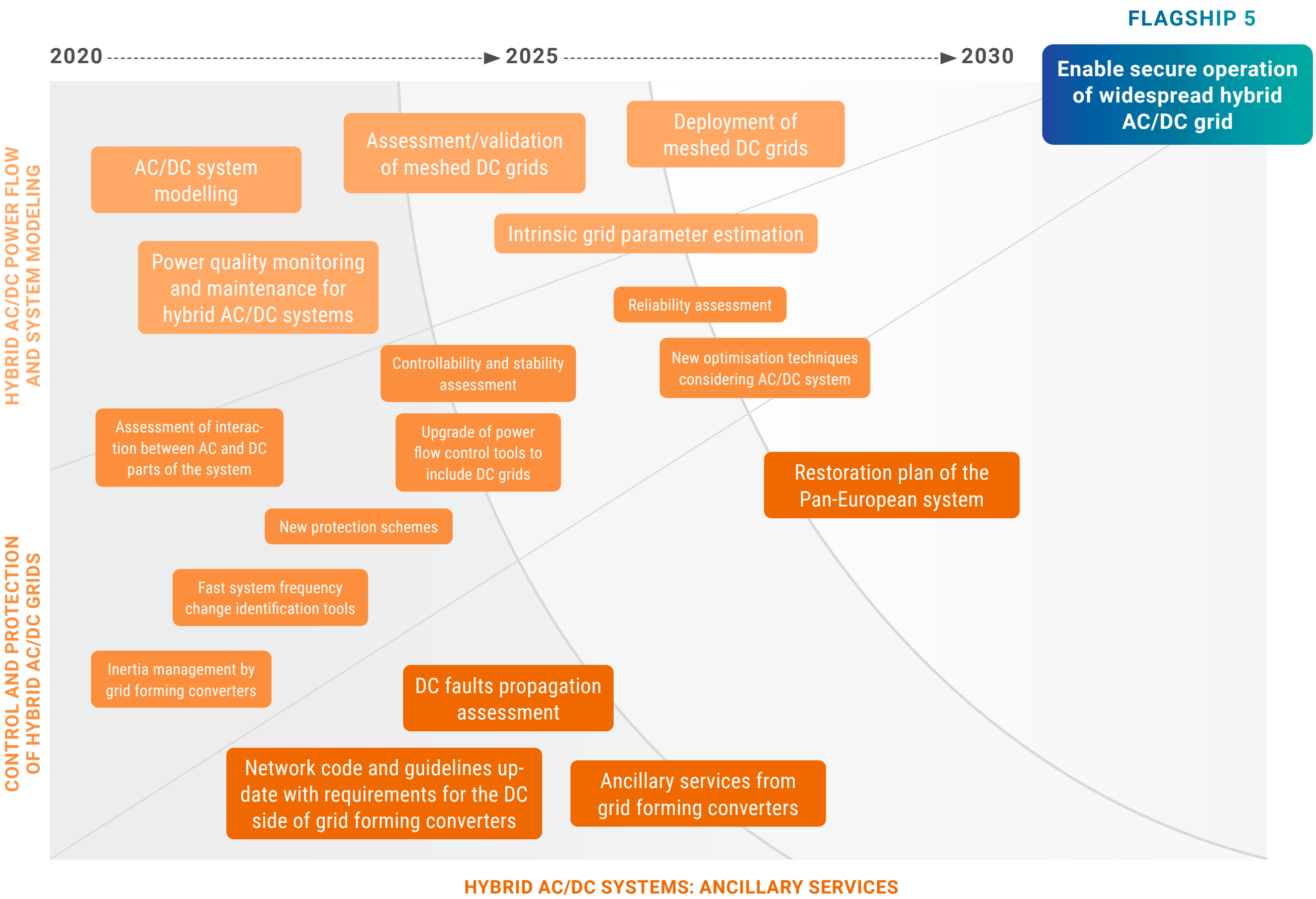


Figure 9: Flagship 5: Enable secure operation of widespread hybrid AC/DC grid

Flagship 6: Enhance control centres operation and interoperability

The energy system is becoming increasingly complex and interconnected. TSOs will have to cope with system management of different scales due to the coexistence of both micro- and mega-grids. However, future control centres will benefit and rely on enhanced ICT infrastructure for improved system monitoring and control capability. An important issue for TSOs is the preservation of the high level of security of the present "closed-loop" control and automation systems in new systems incorporating interaction among various actors and stakeholders, and some, such as customers, local grid and market operators, with weaker and lower-level protected IT systems.

