RDI Implementation Report 2021–2025

Project concepts for delivering the ENTSO-E RDI Roadmap 2020–2030

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ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 39 member TSOs, representing 35 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

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Executive Summary

This Research, Development and Innovation (RDI) Implementation Report 2021 – 2025 will be the guiding instrument for the collaborative research programme of transmission system operators (TSOs) in the coming five years. The report prioritizes the goals outlined in the ENTSO-E RDI Roadmap 2020 – 2030 [1]. It lays out thirteen project concepts (Figure 1) to be initiated by TSOs in collaboration with key stakeholders and supported by policy makers and regulatory authorities in the coming years. These projects come at a pivotal time, when the European Green Deal is taking form with integrated energy systems and smart electrification at its core.

Figure 1 – Thirteen project concepts are set out in this ENTSO-E RDI Implementation Report 2021 – 2025

Although the task ahead to transform the European energy system is enormous, this Implementation Report keeps a clear focus on the main priorities and conveys as clearly as possible the RDI outcomes to be reached. The thirteen project concepts deep dive into the system challenges that TSOs identified in the long run, what recent RDI projects have been delivered already, and which gaps require urgent addressing.

The thirteen project concepts (see Annex I for a more detailed description) are more tangibly outlined than in earlier reports, more system-challenge focused, and less technology driven. They still focus on what is relevant for TSO core activities in ensuring a cost-effective, secure energy transition. An overarching aim is to bring innovative ideas to a technology readiness level (TRL) which allows their uptake in grid planning, asset management and operations. To make this happen, collaborative RDI needs should be identified to aim for the development of prototypes, tools, methods and assets, and push ahead towards field demonstration projects. Although this Implementation Report has a topical focus, additional attention will be required on how to integrate the innovations and demonstration insights into TSOs' operational daily practice. At the same time, the combined set of project concepts allow for an agile research programme as each project concept has its own focus with limited interdependencies and most have a duration of about three years, along with a clear outcome expectation for the transparent follow-up of deliverables and impact. This Implementation Report is part of a dynamic process. It requires review and update every few years, following new technology developments and system needs, and is pushing for high TRL demonstrators in short time horizon.

The total budget to facilitate TSOs efforts for execution of the plan and deliver its benefits is estimated at close to € 130 million. More detailed quantifications will be required when these project concepts are further developed into concrete project proposals, including the development of total project budget. Funding is anticipated to come from EU mechanisms such as Horizon Europe and the Connecting Europe Facility, as well as from national programmes that enable international collaboration, TSOs' own resources.

ENTSO-E's TSO community will coordinate efforts closely in the coming years and commits to working actively with key stakeholders to deliver the goals of the RDI Roadmap and implement its first critical steps via this Implementation Report.

RDI vision

A guiding instrument for implementing collaborative TSO RDI

ENTSO-E's TSO community is committed to driving innovation in the energy sector. The path towards a net zero emissions system by 2050 requires new strategies and the upscaling of emerging technologies. Equally important, it requires a laser focus on truly addressing the system challenges TSOs observe in their core activities of system planning, operations and market facilitation. TSOs are already ramping up investment programmes for new infrastructure and implementing smarter system solutions, and various TSOs have set the goal of being able to run a system with 100 % renewable infeed in the coming decades.

This RDI Implementation Report charts the collaborative path TSOs intend to take in the coming years. It builds on the vision set out in the ENTSO-E RDI Roadmap 2020 – 2030 and translates this into tangible RDI project ideas. The Implementation Report justifies the prioritisation of activities and serves as a guiding instrument for TSOs and the wider energy sector to prepare and activate urgently required RDI projects.

The European Green Deal's ambition serves as a lighthouse for concerted action. A mix of linear and disruptive energy system transformations will play an important role in reaching this target via deeper digitalisation of the energy system, continuous improvements in power system use and a truly cross-sector approach.

The European Electricity Market Regulation (2019/943) mandates ENTSO-E to develop joint research plans and deploy those in an efficient programme-based approach. This work builds on earlier RDI roadmaps and implementation reports, as well as the track record of TSOs in collaborative innovation. This new Implementation Report follows the course set by the Roadmap 2020–2030. It provides the basis for ENTSO-E RDI activities and their concrete planning and coordination in the coming years. It also fully aligns with the clean energy system transformation set in motion by policy makers and markets.

ENTSO-E's RDI Roadmap 2020–2030 sets a clear ambition

To deliver transformational change, the ENTSO-E RDI strategy of the Roadmap 2020–2030 centres around six flagship areas (Figure 2). These flagships give a milestone approach to addressing the key challenges over the coming decade.

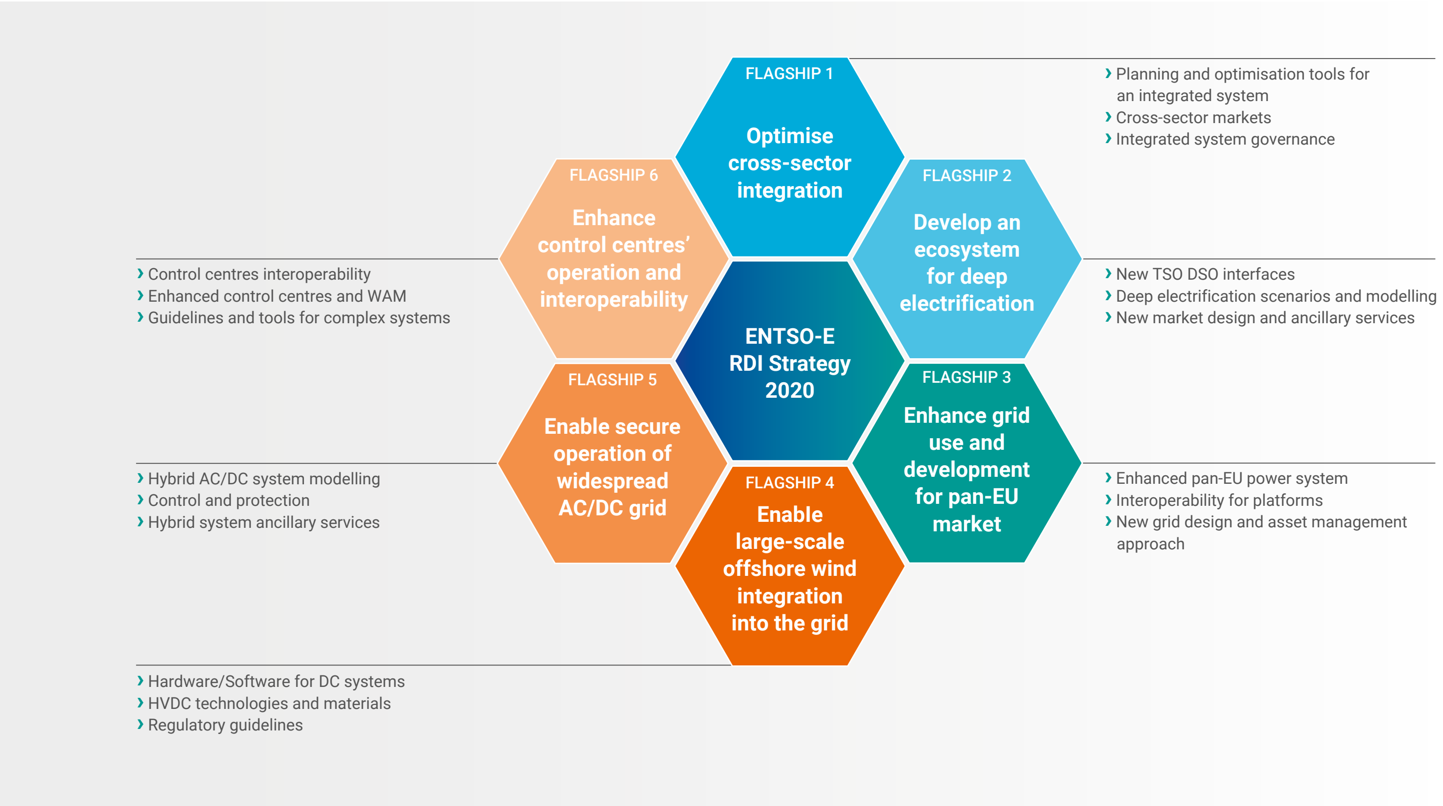

Figure 2 – RDI Roadmap 2020–2030 flagships and the main topics addressed in each

The six flagships are portfolios of interlinked high-level use cases, each represented as a milestone. The Roadmap's six flagships cover over 80 milestones. These are classified in a number of topics for each flagship as shown in Figure 1. These milestones are prioritised in time based on interdependencies and urgency, and sequenced as short-term (2020–2023), mid-term (2023–2027) and long-term (2027–2030) ambitions. The strategy abides by new key principles (Figure 3).

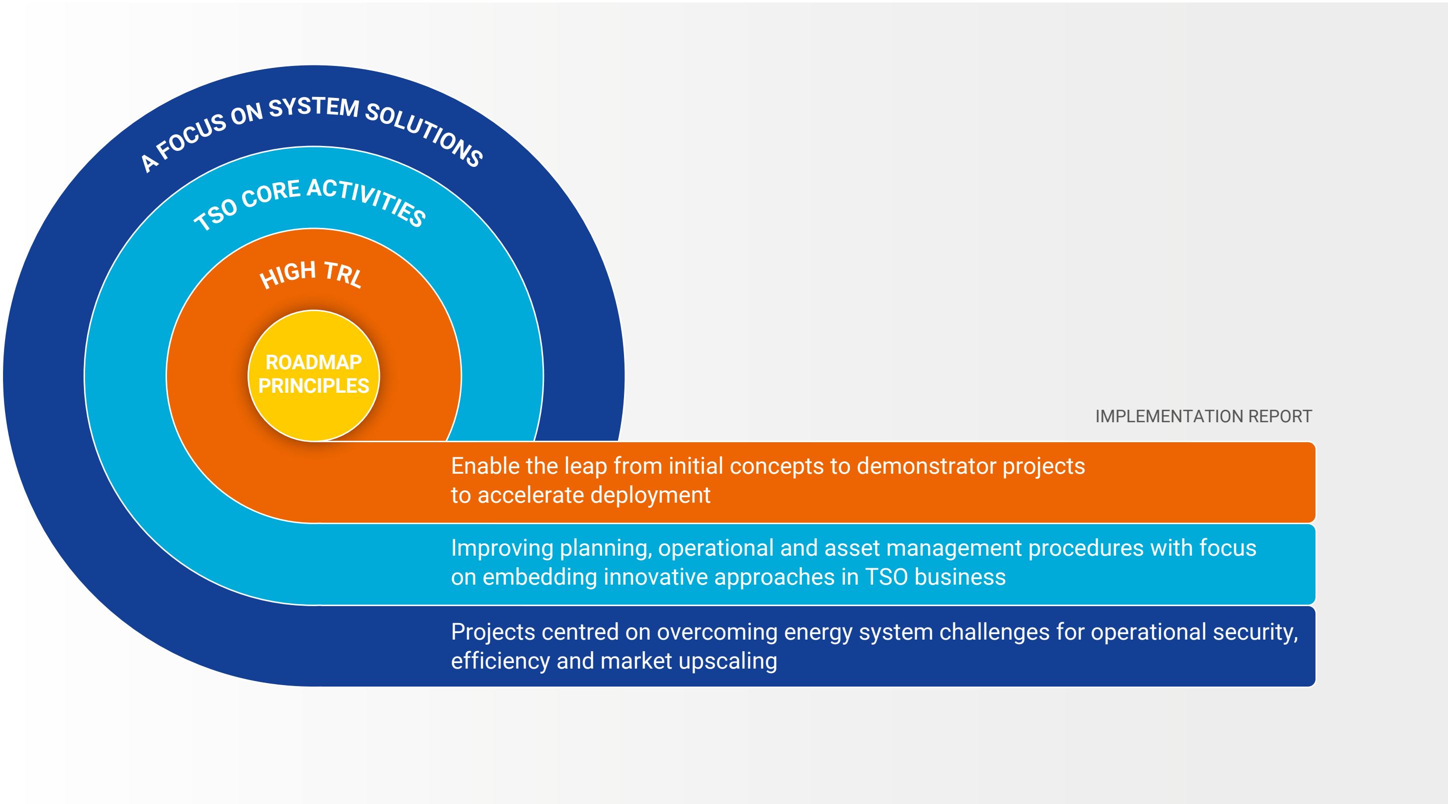

Figure 3 – Roadmap principles applied to the Implementation Report

Key actions for the coming years

Priority projects to turn innovative ideas into reality

For the set-up of this RDI Implementation Report, ENTSO-E closely examined the following questions:

- Do the Roadmap flagships reveal new areas compared to our earlier **RDI Implementation Report 2017–2019?**
- What did we achieve from recent collaborative TSO projects, either at national level or looking at those delivered or ongoing under the EU Research and Innovation programme **Horizon 2020?**
- Where did we see other energy related research projects in **which TSOs did not participate?**
- For which short- and mid-term milestones do we see the **largest gaps between technology readiness levels and system needs?**

This assessment resulted in the identification of thirteen project concepts which TSOs collaboratively plan to undertake in the coming years (Figure 1). In addition to the main principles of the Roadmap, a set of additional criteria guided the selection. First, to reach meaningful results which can truly advance the technology readiness level (TRL), be integrated in TSO business, and be taken up by other market parties, the projects must have a clear focus: 'To do two things at once, is to do neither.' Therefore, all project concepts focus on one or maximum two milestones. The envisaged number of outcomes is not inflated but kept manageable and catches those most urgently needed. Second, the project concepts are kept as independent as possible from each other. This allows for an agile sequencing based on resource and budget availability, as well as enabling consideration of ongoing market and policy developments. Third, as the Roadmap's ambition is to achieve a high TRL, most projects focus on the key phases of field demonstrators or advanced prototypes; typically bringing fundamental concepts to TRL 6–9 (see Annex II for a further clarification of TRL definitions).

The following section summarises the state of play in each flagship and the reason for prioritising a set of project concepts in each. These project concepts are general outlines of a collaborative RDI activity in the coming years, with a substantial drive given by TSOs, and most often together with other relevant and interested stakeholders. Further details on each project concept are given later in this Report. Each project concept is presented in two pages, covering a set of key points (Figure 4).

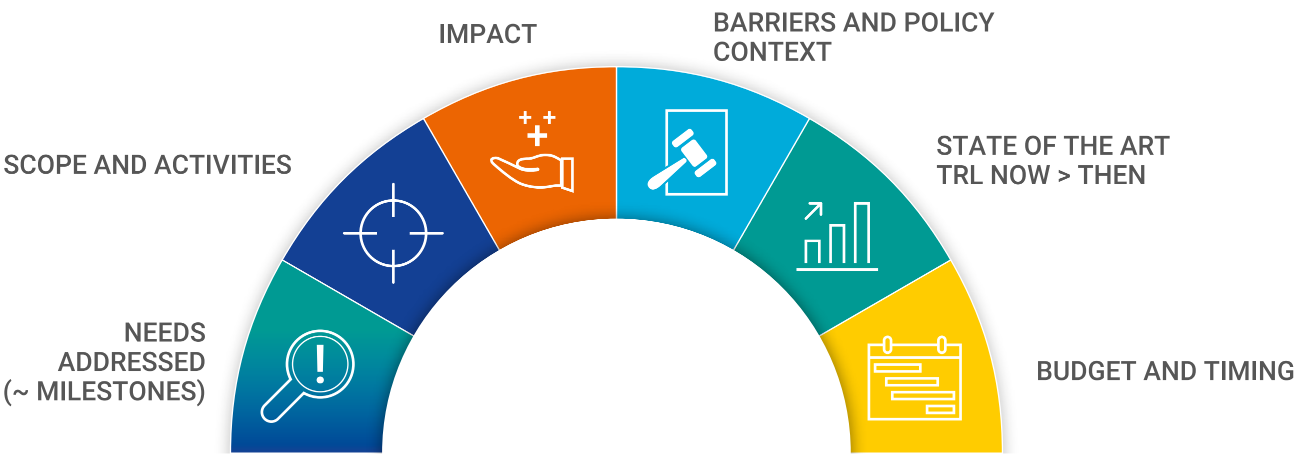

Figure 4 – Descriptions for each project concept in this RDI Implementation Report

Flagship 1 aims to optimise cross-sector integration

The importance of integrating all energy carriers in an effective manner is at the heart of Europe's decarbonisation efforts. It is emphasised in the European Commission's (EC's) recent Energy System Integration strategy [8] and actual progress is made in the joint Ten-Year Network Development Plan (TYNDP) work of ENTSO-E and ENTSO-G [13]. Although recent years have seen many announcements such as P2X infrastructure pilots, long-term decarbonisation strategies or local pilots for system flexibility from smart electric vehicle (EV) charging, substantial work is still to come to create a pan-EU integrated system view in planning, markets and regulatory conditions.

Joint gas/electricity scenarios are developed in the TYNDP or in other collaborative TSO projects such as the North Sea Wind Power Hub. Nevertheless, for most of the milestones in the Roadmap, first large-scale projects are still to be initiated.

The Implementation Report proposes four project concepts in this area, covering **the mass smart charging of EVs (P1), the development of innovative models and tools for coordinated multi-sector operation and planning (P2), the design of a pan-European cross-sector data model (P3) and provision of market architecture for the cross-sector integration (P4).**

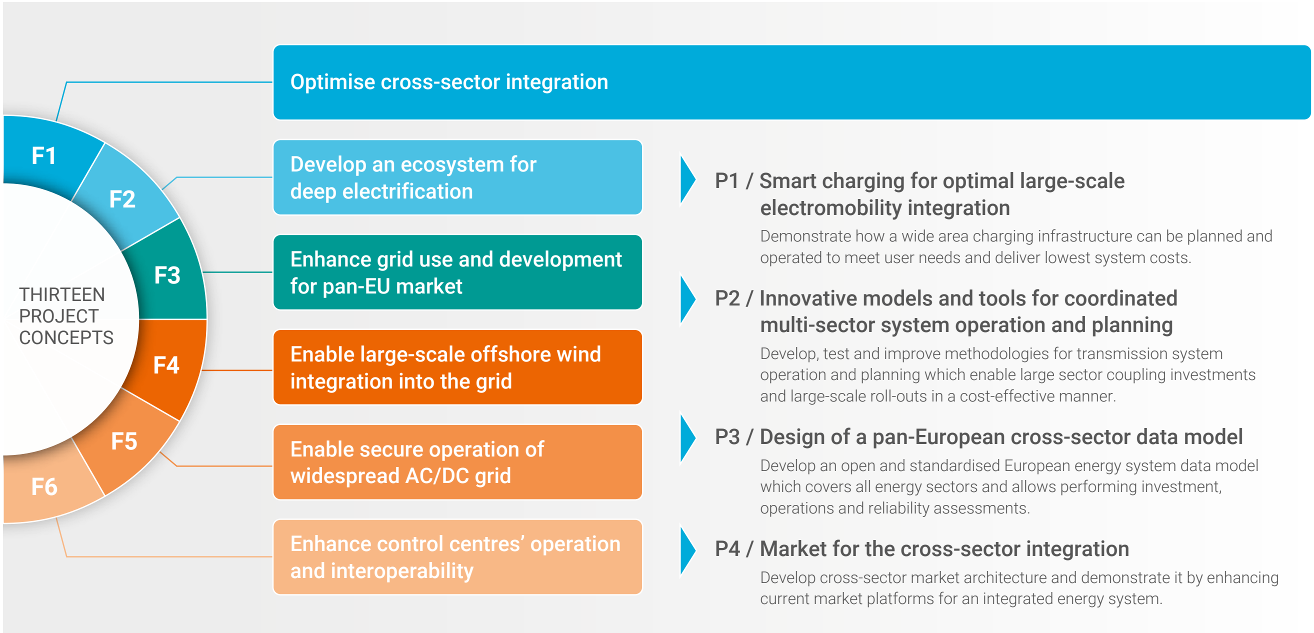

Figure 5 – Flagship 1 project concepts

Flagship 2 aims to develop an ecosystem for deep electrification

In the future integrated energy system, the increased electrification of final energy demand is an effective pathway for decarbonisation based on increasing shares of renewables and other low-carbon sources. This raises the importance of handling distributed flexibility, ensuring proper system planning and setting up new market mechanisms. This area has received significant attention in recent years, with many projects looking into enhanced TSO-DSO-prosumer interactions and large-scale flexibility ('platform') projects. Approximately half of the Horizon 2020 projects in which multiple TSOs have participated have already partially covered some of the milestones in this flagship area. The next steps are concerned with scaling up prototypes and ensuring these solutions are fit-for-purpose in a future cross-energy system.

This Implementation Report focuses on one project concept in this flagship to **integrate the coordinated flexibility potential to the future energy system of systems (P5) by harmonising flexibility assessments and demonstrating how market viability and energy system security can go hand-in-hand in a coordinated approach for a P2X plant**.