The diffusion of ICT in the monitoring and control of infrastructure has yielded immense benefits while increasing the vulnerability grids to cyber-attacks. The availability of **vendor-independent solutions for control centres** has created an imminent need for **standardised data protocols**, and the development of methodologies and systems to ensure the **cyber security for control centres** is critically important.

The future system will be characterised by faster dynamics and the presence of different types of generators; new methods for on-line **dynamic security assessments** capable of considering the transient phase after a disturbance must be developed, and as the operating points of different generators could change rapidly, traditional off-line methods for security assessment will not be appropriate.

Important innovation achievements will include an enhanced integrated **Phasor Measurement Unit (PMU) usage for Wide Area Monitoring (WAM)** in the control rooms operation and the development and training of **AI-based decision support systems integrating technical, social, and ethical aspects**. This will enhance the security of the system and improve control centre operations. **High-speed protection and control for meshed AC/DC grids** is required for seamless deployment. An important target for TSOs is the development of a **cyber-secure and resilient pan-EU ICT platform for data exchange** to ensure the proper operation of the EU power system. However, the quantity of information and data to be processed and evaluated by control centres is increasingly large and complex; therefore, a long-term innovation target for TSOs must include the development of **backup procedures for automated systems**.

In view of the full deployment of such systems, TSOs need to consider **innovative training approaches** for control room operators to enable them to deal with all the new procedures and to empower them to intervene in the control process