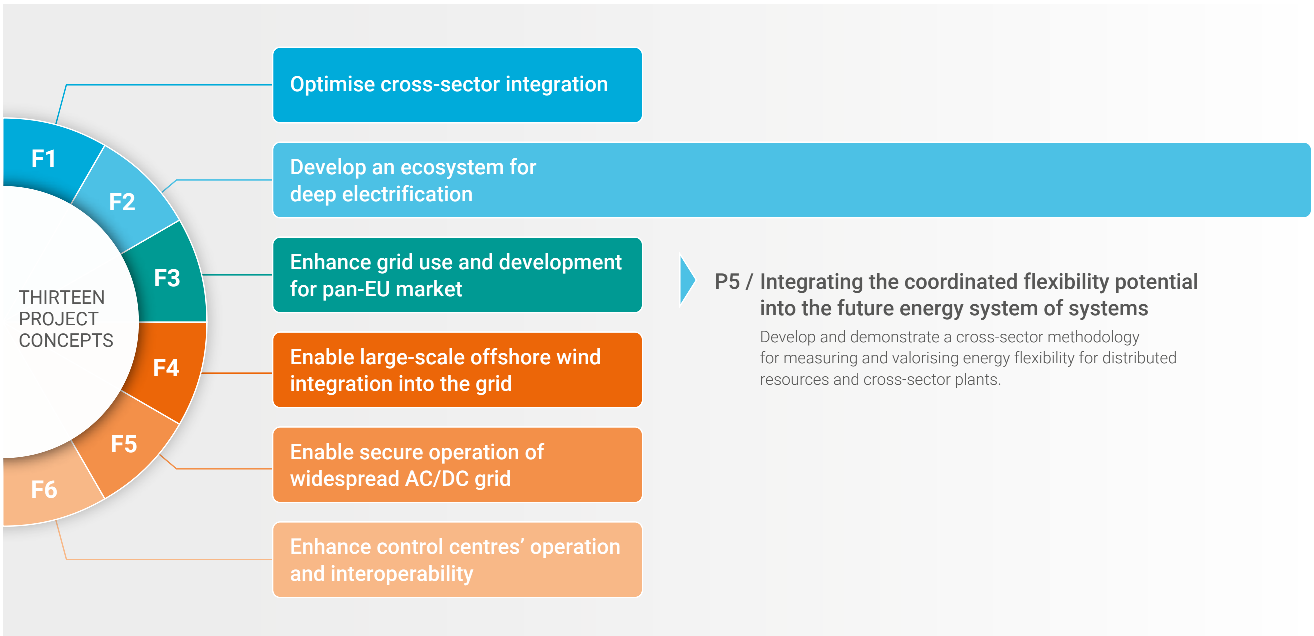

Figure 6 – Flagship 2 project concepts

Flagship 3 aims to enhance grid use and development for the pan-EU market

Recent RDI projects have focused mainly on collaborative ICT platforms, coordinated planning and the interoperability of systems. Core asset management processes from TSOs will also benefit from newer techniques to lower lifecycle emissions and get maximum utility from advanced digitalisation solutions; so far this has been mainly addressed in national initiatives.

This Implementation Report focuses in particular on new approaches to grid design and asset management. It proposes a project concept on **eco-design processes to reach SF_6-free solutions (P6), as well as a project concept to lower the carbon footprint of TSOs via lifecycle assessments embedded in smarter asset management processes (P7).**

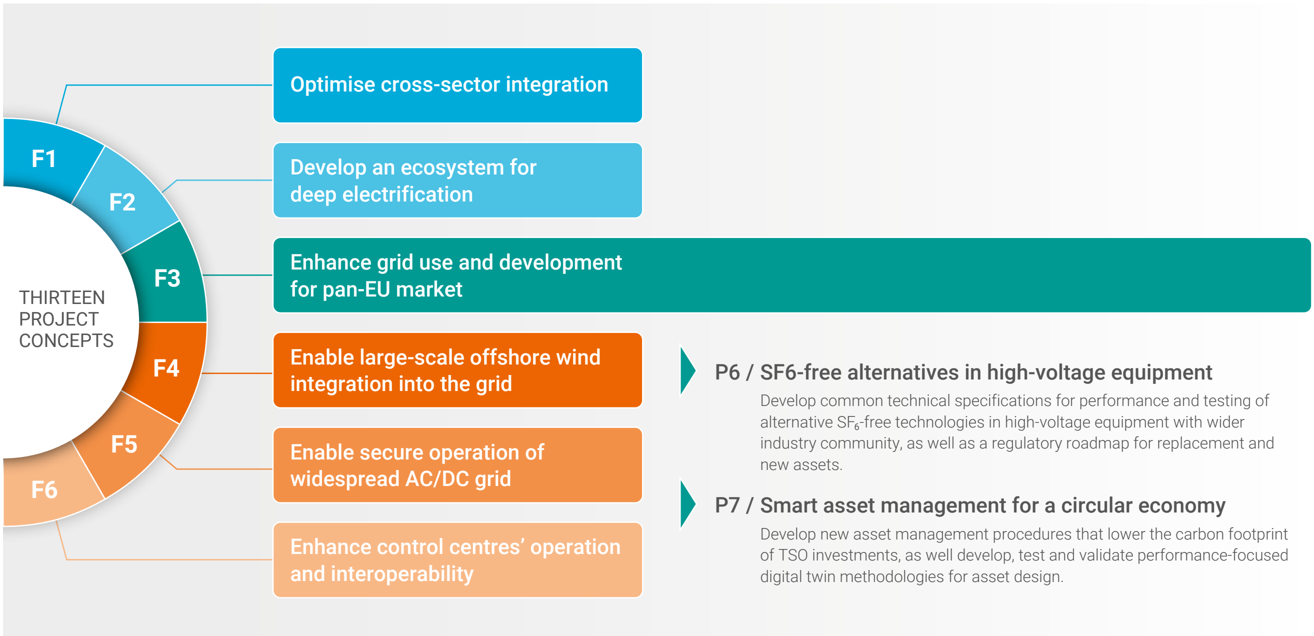

Figure 7 – Flagship 3 project concepts

Flagship 4 aims to enable large-scale offshore wind integration into the grid

The Green Deal goal is offshore capacity towards 100 GW by 2030 and several hundreds of GW by 2050. Recent projects have focused mainly on coordinated planning and regulatory conditions. Progress has also been made for specific technology options. In general, the majority of technical solutions required to reach these goals are available today. The main gap in this area focuses on interoperability processes and governance rules.

This Implementation Report aims to close this gap with two projects that focus specifically on interoperability, with **a first project concept developing an interoperability framework (P8) and a follow-up project demonstrating this in practice with a full-scale multi-vendor multi-terminal high-voltage direct current (HVDC) system (P9)**.

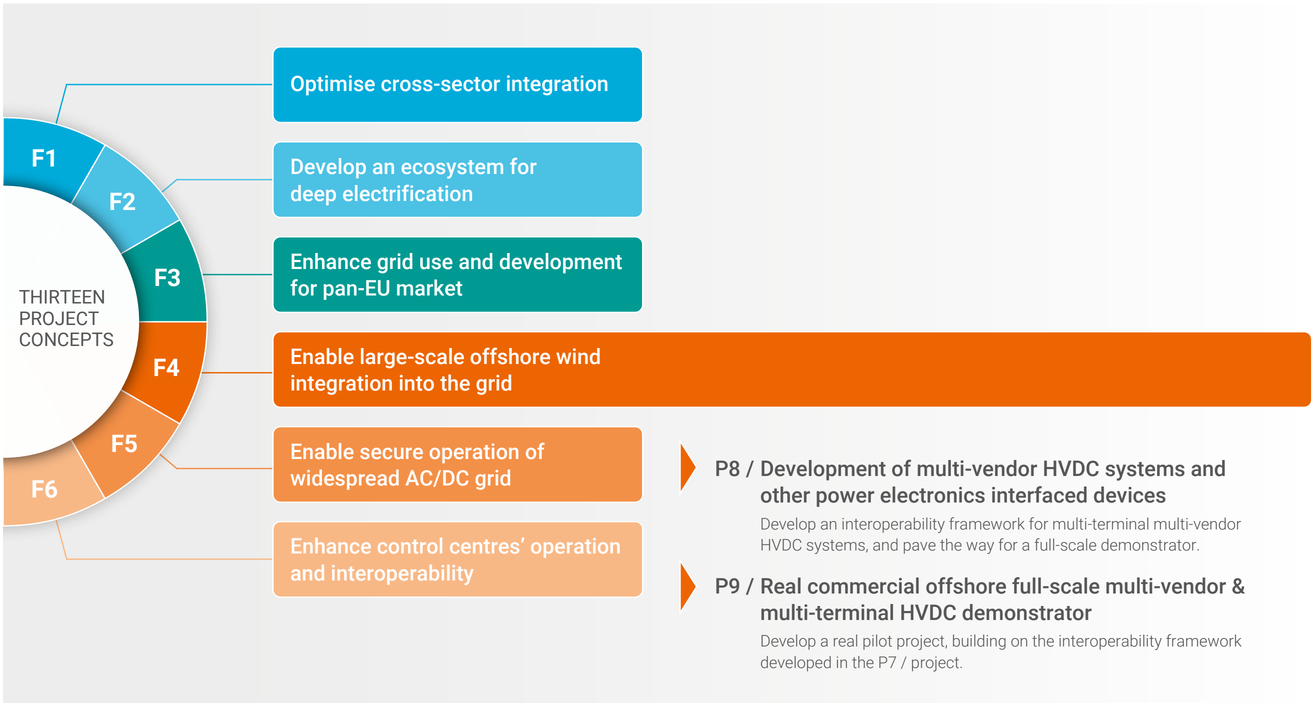

Figure 8 – Flagship 4 project concepts

Flagship 5 aims to enable a secure operation of widespread hybrid AC/DC grids

As the share of power electronic coupled sources increases in the system and as more DC projects are embedded in the system, the main needs are concerned with the capability to properly model such systems in planning and manage them in operations. These are urgently required next steps after earlier RDI actions focused mainly on technology concepts such as grid-forming converters (GFCs) and general techno-economic planning pathways for hybrid AC/DC transmission.

This Implementation Report suggests **a project concept on the stability management of a power electronics dominated system, including GFCs (P10), and another project on assessment models for interactions, controllability and protection schemes (P11).**

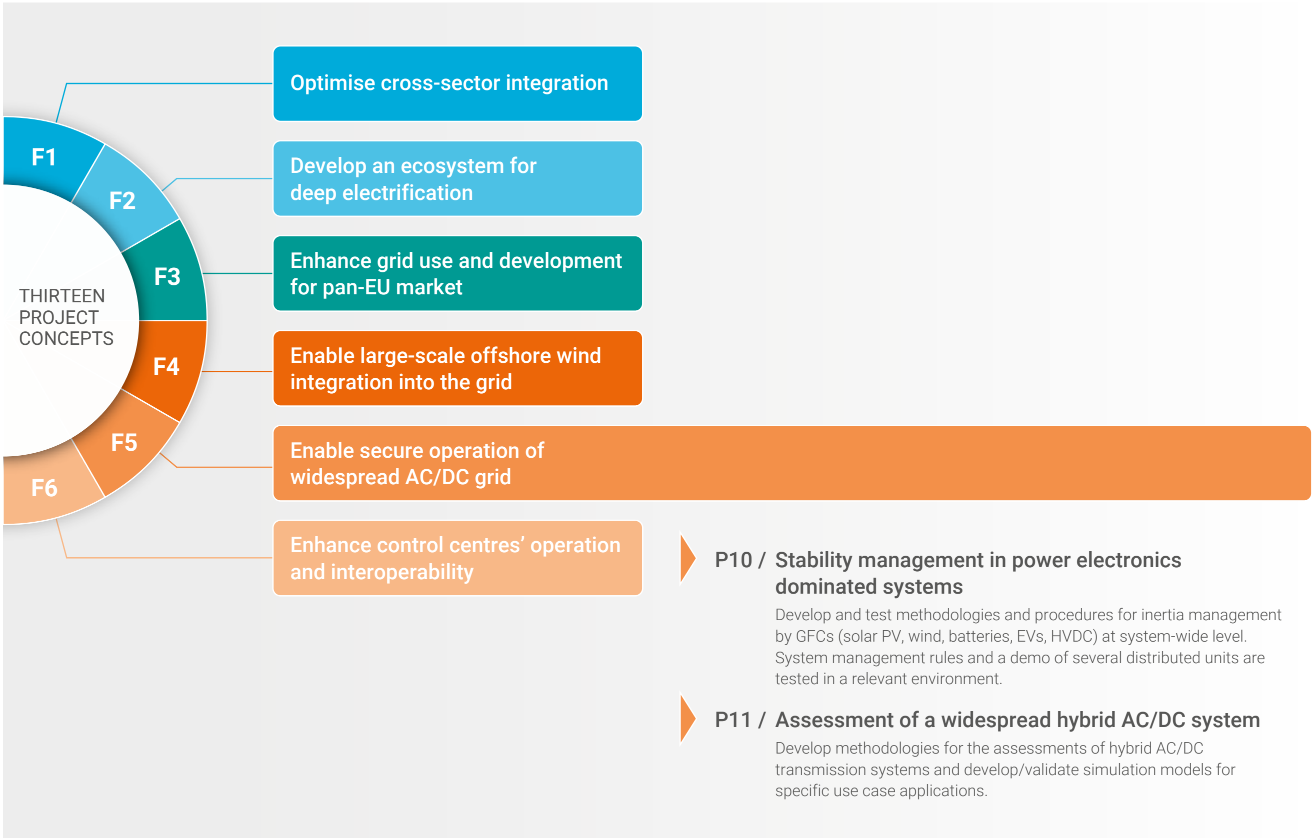

Figure 9 – Flagship 5 project concepts

Flagship 6 aims to enhance control centres' operations and interoperability

Recent RDI projects have focused mainly on the increased use of phasor measurement unit (PMU) data, probabilistic techniques in system operations and the standardisation of communication. With increased digitalisation of the system, cyber resilience also emerges as a key concern, which is mostly addressed at the national level and at initial steps at the European level, such as the preparation of a dedicated network code. Next steps towards the control centre of the future include a higher degree of interoperability in TSOs' Energy Management Systems, a further focus on AI-driven solutions and especially on mitigating cyber risks in an efficient manner.

This Implementation Report proposes **a project concept on cyber resilience schemes focused on control centres (P12) and one on open IT solutions to ensure TSOs can take an agile, cost-effective and secure modular approach in extending control centre platforms and applications (P13).**

Figure 10 – Flagship 6 project concepts

How to move forward from here?

All thirteen proposed project concepts have a clear, specific system challenge focus. This is intentional to maximise the relevance of project outcomes in increasing TRL and their ability to be integrated in TSO core businesses. It also enables all projects to be initiated in an agile manner depending on a fast changing context, and to each be run in 3 – 4 years' time.

Figure 11 shows the timeline for all project concepts. Overall, the project concepts have no strong interdependencies, which enables flexible planning. Exceptions include project concept P9, which critically depends on P8 as it is a full-scale demonstrator for an interoperability governance framework, which is still to be developed in the preceding project. Project concept P3 ideally builds on P2 for specifying data requirements; this can start before P2 is finalised so this is a natural connection but not a critical interdependency. In the same manner, project concept P7 can take some input from P6 in terms of asset inventories, which is also not a critical interdependency.

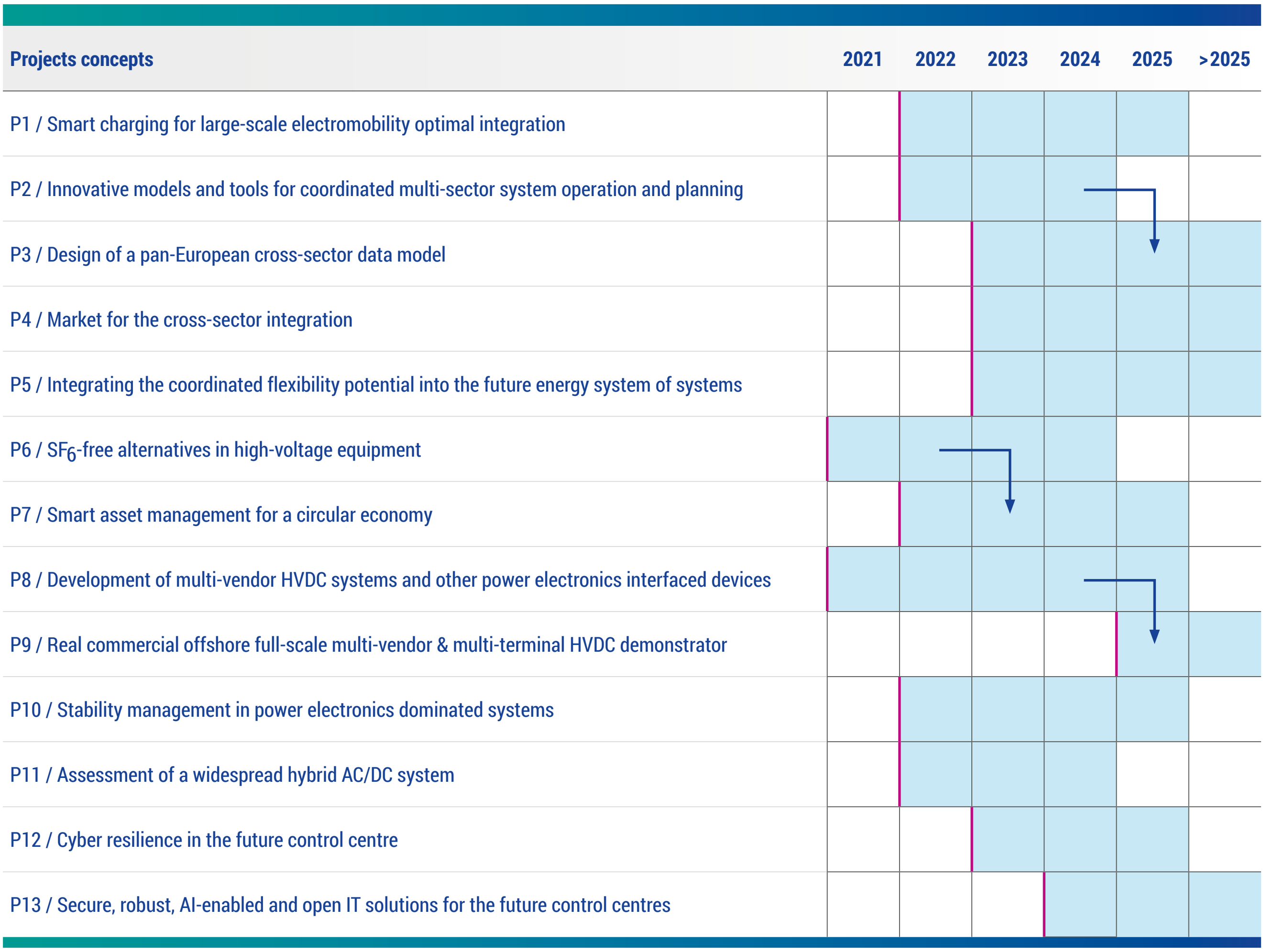

Figure 11 – Timeline for the project concepts of this RDI Implementation Report

RDI progress

Leveraging earlier RDI project results

The future RDI project concepts concentrate on system challenges to enable a secure, affordable and clean energy system. It is crucial to understand how they relate to earlier RDI priorities and actual deliveries from past/ongoing collaborative TSO projects.

Extensive insights on TSOs' RDI initiatives can be found in the ENTSO-E RDI monitoring reports **[3]**, RDI application reports, the report on the Cyber Physical system and the ENTSO-E Technopedia platform. A brief look at recent EU-funded projects under the Horizon 2020 umbrella shows 37 projects had an active participation of at least one TSO; of those, 17 included at least two TSOs. These projects were initiated several years ago and some of them have already concluded. They show an alignment with previous RDI roadmaps and confirm how the most recent Roadmap 2020–2030 is covering new ground. Figure 12 illustrates how most projects focus on planning and operational tools for a future (more electrified) energy system as well platforms for the orchestration of TSO–DSO prosumer interfaces in, respectively, flagship 2 and 3. Some projects covered part of the milestones related to DC grids in flagship 4 and 5. Others covered PMU-based opportunities and secure interoperability for control centres under flagship 6. This assessment of where TSOs have put most of the RDI focus so far is also confirmed in a survey included in the latest RDI Roadmap (Chapter 7). This shows how TSOs have prioritised resources in the recent past, mostly on flagships 2, 3 and 6.

These assessments are applied in the scoping of the project concepts.

Roadmap flagship covering recent Horizon 2020 (H2020) projects

Extent to which recent H2020 projects with multiple TSOs directly participating fall in one or more flagship domains

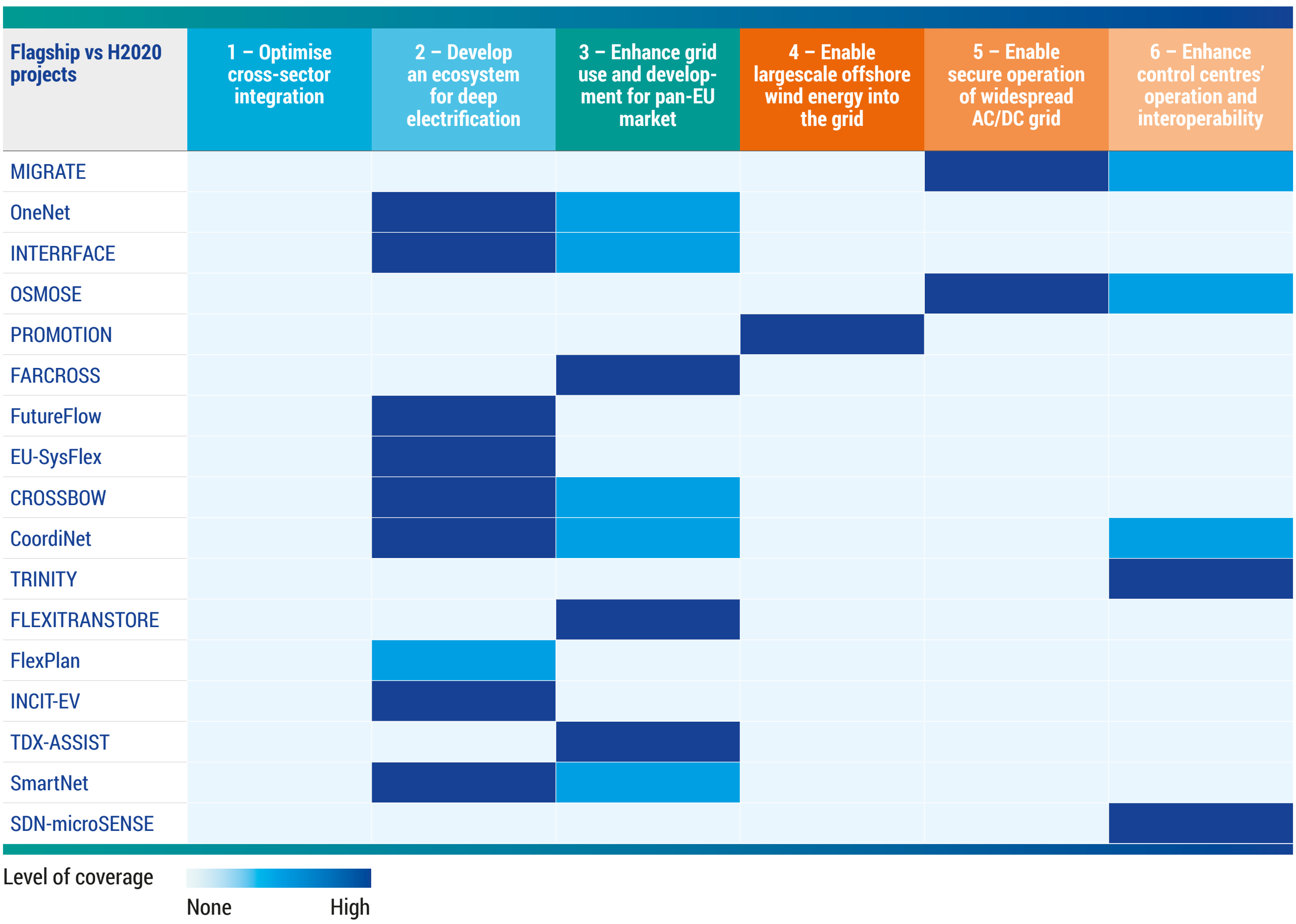

Figure 12 – Mapping of past collaborative TSO projects (H2020 funded) and how they relate to the latest RDI Roadmap