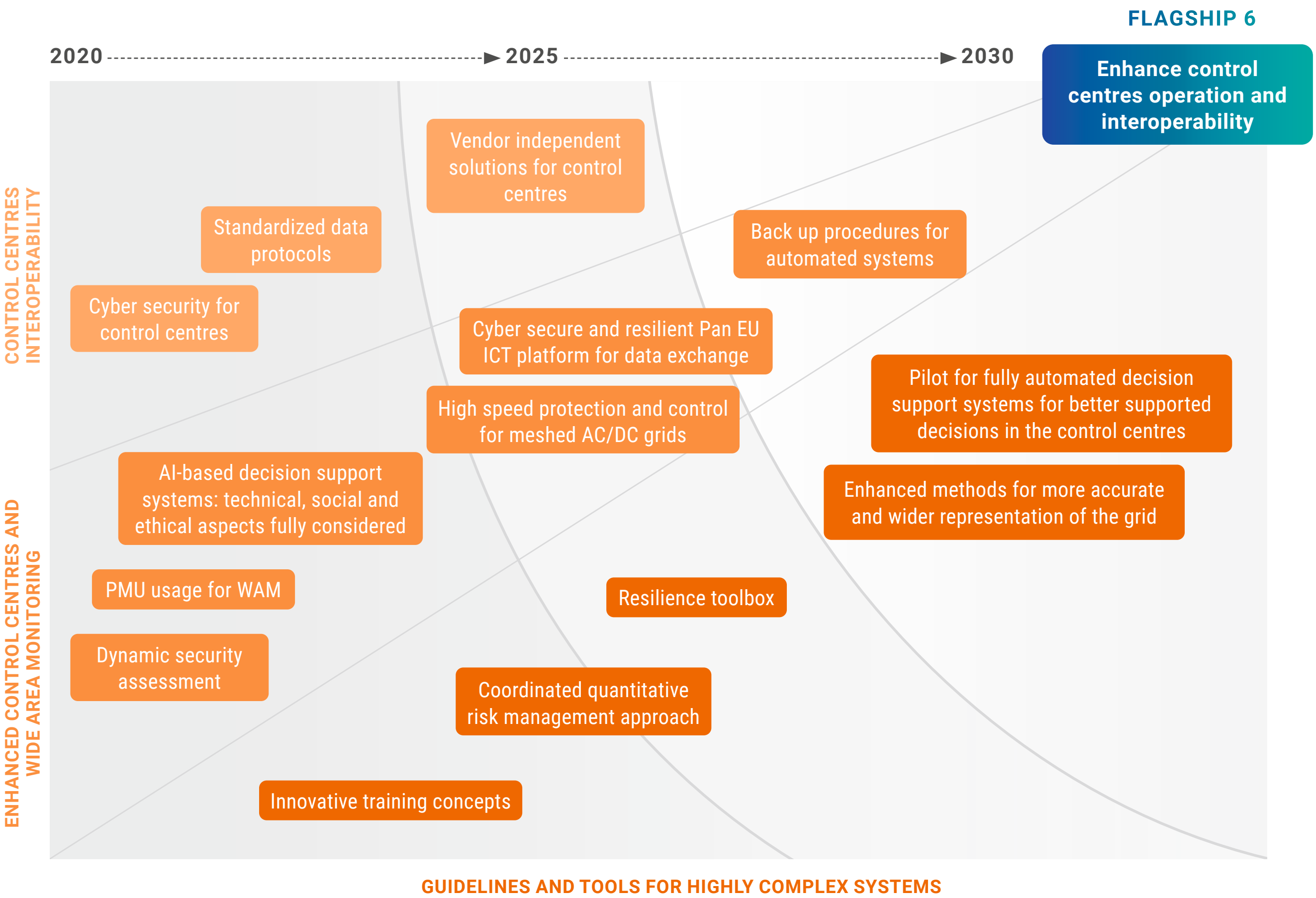
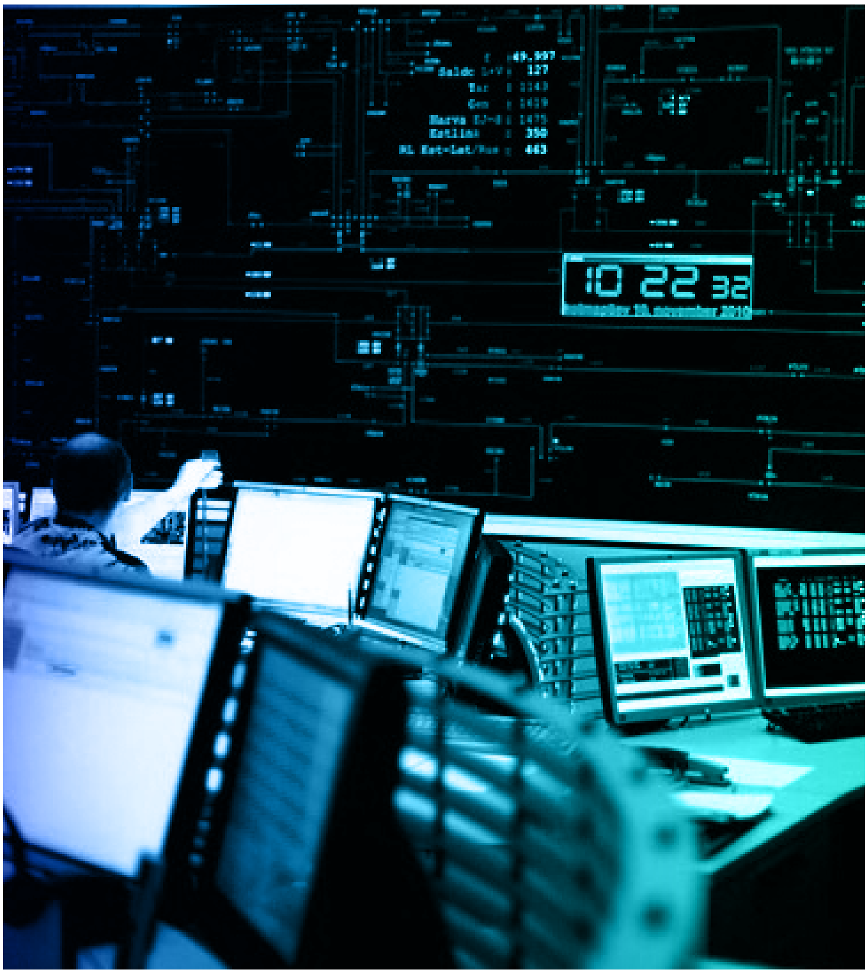


Figure 10: Flagship 6: Enhance control centres operation and interoperability

when human intervention is needed, especially in critical situations. Innovation achieve a more **coordinated risk-management approach** and the development of a so-called **resilience toolbox** for system operators to assist them with consistent assessment and improvement by at all times considering possible failures of both physical and digital infrastructures. One of the final innovation achievements is the development and deployment of **enhanced methods to create more accurate and wider representations of the depth and breadth of the grid**. The ultimate goal for this Flagship is to develop a **pilot for fully automated decision-support systems to ensure well- supported decisions in the control centres, particularly in times where quick action is required**.



Chapter 5: TSOs' current innovation portfolio

TSOs are committed to the achievement of the EU energy system goals and are fully engaged in many RDI activities, both funded directly or by different instruments available at national, regional, and EU levels. TSOs are active within the EU RDI framework, a vast system in constant evolution and with a large number of actors involved in a wide array of ever-changing interactions.

What follows is an overview of ongoing TSOs RDI activities based on the 2018 ENTSO-E Monitoring Report and the 2017–19 ENTSO-E Implementation Plan, clustered in five areas as shown in **Figure 11**.

Assets and Technologies

Asset management is one of the TSO core activities. Testing new solutions and developing new failure models is very important to fully understand how working conditions impact critical network components. This understanding enables the exploitation of the most cost-effective technologies, while increasing human safety and enhancing asset availability. Current RDI activities focus on new transmission systems components, enhanced power electronics converters, and applications of superconductivity. Another key innovation topic is the reduction of the environmental impact of grid assets – e.g. life-cycle assessment methodologies and finding alternatives to SF_6 and other greenhouse gases, as well as to the use of mineral oil in transformers. Recently, TSOs have also made important developments in optimal grid design and in planning methodologies and new software implementations.

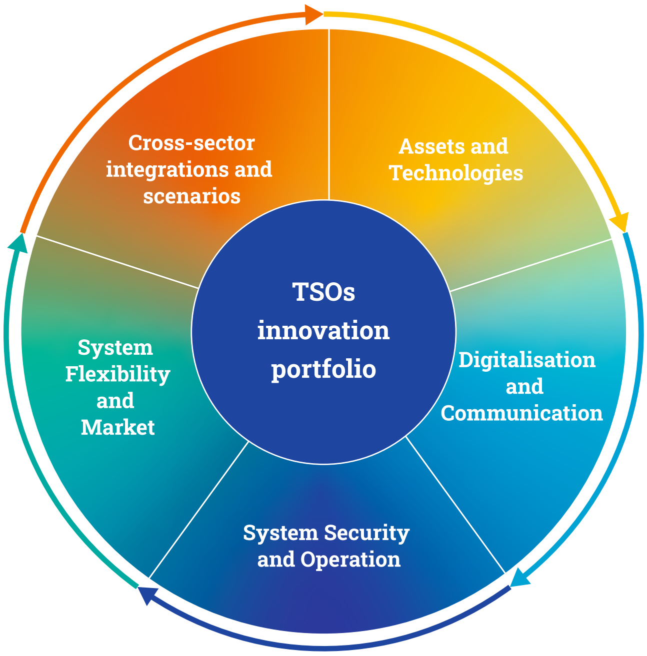


Figure 11: Main areas covered by the TSOs ongoing RDI activity

Digitalisation and Communication

Modern grids increasingly rely on ICT combining smart controls with hardware infrastructure. Digitalisation offers many opportunities for TSOs in terms of system and operational efficiencies, improved asset management, and performance. European TSOs are already investing in and engaging with a wide variety of digitalisation technologies and projects use cases. Significant progress has been achieved thanks to RDI activities developing grid observability tools, enhanced control and risk-awareness systems, methods for real-time evaluation of grid parameters, etc.