Adjusting course after the previous Implementation Report

The previous ENTSO-E RDI Implementation Report (2017–2019) adopted another approach compared to the present version **[2]**. At that time, 23 mostly technology-driven topics were proposed. It is worth noting that in this new Implementation Report, some of these topics remain relevant (or become even more relevant), such as the interaction with other energy systems and the need for 'big data' modelling tools. Some topics from the previous plan maintain a one-on-one match with the new project concepts, such as that of cyber resilience in control centres. Others emphasised less the new RDI priorities as they are considered part of normal TSO business, such as technologies for demand response use, probabilistic modelling, and secure cross-border exchanges for trading and ancillary services. Figure 13 gives an indication of how strongly each new project concept is matched with the earlier priorities (i.e. the 23 topics in the 2017–2019 report). For example, 'P7 / Smart asset management capabilities to reduce lifecycle emissions' in this report relates to two of the previous plan's topics, being 'ICT tools for data management' and 'Smart asset management through the use of "Big Data"'. 'P12 / Cyber resilience in the future control centre' has a one-on-one match with a similar topic in the previous plan. 'P5 / Integrating the coordinated flexibility potential to the future energy system of systems' covers multiple earlier topics such as 'Coordination of centralised and distributed flexibility', 'Power system planning for flexible transmission systems' and others. Most of the new project concepts have emerged as a priority in recent years and have no strong legacy in the previous Implementation Report.

Coverage of topics from earlier Implementation Report

Number of topics (out of 23 in total) from the previous RDI Implementation Plan 2017–2019 covered at least partially by each new project concept

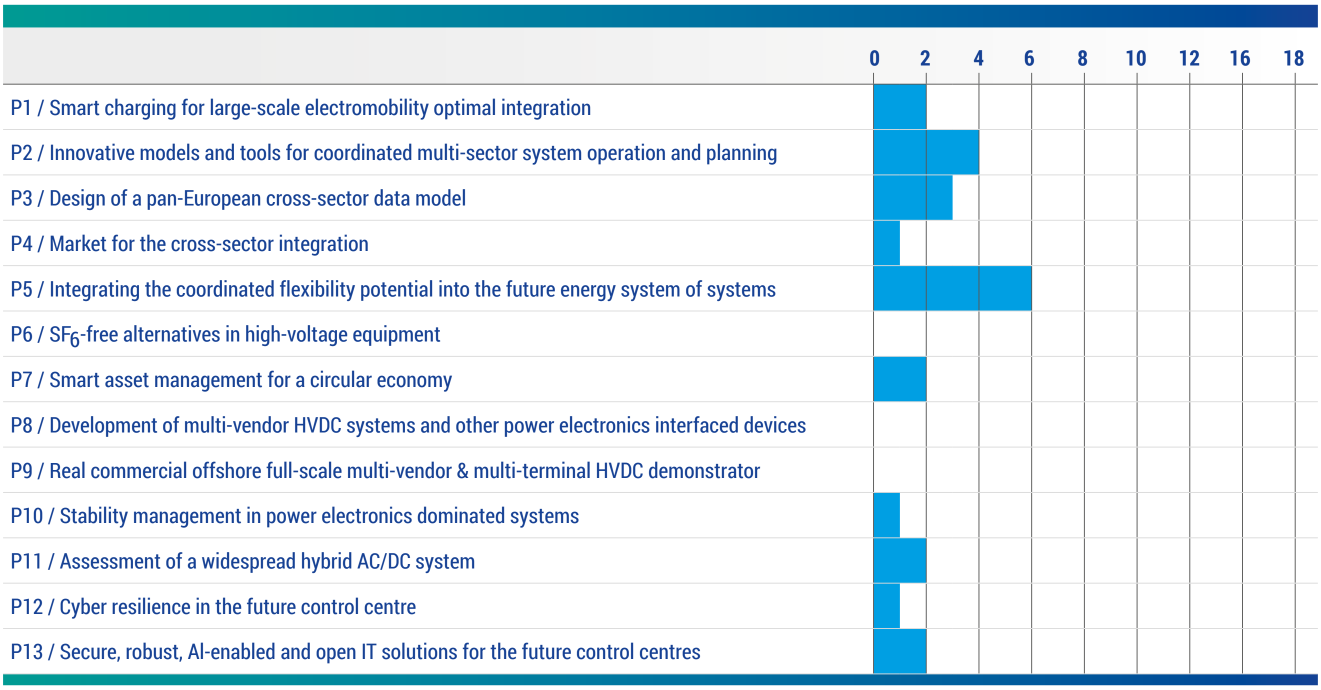

Figure 13 – Project concepts of flagship 1 and 2 relate to various topics from the earlier RDI Implementation Plan 2017–2019 but have now a stronger focus on cross-sector system, electrification and demonstrators. Some projects (P6, P8, P9) have no legacy in the former plan.

It is also worth emphasising that various areas of energy system RDI saw substantial activity in past years, though had no direct TSO involvement. In addition to the 37 Horizon 2020 funded projects with at least one TSO involved, there were approximately 60 other projects funded under this scheme with some power system focus but no TSO involvement. For most, this is perfectly understandable as the focus was on technology concepts such as smart inverters, smart building concepts, microgrids and demonstrators of new storage technologies. Although arguably everything is interlinked in the energy sector, it is not the ambition of this Implementation Report to broaden the scope of RDI activities. As stated earlier, the aim is to focus on what is urgent, provides highest impact and is directly linked to TSO core activities, while simultaneously balancing this prioritisation with the resource means of TSOs.

Impact for all

Crucial steps to advance technology readiness

The thirteen project concepts in this RDI Implementation Report mostly focus on advancing system solutions from initial concepts and first small-scale pilots (typically TRL 3–4) towards tools, methodologies, standards and investment options that can be demonstrated in TSO operational environments of grid development, asset management and system operations (TRL 6–8). Although this Implementation Report has a topical focus, additional attention will be required on how to integrate the innovations and demonstration insights into TSOs' operational daily practice. Such demonstrators are crucial in making the bridge from fundamental research to eventual wide-scale application. Figure 14 shows the maturity level (TRL) of all project concepts now and what the project concept aims for. The more detailed project concepts descriptions give further nuance on these scales as TRLs now/then may differ for specific subtopics.

TRL ambitions

This Implementation Report is part of a dynamic process. It needs to be reviewed and updated every few years, following new technology developments and system needs, and pushing for high TRL demonstrators in short run.

	TRL now	TRL after project
P1 / Smart charging for large-scale electromobility optimal integration	5	7
P2 / Innovative models and tools for coordinated multi-sector system operation and planning	4	7
P3 / Design of a pan-European cross-sector data model	3	6
P4 / Market for the cross-sector integration	3	8
P5 / Integrating the coordinated flexibility potential into the future energy system of systems	3	7
P6 / SF_6-free alternatives in high-voltage equipment	5	8
P7 / Smart asset management for a circular economy	3	6
P8 / Development of multi-vendor HVDC systems and other power electronics interfaced devices	2	6
P9 / Real commercial offshore full-scale multi-vendor & multi-terminal HVDC demonstrator	6	9
P10 / Stability management in power electronics dominated systems	4	6
P11 / Assessment of a widespread hybrid AC/DC system	3	6
P12 / Cyber resilience in the future control centre	3	6
P13 / Secure, robust, AI-enabled and open IT solutions for the future control centres	1	6

Figure 14 – RDI Implementation Report TRL ambitions showing status today and anticipated status after the project

TRLs are key metrics for a harmonised understanding of RDI needs and impacts. Annex II gives further information on how to interpret TRLs in the context of methodologies, tools, standards and asset-based solutions.

Figure 15 summarises the type of outcomes for each project concept (methodology / tool / field demonstrator), with most project covering multiple elements.

The project concept descriptions give further context on the expected impact of delivering on the project ambition. Key dimensions that are of value to all system users are mainly i) higher cost efficiency, ii) maintained security of supply, iii) asset environmental footprint, iv) an acceleration of the energy transition (including more timely new connections, the capability to make better use of new technology, and the de-risking of priority investments). Figure 15 also shows the main benefit dimensions each project concept targets in the evolving energy system.

Project concepts > Expected impact	Outcome(s)			Expected impact			
	Methodology	Tool prototype	Demonstrator	Cost efficiency	Security of supply	Asset environ-mental footprint	Accelerated transition*
P1 / Smart charging for large-scale electromobility optimal integration	○	○	●	●	○	○	●
P2 / Innovative models and tools for coordinated multi-sector system operation and planning	●	●	○	●	●	○	●
P3 / Design of a pan-European cross-sector data model	●	●	○	●	○	○	○
P4 / Market for the cross-sector integration.	●	●	●	●	○	○	●
P5 / Integrating the coordinated flexibility potential into the future energy system of systems	●	●	●	●	●	○	●
P6 / SF_6-free alternatives in high-voltage equipment	●	○	●	○	○	●	○
P7 / Smart asset management for a circular economy	●	●	○	●	○	●	○
P8 / Development of multi-vendor HVDC systems and other power electronics interfaced devices	●	○	○	●	●	○	●
P9 / Real commercial offshore full-scale multi-vendor & multi-terminal HVDC demonstrator	○	○	●	●	●	○	●
P10 / Stability management in power electronics dominated systems	●	●	●	●	●	○	●
P11 / Assessment of a widespread hybrid AC/DC system	●	●	○	○	●	○	●
P12 / Cyber resilience in the future control centre	●	○	○	○	●	○	○
P13 / Secure, robust, AI-enabled and open IT solutions for the future control centres	●	●	●	●	●	○	○

* including more timely new connections, capability to make better use of new technology, and de-risking of priority investments

Figure 15 – Main outcomes and system benefits for each project concept

Regulatory enablers and funding streams

The execution of the project concepts covers approximately € 130 million. Estimated Budget to facilitate TSOs efforts per project concept are given in the respective project concept sheets, further in this report.

The budget comes from bottom-up estimates of full-time equivalent (FTE) needs, as well as benchmarking with earlier collaborative TSO projects under H2020 (see list in Figure 12). Past H2020 projects often had budgets in order of magnitude of tens of million euros each. The projects in the RDI Implementation Report aim for more focus and underline TSOs efforts only. Hence, the budget-per-project concept is typically lower. The reader should consider that for large-scale demonstrators, only the TSOs innovation related cost is included not the business-as-usual investment. For example, if P6 on SF_6-free alternatives explores a field demonstration from one or more vendors for an SF_6-free substation, this investment counts typically as a normal TSO expenditure and is thus not included in the budget estimates of this RDI report. Past collaborative TSO projects under H2020 also typically showed a TSO share ranging from 10 % in large consortiums up to 30 – 50 % for projects that are strongly TSO-driven. Projects with prototype tool development or demos lead by other organisations are assumed to have a TSO share of approximately 20 – 30 %.