Significant innovation is also happening in control centres. There are now several ongoing RDI activities involving data hubs, ICT architecture, data protocols, and artificial intelligence.[14] Because digitalisation entails new risks too, RDI activities also focus on cybersecurity and critical infrastructure protection.

14 See ENTSO-E, *The Cyber Physical System for the Energy Transition*, 2019

System Security and Operation

TSOs must securely operate the power system while considering all likely contingencies, as well as high impact/low probability emergencies. Power system reliability and resilience, including risk assessment, defence, and restoration, as well as control methods, have been addressed by several TSO projects. Continuing RDI activities on these topics should include additional validation and demonstration steps. Moreover, several ongoing RDI projects are developing and validating suitable automatic decision-support systems, self-healing tools, and enhanced software platforms to help TSO control room operators better manage their daily activities.

Because data are crucial to the secure operation of the electrical system, RDI activities are also addressing the use of exogenous data in system operations, measurements from grid components, grid topology, and TSO–DSO communication interfaces.

System Flexibility and Market

The large-scale integration of renewables energy sources such as photovoltaic and wind energy can be done effectively only if system operators have the necessary tools to handle their inherent variability. In this respect, RDI projects have made good progress toward accurate power forecasting and management.

TSOs are now testing emerging power technologies and ICT to increase system flexibility and develop suitable market models allowing small scale, widely distributed resources, such as storage devices and demand response units, to provide flexibility services (especially in light of further transport electrification).

As neutral market facilitators, TSOs need to organise efficient and secure data exchanges between market parties. TSO RDI activities investigate a range of digital technologies such as blockchain in the ongoing effort to support secure information exchange and payments involving end users.

Cross sector integration and scenarios

Cross-sector integration – "sector coupling" – assumes the coordination of the different energy networks (electricity, gas, heat and cooling, transport, fuels, etc.) with the supply, storage (electricity and thermal) and end use (transport, industry, households, and services). European TSOs are preparing to deal with these challenges as well as to harvest the foreseen benefits.

In the past year, the integration of different energy vectors has become quite relevant in future system development. At EU level, ENTSO-E and ENTSOG have, for the first time, developed coordinated scenarios for future infrastructure investment needs as part of the 2018 Ten-Year Network Development Plan (TYNDP). This collaboration will go continue, potentially expanding into new sectors like heat and transport.

Several EU-funded research activities are assessing the general framework for sector coupling and the related cost-benefit analyses when compared to other decarbonisation alternatives for specific use cases. At national level, TSOs are assessing the potential, the impediments, and the future TSO role in the integration of these sectors.

Chapter 6: Analysis of the current resources available for innovation

TSOs use different strategies and instruments for RDI activities. One option is to rely on external environments, including contracting and collaborating with research centres, universities, technology developers, and ICT providers. In this way, synergy among experts from different fields and organisations is created to tackle the new, multi-disciplinary power system challenges. TSOs also rely on their own internal RDI capabilities to assess the different RDI phases and steps. Among TSOs, different organisational models exist to pursue RDI activities.

Some TSOs have a central innovation department dedicated to performing and overseeing RDI projects and laboratory-testing new solutions; others are decentralising such activities by involving collaboration between different units to devise, validate, and implement innovative approaches and solutions. Despite these differences, TSO innovation strategy is always a collection of different ideas. In fact, TSO innovation activity is the outcome of both a bottom-up approach, whereby technical teams channel specific needs or innovation ideas up to executive managers, and a top-down approach, whereby innovation trends are agreed to within ENTSO-E, taking into account overall EU energy targets.

TSOs mobilise either internal or external innovation schemes depending on the specific RDI topic, budget availability, timeline/urgency, and other considerations. In general, TSOs prefer to lead or to be involved in RDI projects that starts from high TRLs in order to be in the position to reach new technological solutions at the end of the project or to launch a pilot project to test an already devised solution in the field. Nevertheless, TSOs are also active in longer-term projects and address less mature topics and lower TRLs.

TSOs are regulated bodies and their financial expenditures must be compliant with the regulatory framework set by the different National Regulatory Authorities (NRA); this includes TSO RDI investments. However, the situation is not fully homogenous across Europe. NRAs have significant influence over the funding of RDI projects, especially setting tariff schemes to support TSOs innovation activities; however, tariffs are not the only financial source for TSO innovation activities. EU-funded projects are also an important source of funding for RDI activities, and in many cases, TSOs can also seek financing through national budget allotments and incentives.

ENTSO-E analysed TSO-involved projects in recent years. In its 2018 Monitoring Report 2018, 32 % of TSO RDI projects were funded by EU programmes, either the Framework Program 7 or Horizon 2020. Projects funded through other sources usually address topics where TSO management requires immediate results. EU-funded programmes tend to finance larger RDI projects with budgets over 1 M€ (some exceeding 10 M€), while nationally-funded projects are usually lower budget – i.e. hundred of thousands euros.

ENTSO-E analysed TSOs RDI efforts through key parameters which are reported in **Table 1**[15]. It should be noted that

Share of total yearly budget dedicated to RDI	Average share of total employees dedicated to RDI
0.50 %	0.36 %

Table 1: Selected parameters considered to rate the TSOs RDI effort.

budgets for RDI in the last four years (2016–2019) show a slight increase in comparison to the 2013–2015 period but still remain as lower than 1 % of total revenues.

Taking into account the total number of employees per TSO, the share dedicated to RDI activities is approximately 0.36%. The size of the TSO does not seem to have an impact on percentage of annual budget dedicated to RDI activities. Moreover, regarding the highest percentage of employees fully dedicated to RDI activities with respect to the total number of employees was 1.65 %.

By using a use case approach and the prioritisation of activities around a few well-defined Flagship projects, this RDI Roadmap aims to mobilise and enhance the RDI efforts and spending of TSOs and through the next years which will be made even more visible in the implementation phase.

15 ENTSO-E, "RDI Governance and innovation uptake" (internal report) by Dowell Consultancy

Chapter 7: Towards implementation

TSOs have defined a suitable innovation strategy to address the foreseen challenges described in the present 2020–2030 RDI Roadmap. This strategy assumes an enhanced synergy among TSOs to avoid overlaps and assure coordination towards common goals. The main challenge for the implementation of this strategy is the number of milestones to be achieved already by 2025 (see Figure 4).

The successful implementation of this RDI Roadmap depends on the leveraging of ongoing RDI activities to include interest in and commitment to the new six Flagships.

Leveraging the current ongoing TSO RDI activities

Leveraging on the current ongoing TSOs RDI activities and the recent projects' results will be key to delivering innovative solutions in the given timeframe. The ENTSO-E survey aimed at collecting updated information about TSOs ongoing RDI activities and projects with respect to the 18 selected relevant RDI Topics (T1.1. –T6.3) presented in Figure 12 which shows to what extent TSOs current innovation portfolio matches the RDI topics identified in the present RDI Roadmap (see Chapter 5 for more details).

The figure shows a good match between the 18 RDI Roadmap Topics and present TSO priorities. There are seven RDI Topics that are addressed by 80% or more of TSO respondents. Topics included in Flagship 2, "Ecosystem for deep electrification," are the most addressed by TSOs' ongoing RDI projects. RDI Topics related to the Flagship 3, "Enhanced grid use and development for pan-EU market," and Flagship 6, "Enhance control centres operation and interoperability," are also receiving a lot of attention. In contrast, less than 30% of interviewed TSOs are currently addressing the RDI Topic, "Integrated system governance"

Figure 12: ENTSO-E 2020 survey: selected RDI topics and their coverage by TSOs present innovation

TSOs' planned future RDI activities

In the survey, TSOs were asked to indicate the level of interest in the RDI topics covered by the six Flagships of this RDI Roadmap. Figure 13 shows that a high share of TSOs expressed their willingness to engage and to lead specific projects (and/or work packages) within the different Flagships. Flagships 1 and 2 account for the highest TSOs availability to lead a project or a work package. Several TSOs also indicated their willingness to provide technical expertise for Flagships 5 and 6 and in general for all the Flagships, as an important indication to open and fruitful cooperation.