Most project concepts in this Implementation Report would fit well under EU funding schemes. One key reason for this is the scale of projects, which goes beyond what many TSOs can obtain under national innovation funding or regulatory regimes. Another reason is that in all these projects, TSO collaboration is key as dispersed national actions would be suboptimal. EU funding is a logical option for large regional projects. Some national innovation schemes allow for international partnerships and will be considered in the future, though this Implementation Report has not yet screened for such options.

Further information on the regulatory framework conditions for TSO innovation work and general TSO priorities can be found in the ENTSO-E RDI Roadmap Chapters 6 and 7.

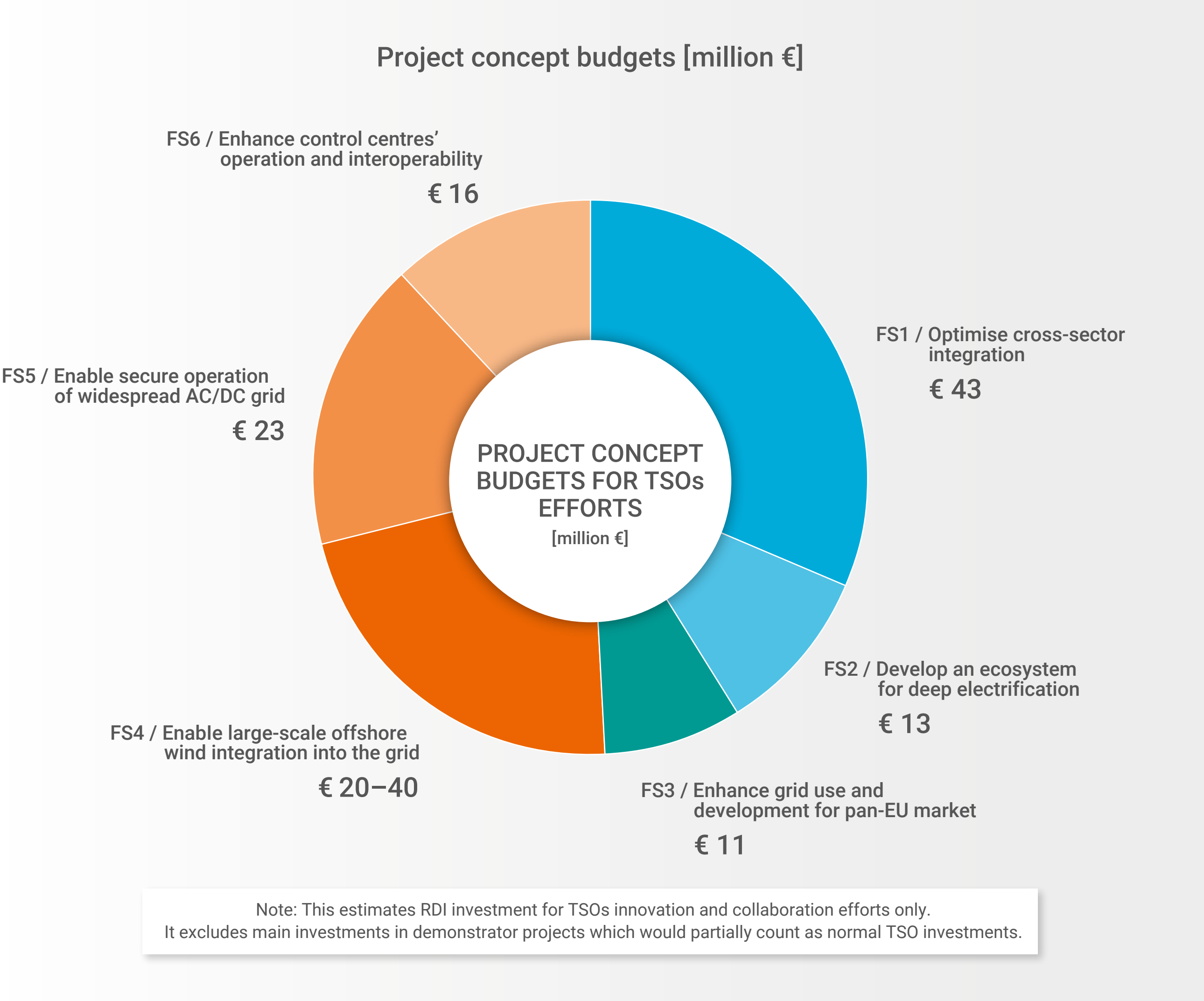

Figure 16 – Total estimated project budgets to facilitate TSOs efforts, grouped per flagship

Stakeholders involvement

The thirteen project concepts are planned to be further developed to reach complete project stage. The deeper scoping of the work must be accomplished in coordination by numerous stakeholders. Gathering key stakeholders and assembling the necessary expertise to support TSOs around each concept are the key factors to target funding from collaborative research programmes and ensure supports of policy makers and regulatory authorities on delivering the ENTSO-E RDI Roadmap 2020–2030.

Annex I:

Thirteen project concepts of ENTSO-E RDI Implementation Report 2021–2025

Flagship 1 – Optimise cross sector integration

P1 / Smart charging for large-scale electromobility optimal integration

Needs addressed	Most recent TYNDP (2020) scenarios depict the number of EV growing by 2040 towards 100 to 245 million [5]. Together with the electrification of heat and cooling demand, these will have the largest impact on demand (energy and peak). The past decade has seen numerous innovation projects examining small-scale smart charging pilots and commercial parties offering charging solutions. However, we urgently need to investigate the system-wide impact of mass deployment and measures to manage the impact using market-based solutions [35]. **Optimisation tools and strategies are required for planning, developing and operating the integrated energy system**
Scope	The overall objective of this project is to demonstrate how a wide area charging infrastructure can be planned and operated to meet user needs and deliver the lowest system costs. This includes the following interlinked tasks: › Develop processes and methodologies for the integrated planning and operation of charging infrastructure (by market parties) and grid infrastructure (by TSOs and distributed system operators [DSOs]). Develop regulatory and policy recommendations for how to optimally deploy electromobility charging infrastructure based on user needs, market options and energy system impacts. › Identify technology performance and data exchange needs for using the flexibility from electrified transport (EVs, marine, aviation) in balancing services, transmission congestion management and other market-based flexibility services, considering user acceptance, charging standards, charging infrastructure roll-out options, and distribution impact. Identify trade-offs and apply integrated system and probabilistic views. › Based on performance characteristics, define business models and charging concepts (infrastructure roll-out, operation, market design, regulatory conditions) for future 'millions level' EV scenarios, which also consider electrification of heavy-duty transports, marine and aviation. Quantify benefits on renewable energy (RE) integration and integrated system cost. › Develop electricity system operation and market design recommendations, which ensures that required recharging operations of EVs, rail, maritime and other transport modes are optimised, cause no congestion and takes full advantage of the availability of renewable electricity and low electricity prices. › Set up a large-scale demonstrator for charging infrastructure to provide stacked flexibility services. Measure performance, user impact, power system impact and electricity market impact. The main differentiators compared to earlier EV integration projects are: i) the full scope ranging from planning to operations including all actors covering both e-mobility infrastructure and power system perspective, ii) the mass scale and wider transportation (heavy-duty, marine, aviation) means.
Expected impact	The grid cannot become the bottleneck in this roll-out and electrification of transport sector. Potential benefits for flexibility and cost reduction in an integrated system approach must be grasped. By 2050, up to 20% of system flexibility on a daily basis could be delivered by EVs [8]. Electrification of mobility could account for 4–6% of total electricity demand in Europe by 2030 [7]. Although the rise of EVs has been announced many times before, present projections see EVs becoming cost competitive with internal combustion engine vehicles by 2025, distance ranges are steadily increasing, and the EC also plans a roll-out of 1 million charging points by 2025 and trigger electrification of heavy-duty transport as well as marine and aviation. This provides grounds to expect a similar exponential take-off in electromobility as seen in PV and wind in the past 10–15 years.
Barriers	A large-scale charging demo implies either collaborating with market parties responsible for the capital investment (who may be reluctant) or setting up a grid operator owned infrastructure (which may see regulatory red tape). It is essential to keep the focus on the full stakeholder spectrum and avoid narrowing down to a small-scale demo which only examines a small part of the grid. [10]
Policy context	Mobility is partly incentivised via Trans-European Networks for Transport (TEN-T), whereas main electricity grid corridors and smart grid options are reviewed via Trans-European Networks for Energy (TEN-E). Greater synergy is required, as national policy differences across the EU may imply different levels of possible success within each jurisdiction. A new Network Code on Demand Side Flexibility as envisaged in the Electricity Regulation could be initiated late 2021.

Flagship 1 – Optimise cross sector integration	
State of the art	Recent projects in this field include a pilot by Statnett on fast frequency response (FFR) performance when delivered by EVs, and a vehicle to grid (V2G) demo in Spain (Invade project) examining local distribution impact. [4] Today, EV platforms are at TRL 8 and 9 with several commercial providers active. Balancing service pilots are at TRL 6. Small-scale V2G is at TRL 5.
TRL now/target	This project aims for TRL 7 in a mass-scale smart charging demonstrator (infrastructure concept still to be defined).
Proposed Timeline	2022 – 2025
Estimated Budget to facilitate TSOs efforts	€ 9 million
Funding Scheme	This can fit under the Horizon Europe call CL5-2021-D5-01-03 on 'System approach to achieve optimised Smart EV Charging and V2G flexibility in mass-deployment conditions (2ZERO)'

P2 / Innovative tools for coordinated multi-sector system operation and planning	
Needs addressed	The EU strategy for European System Integration defines this integration as 'the coordinated planning and operation of the energy system "as a whole", across multiple energy carriers, infrastructures, and consumption sector' [8]. This implies a **need for planning tools to enable sector coupling investments**.
Scope	The overall objective of this project is to develop, test and improve methodologies for transmission system operation and planning which enable large sector coupling investments and large-scale roll-outs in a cost-effective manner. This includes: › Develop and test new methodologies in ENTSO-E's ERAA and TYNDP/multi-sectorial planning support (MSPS) innovation tracks and enhance security of supply for applicable cross-sectors operation and planning. Apply the pan-European cross-sector energy system data model (see project 'Design of a pan-European cross-sector data model'). › Develop methodology for TSOs and DSOs to assess the potential of balancing and other system services provided by operators of district heating, cooling and other (e.g. hydrogen) systems in the framework of grid planning, grid investment and infrastructure assessments. › Demonstrate new planning and operational tools using advanced optimisation techniques in various regional contexts (different regions, different sector focus, transmission vs. aggregated distribution focus). Develop framework for assessing system costs in terms of CAPEX, OPEX and enabled flexibility. Consider the time dynamics of sector coupling at investment and operational level. › A large demonstration of a specific industrial cluster to assess synergies in industrial demand, RE integration, fuel switch, efficiency, and grid impact. For instance, a port area with heavy industry transitioning from fossil fuels to offshore wind and sustainable fuels. › Develop a cost–benefit analysis (CBA) and cross-border cost allocation (CBCA) for sector coupling investments in network infrastructure. › Review and assess the impact of different regulatory conditions and provide suggestions on removing potential regulatory barriers for large sector coupling investments and large-scale roll-outs in a cost-effective manner.
Expected impact	The project concept contributes to the ENTSO-E Roadmap for a multi-sectorial Planning Support [13] and aims progressively to deliver infrastructure planning using a framework to enable greater coordination of infrastructure planning across different sectors by taking a long-term, holistic view of system planning. This results in a smarter, more integrated and optimized 'one energy system' view which strengthens links across sectors and supports coordinated decarbonisation efforts on all fronts through, among other things, the centrally-integrated role of the electricity grid.
Barriers	Delivering the desired outcome does not only rely on methodological progress, but equally important it requires a solid dataset covering all energy end uses, conversion options and technology costs. This will be further developed in project 'P3 / Pan-European cross-sector data model' based on the modelling insights from this project. The regulatory gaps may prevent the uptake of the multi-sector system of systems, so regulatory sandboxes can enable the execution of specific pilot projects and their results may support regulatory recommendations.
Policy context	This project is aligned with the most recent TEN-E draft regulation that calls for further coordination between electricity and gas transmission assets but also transport and heat in the scope of TYNDPs.