Figure 13: Level of TSO's foreseen future engagement on the six Flagships

Type of RDI activity and projects to be launched

Regarding the type of RDI activities to undertake for each of the Flagships, Figure 14 indicates, by percentage, the type of RDI projects considered appropriate to cover the different topics. They are ranked from the least to the most resource intensive type of RDI activity: regulatory analysis, simulations/studies, new tools/feasibility studies, small scale demo/prototypes, and large-scale demos.

For all Flagships, simulation/studies are indicated as an appropriate mean. Large-scale or small-scale demo are appropriate to be launched for all the different Flagships, and the number of TSOs indicating the need to launch demo projects is particularly high for Flagship 3 related to markets and enhanced grid use as well as for Flagship 6 dealing with control centres. The need for a full- or small-scale demos is also high for Flagship 4 covering offshore grid development.

For ongoing TSO RDI activities, interest in the RDI activities of the Flagships presented in the RDI Roadmap requires future commitments, mobilisation of different funding sources, and actions at national, regional, and pan European levels.

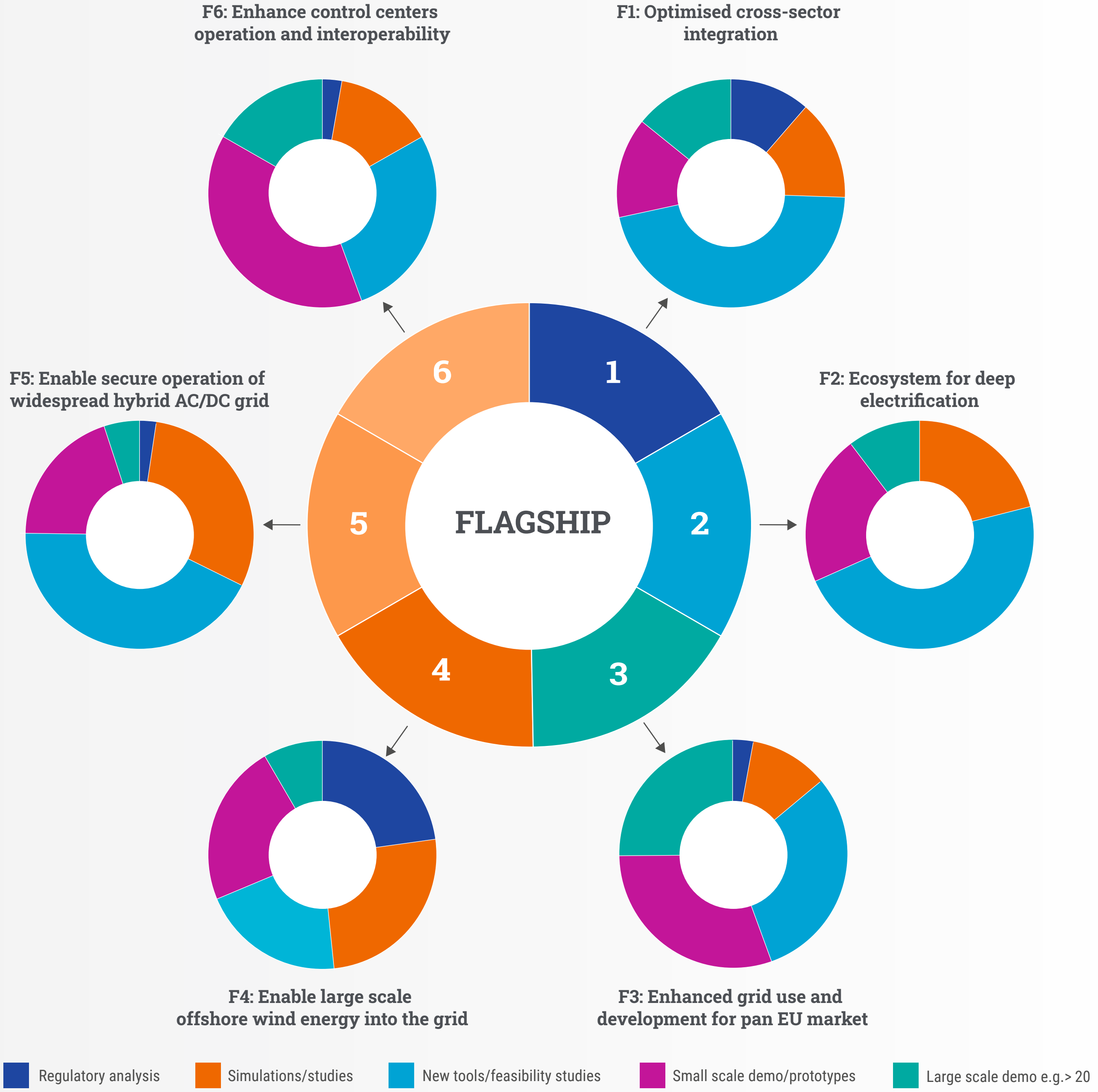


Figure 14: TSO's survey: foreseen type of RDI activity and projects

Chapter 8: Conclusion and next steps

The ENTSO-E RDI Roadmap with the three RDI Clusters and six Flagships prioritising the TSOs RDI activities for the next ten years requires the mobilisation of the whole energy value chain, enhanced cooperation with other actors, and innovative structures that will mobilise the ecosystem on reaching the decisions, rules and initiating use case or mission oriented long term actions. It also requires the pooling of different resources financial and human capacity being from own TSOs resources, tariffs, national and pan European RDI funds.

The RDI Roadmap is expected to deliver not only solutions for TSOs and the transmission grid but benefits should emerge for the whole energy system in terms of security of supply, more and better integration of renewable energy sources, environmental protection, optimised use of infrastructures, enhanced customer engagement and services.

The ENTSO-E RDI Implementation Plan following this RDI Roadmap will address more in detail how the RDI activities within individual Flagships will be carried out in order to reach the foreseen milestones. With a clear focus on just a few prioritised topics per year, the Implementation Plan represents a crucial step in making innovations into realities.

Drafting Team

Sonja Berlijn, Statnett (Norway)

Håkon Borgen, Statnett (Norway)

Mattia Cabiati, Ricerca sul Sistema Energetico – RSE (Italy)

Antonio Iliceto, Terna (Italy)

Luciano Martini, Ricerca sul Sistema Energetico – RSE (Italy)

Luca Orrù, Terna (Italy)

Nuno Pinho Da Silva, Rede Eléctrica Nacional S.A (Portugal)

Uroš Salobir, Eles Ltd. (Slovenia)

Vladimir Stanojevic, JP Elektromreža Srbije (Serbia)

Diana Stefanova, Elektroenergien Sistemen Operator EAD (Bulgaria)

Victor Charbonnier, ENTSO-E

Norela Constantinescu, ENTSO-E

ENTSO-E would like to thank Ricerca sul Sistema Energetico – RSE for its contribution to the supporting analysis and drafting of the present RDI Roadmap.

Acronyms

Acronym	Definition
AC	Alternating Current
CBA	Cost-Benefit Analysis
DC	Direct Current
DSO	Distribution System Operator
HVDC	High-Voltage Direct-Current
ICT	Information and Communications Technology
NRA	National Regulatory Authorities
PMU	Phasor Measurement Unit
R & D	Research and Development
RDI	Research, Development and Innovation
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
WAM	Wide Area Monitoring

European Network of
Transmission System Operators
for Electricity

ENTSO-E

Research, Development & Innovation Roadmap 2020–2030

entsoe