Flagship 1 – Optimise cross sector integration	
State of the art	Multi-sector system operation and planning will be the starting point for system and sector development plans and focus on even more comprehensive and consolidated scenarios compared to today's joint scenarios of ENTSO-E and ENTSOG. It addresses the aims set out in the ENTSO-E roadmap towards 2030 for a multi-sector planning support **[13]**. It builds on the a study recently published by ENTSO-E and ENTSO-G on the interlinkages of gas and electricity investments, which brings the concept generally at TRL 4.
TRL now/target	This project aims to demonstrate the planning tool for relevant real-life case studies, reaching at least TRL 7
Proposed Timeline	2022 – 2024
Estimated Budget to facilitate TSOs efforts	€ 10 million
Funding Scheme	The concept could fit under the Horizon Europe call CL5-2021-D3-02-05 on 'Energy Sector Integration: Integrating and combining energy systems to a cost-optimised and flexible energy system of systems'. However, if the project is to build on an earlier system data model project, a similar call later would be a better opportunity. In any case, closer integration of planning tools continues via the ENTSO TYNDPs.

P3 / Design of a pan-European cross-sector data model	
Needs addressed	To achieve a sustainable, reliable and cost-effective integrated energy system, it is necessary for policy makers, market actors, grid planners and system operators to understand the impact of policy options and market drivers on investments and system costs. This all relates to the **need for a pan-European cross-sector data model** covering all end uses, sources, conversions, storage and networks.
Scope	The overall objective of this project is to develop an open and standardised European energy system data model which covers all energy sectors and enables investments, operations and reliability assessments to be performed. Such data models have been developed in the past, though they were either not open source, not standardised, not maintained, focused on single energy sectors and/or focused on either short- or long-term dimensions only. This project covers the following: › Define use cases and related data requirements to enable – Studies across energy domains (energy carriers) and system actors (supply, demand, storage, grids) – Studies for various time horizons (short-term operations, mid-term planning, long-term investment) and purposes (policy impact, operational performance, reliability, investment viability) – Studies for either pan-European dimension and more regional deep-dives (in line with NUTS levels) › Identify possible harmonisation and standardisation to bridge existing models such as electricity (Common Information Model [CIM] for market, transmission, distribution), gas model, building information model (BIM), World Wide Web Consortium (W3C) ontologies, EU ontologies, etc. › Run a data collection, at least for specific regions (e.g. country, industrial cluster, other) and use cases (e.g. green hydrogen development, examining supply/end-use/interconnection options and alternatives). › Initiate the development of tools and services for data availability and quality checks from a general perspective that will be flexible enough to adapt to the different cross-system needs. › Benchmark with outputs of existing modelling tools for a number of sufficiently diverse test use cases. Note that the development of new modelling tools is not in scope here. › Develop visualisation tools for the energy system data content; develop recommendations for interpreting and visualising data for a cross-system energy view. › Re-assess 'one system' strategies such as P2X in scenario development (e.g. TYNDP scenario innovation) with the developed system data model. › Propose a process for the continuous maintenance and development of the energy system data model and possibly partial open source data maintenance. › Demonstrate the European cross-sector data model applicability for provision of information on the share of renewable electricity and greenhouse gas emissions in each bidding zone, real time, with forecasting in format to read by electronic communication devices (e.g. smart charging systems or building management systems).
Expected impact	Data models build on TSOs' mandate to ensure data transparency as a public good, which in turn stimulates market efficiency and innovation. The share of electricity in total energy demand is projected to increase from 21 % today to 30 % by 2030 and even 50 % by 2050 **[8]**. For TSOs this brings an urgent need to better handle sector integration options in operations and investments and inform the wider sector correctly on how electrification can drive a reliable and secure decarbonisation of the full energy system. This includes demonstrating how higher shares of renewables can be connected, how transmission investments fit into this integrated system with minimal risks for stranded assets across energy sectors, and how fossil fuel usage in various sectors can shift to sustainable options.

Flagship 1 – Optimise cross sector integration	
Barriers	This project is an enabler for other innovation projects, to guide policy decisions and inform infrastructure investments. As such, it is difficult to quantify its direct benefit, which may complicate attaining buy-in from decision makers and interested parties. Other barriers include biased positions from any involved stakeholders (one-sided view to own sector) and concerns over data confidentiality or commercial sensitivities. Nevertheless, the creation of a standardised data structure is valuable for many stakeholders. Actual data collections in the project can be appropriately scoped or legally ringfenced to avoid confidentiality issues. In addition, low data availability or/and quality across the sectors could block the data model usage for investments, operations and reliability assessments.
Policy context	This builds on transparency obligations that are already commonplace for power and gas markets [11, 12]. This also builds on transparency efforts already undertaken in system analysis and grid development. Both ENTSOs already take the initiative to integrate TYNDP processes.
State of the art	High TRL levels are in place for grid and market data (TRL 9). There is also a high TRL for cross-sector long-term investment models such as TIMES-MARKAL, METIS and PRIMES (TRL 9). However, a full cross-sector model that allows for all possible use cases has not yet been demonstrated (TRL 3).
TRL now/target	This project aims to bring the concept to at least TRL 6
Proposed Timeline	2023 – 2026
Estimated Budget to facilitate TSOs efforts	€ 10 million
Funding Scheme	This can be linked to Horizon Europe call 'CL5-2022-D3-01-13: Energy system modelling, optimisation and planning tools.

P4 / Market for the cross-sector integration	
Needs addressed	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 small-scale energy storage, heat pumps (and cooling), smart charging of electric vehicles, power-to-gas, smart buildings solutions etc. – system operators will be able to define and implement innovative approaches and solutions at the systems level. One of the important steps in this process is the evolution of the current market structures by adding new market architecture concepts for the deployment of suitable market platforms for the newly cross-integrated energy system.
Scope	The overall objective of this project is to develop cross-sector market architecture and demonstrate it by enhancing current market platforms for an integrated energy system. This includes: › Development and integration of cross-sector markets to provide coordinated system services via efforts of various actors (prosumers, aggregators, TSOs, DSOs, heating/cooling systems & networks, smart building management systems, domestic batteries, smart charging systems operators, hydrogen, gas systems). › Development of business models for bi-directional energy services integration with services of other sectors (e.g., health and social care, security & surveillance, home automation, mobility services etc) › Explore cross-sectors system integration opportunities to enable long term (weekly, seasonal) energy storage. › Enhance existing market design and regulation rules, to ensure that balancing, storage and other flexibility services, provided by district heating, district cooling and other system operators as well as domestic batteries or electric vehicles, can participate in wholesale electricity markets and provide system services to TSOs and DSOs. › Based on the marked design defined above, develop market platforms to support products for the optimised cross sector integration under coordinated framework of the different markets (e.g. local flexibility, peer-to-peer, ancillary services, wholesale electricity and gas, balancing, heating/cooling and other markets). › Address the cross-sector market data exchange challenges and systems interoperability by demonstrating applicability existing standards (e.g. CIM) and the potential usage of a pan-European cross-sector data model. › Identify and provide regulatory improvements on local and EU level for removing barrier and enable business models for optimise cross sector integration and new market players (like district heating and district cooling system operators) access to the electricity markets and services.
Expected impact	The project concept is expected to develop new business models for cross-sector markets coordination and integration. Optimised operations of coupled networks (e.g. electricity & heating), would bring more flexibility on both side and result in a higher and more efficient uptake of renewable energy. It will also boost digitalisation, consumer engagement and development of additional flexibility resources from other sectors, which would contribute to electricity system stability and security of supply.

Flagship 1 – Optimise cross sector integration	
Barriers	The project concept focuses on a wide range of different sectors, each of them having its own specifics, rules, regulations and markets. The complexity is added by different geographic, climate and economic conditions in each Member State. Data exchange and market platforms interoperability are additional challenges to be addressed by the project concept. It is also important to address holistic view of cross-sector business models to ensure, that optimal integration addresses not only needs of energy system but of other sectors (e.g. mobility service needs [37]).
Policy context	This project is aligned with the most recent TEN-E draft regulation and further build on the requirements emerging in the Fit for 55 package (especially on the amendments of the Renewable Energy Directive) under the European Green Deal.
State of the art	This project concept will build on the achievements of EU funded projects: FEVER project, focuses on the flexibility measures that address the local needs for flexibility at the distribution grid, leveraging flexibility assets such as residential and industrial loads, EVs, stationary batteries, as well as the potential for flexibility due to the electrification of various sectors, such as heating and cooling [38] Similar area is also targeted by FlexiGrid and InterFlex projects, while InterConnect compliments the concept by focusing on the connection of Smart Homes, Buildings and Grids.
TRL now/target	This project aims to bring the concept to at least TRL 7–8
Proposed Timeline	2022–2025
Estimated Budget to facilitate TSOs efforts	€10–14 million
Funding Scheme	This can be linked to Horizon Europe call 'HORIZON-CL5-2021-D3-02: Sustainable, secure and competitive energy supply'. Namely, "HORIZON-CL5-2021-D3-02-06: Increasing energy system lexibility based on sector-integration services to consumers (that benefits system management by DSOs and TSOs)" and "HORIZON-CL5-2021-D3-02-05: Energy Sector Integration: Integrating and combining energy systems to a cost-optimised and flexible energy system of systems".

Flagship 2 – Develop an ecosystem for deep electrification	
P5 / Integrating a coordinated flexibility potential into the future energy system of systems	
Needs addressed	Higher electrification of final energy demand raises the need for improved **assessments of the flexibility potential unlocked by sector coupling**. As P2X pilots are rapidly expanding and scaling up, there is value in using such a pilot as a **demo for how to operate an integrated energy system** by close coordination across sectors [14].
Scope	The overall objective of this project is to develop and demonstrate a cross-sector methodology for measuring and valorising energy flexibility. This results in new data-driven business models for end consumers and better insights into the role of regulated system operators. This includes: › Up-to-date overview of flexibility potential (TRL, time-to-market, performance, impacting factors, cost level and cost reduction potential) from all energy sectors towards the power system; assessment of regulation, market and operational barriers for upscaling and possible solutions in all these areas. › Flexibility metrics methodology for TSO operations and grid development based on the flexibility potential of energy end users and sector interlinkages. Cover explicitly: – distributed energy resource mass aggregation in buildings and electromobility (distribution level), – industrial flexibility – advanced P2X (transmission level) › Demonstrate P2X ancillary services, revenue streams and coordinated system security by involving at least gas TSO, electricity TSO, P2X operator and market operator for a specific P2X facility.
Expected impact	The joint 2050 outlook by TenneT and Gasunie highlighted how an integrated system delivers more efficiency [15]. Although power system reinforcement is required in any case, an uncoordinated expansion of P2X technologies can have knock-on peak load impacts. Developing of integrated approach and business models for implementation and use as efficiently as possible incoming large amounts of projects with P2X technology hand with hand with sector coupling is much needed for transmission and distribution grid to meet the challenges and to achieving the goals for carbon neutrality. The location, capacity and operation of commercial P2X installations for example: P2V, P2H (and cooling), P2G as well as H_2 storage and H_2 grid development/conversion, are decisive factors in network flexibility and stability at all levels and need better coordination and planning between all actors (especially system operators like TSOs and DSOs) in sectors. Depending on regional context locations close to RE sites, interconnection points, large industrial demand or more distributed set-ups are beneficial.
Barriers	The buy-in of market parties owning and operating a P2X facility may become essential. This could be supported by some regulatory sandbox frameworks, to allow de-risking the P2X business case, which would allow TSOs and P2X facility operators to pilot new processes and market interactions. In addition, there are gaps P2X related regulation including definition of roles and responsibilities, traceability of electricity used as well as priorities of different system operators etc.

Policy context	This project is fully in line with the H_2 strategy at European and many national levels as well as with the most recent TEN-E draft regulation. It also addresses the new requirements emerging in the Fit for 55 package (especially in the amendments of the Renewable Energy Directive).
State of the art	Although electrolyser sites are scaling up to reach TRL7 **[16]**, the understanding of energy system flexibility remains limited to scenario analyses (TRL 4). Demos for distributed flexibility are fairly advanced thanks to recent H2020 projects such as Interrface, CoordiNet and OneNet (TRL 6). Industrial demand response is in the range of TRL 3 to 9 depending on the type of service **[17]**.
TRL now/target	A cross-sector flexibility methodology needs to reach TRL 6. The demo for P2X flexibility aims to bring operational understanding, new ancillary services and business models for P2X plants that support system efficiency to TRL 7.
Proposed Timeline	2023 – 2026
Estimated Budget	€ 13 million
Funding Scheme	This can be linked to the upcoming Horizon Europe call CL5-2021-D3-02-06 'Increasing energy system flexibility based on sector-integration services to consumers (that benefits system management by DSOs and TSOs)' or CL5-2021-D3-02-05 'Energy Sector Integration: Integrating and combining energy systems to a cost-optimised and flexible energy system of systems'. In case of incompliance, it could also be picked up in a similar call later.

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

P6 / SF_6-free alternatives in high-voltage equipment

Needs addressed	The TSO community is committed to further efforts in reducing SF_6 emissions as much as possible in the coming decades in both existing and new equipment (switchgear, gas-insulated lines and gas insulated substations). Although some **SF_6-free alternative technologies** are becoming available for lower voltage levels (< 52 kV) **[19]**, the majority of TSO applications still rely on SF_6. ENTSO-E wants to continue its work with the research and manufacturer sector to address this[1].
Scope	The overall objective of this project is to develop common technical specifications for performance and the testing of alternative SF_6-free technologies in high-voltage equipment with the wider industry community, as well as a regulatory roadmap for replacement and new assets. This includes › Harmonised and transparent SF_6 emissions monitoring and reporting by TSOs in an SF_6 register. This also complements actions TSOs already take to ask guarantees from suppliers that SF_6 leakages are contained below a specific threshold in both production, operations and decommissioning. › Technical analysis of possible trade-offs in performance, ambient condition impact, maintenance, reliability, dimensioning, testing procedures, etc. › Economic and environmental assessment of replacement and new installation roll-out options (timeline, perspective of global market, full lifecycle impact) › Regulatory recommendations at EU level to cope with financial risks inherent with putting novel technologies into the system and transition time options to move from SF_6 to SF_6-free technology for new equipment A next step could be an actual demonstrator for an SF_6-free gas-insulated substation or for air-insulated SF_6-free instrument transformers or switchgear at different voltage levels. The involvement of manufacturers (e. g. via T & D Europe) who already look into these topics would be highly valuable to identify requirements and develop solutions to address system needs.
Expected impact	SF_6 has a much higher greenhouse warming potential than CO_2; in particular, it remains active in the atmosphere for much longer. In 2017, SF_6 emissions had an equivalent impact of 0.2 % of CO_2 emissions in the EU. As such, SF_6 equipment remains a substantial element in emissions under TSO control as long as the alternative do not reach sufficient maturity; for a typical TSO, this is approximately a few % of their total annual GHG emissions **[20]**.
Barriers	Although several large manufacturers have made progress in developing SF_6-free alternatives, the exchange of information remains limited due to commercial reasons. An innovation project needs to shape a collaborative environment to work on technical specifications, socioeconomic impacts and regulatory conditions. In a follow-up, this could lead to actual demonstrators of alternative options being developed by manufacturers in the field environment. The SF_6-free solutions available today reach only up to the voltage level of 245 kV for instrument transformers and 145 kV for circuit breakers. Some physical limitations still need to be resolved when aiming for extra high voltages (> 245 kV).

1 In April 2020, ENTSO-E published a position paper stating i) for the existing fleet, minimise annual SF_6 emissions to levels below 0.5 % of the installed SF_6 in 2019, and ii) for new equipment, work towards achieving either SF_6 free or very low GWP3 equipment by 2050 **[18]**.

Flagship 3 – Enhance grid use and development for pan-EU market	
Policy context	Policies have not yet pushed for a phase-out in the absence of reliable alternatives. The F-gas regulation is currently up for review. The initial 2014 regulation called for an assessment of medium voltage options by 2020, and for the 'review of the availability of technically feasible and cost-effective alternatives to products and equipment containing fluorinated greenhouse gases' in other parts of the energy sector by 2022. A review of the F-gas regulation is expected later in 2021.
State of the art	Although for medium voltage equipment, alternatives have become commercially available (TRL 8), for high-voltage levels only first trials have been done by several large vendors (TRL 5).
TRL now/target	This project aims to create a common TSO/industry view (TRL 6). Actual field demonstrators allow TRL 8 to be reached.
Proposed Timeline	2021 – 2024
Estimated Budget to facilitate TSOs efforts	€ 5 million for initial RDI efforts and developing SF_6-free equipment for niche markets. An actual demonstrator for an SF_6-free high-voltage substation would have a budget orders of magnitude higher. Such substation is typically part of normal TSO investments, but has an additional innovation/risk component that requires acknowledgement in regulatory review or leveraging via innovation funding.
Funding Scheme	This is mainly ongoing work by TSOs based on own resources. This should also fit under a future Horizon Europe call. Progress is also subject to directions given by a possible F-gas regulation review. A possible demonstrator is covered typically under normal regulatory schemes if national approaches allow for innovative first-of-a-kind projects to reach high TRL. The manufacturers can also use the funding to develop SF_6-free equipment for niche markets such as HVDC offshore substations.

P7 / Smart asset management for a circular economy	
Needs addressed	As TSOs aim for a circular economy approach into planning and asset management, there is a need for robust and transparent **lifecycle management procedures for power system assets** that can be implemented by the wider TSO community, as well as **new solutions for designing substations of the future**. These allow the carbon footprint of European power system assets to be lowered and the investment wave flattened.
Scope	The overall objective of this project is to develop new asset management procedures that lower the carbon footprint of TSO investments, as well to develop, test and validate performance focused digital twin methodologies for faster asset design phase and better lifecycle management of inventories. This includes: › Set up a common TSO evaluation methodology and repository to track CO_2 equivalent emissions and other environmental impacts. › Develop procedures for green procurement of new assets based on common evaluation processes which provide clarity to the market without distortions. › Develop standardised asset BIMs for creating a digital twin [21] and artificial intelligence (AI) methodologies for descriptive and predictive models supporting decision making across a TSO's asset base in line with circular economy concepts. This includes exploring the benefits of new asset management techniques such as health assessments, economic appraisals for value at risk, LCA and refurbishment programmes. › Develop and pilot new network components with reduced environmental impact such as HV cables without lead, application of superconductors, DC cables/gas insulated lines for voltages above 550 kV.
Expected impact	Over three quarters of greenhouse gas emissions in Europe stem from energy, in which electricity and heat production covers over 30 %. In this domain, the share of emissions partially under control of a TSO is probably in the single digit percentages and largely related to SF_6 assets. A joint initiative can accelerate the reduction pathway and rally support from regulatory authorities to create a convenient framework. Digital twins in particular are a means to grasp the benefit of an exponentially growing set of data points and computational techniques. Some TSOs have already applied a digital twin-based asset management process in their investment scenarios and were able to reduce time for data collection and validation over five times. Such new asset management tools are not only timely because of technological opportunities but also able to cope with a general replacement wave most grid operators anticipate in the coming decades. The application of environmentally friendly technologies should speed up approval processes and hence accelerate the realisation of numerous projects for delivering the Green Deal objectives.
Barriers	Successful implementation requires a considerable level of data transparency.
Policy context	This is aligned with a TSO mandate to support sustainability.

Flagship 3 – Enhance grid use and development for pan-EU market	
State of the art	Most TSOs report on their sustainability actions and general carbon footprint. The TRL for thorough lifecycle management is generally around TRL 3, with some TSOs more advanced. Digital twins are becoming more commonplace (at the risk of being overhyped) in recent years, also in the power system sector. To date, there is some experience in digital twins for conventional assets (generally at TRL 6), but considerable progress is still to be made for full digital substations (TRL 3 – 4). Environmentally friendly technologies in TSO assets have varying TRLs.
TRL now/target	This project aims to develop lifecycle assessment, asset management methodologies and demonstrators of environmentally friendly technologies (at least TRL 5 – 6).
Proposed Timeline	2022 – 2025
Estimated Budget to facilitate TSOs efforts	€ 6 million
Funding Scheme	This is part of ongoing activities across TSOs and based on internal TSO resources. Further work on asset management techniques involving digital twins for substations could fit in a future wide Horizon Europe project.

Flagship 4 – Enable large-scale offshore wind energy into the grid	
P8 / Development of multi-vendor HVDC systems and other power electronics interfaced devices	
Needs addressed	Europe foresees the integration of 300 GW offshore energy into the power system by 2050 [22]. This massive deployment will be largely by HVDC connected hubs and multi-terminal systems to increase market coupling, reduce infrastructure costs and maximise the controllability and stability of the system. This new roll-out generates a need to ensure the **multi-vendor compatibility of HVDC systems**. Today, TSOs cannot draft detailed specifications for HVDC multi-terminal, multi-vendor multi-purpose systems due to limited operational experience. At the same time, manufacturers cannot develop products without specifications at a sufficient level of detail. A governance framework for multi-vendor interoperability and a demonstration in a real project need to be set up to break this vicious circle [23].
Scope	The overall objective of this project is to develop an interoperability framework for multi-terminal multi-vendor HVDC systems and pave the way for a full-scale demonstrator. This includes: › Develop tools and processes to prepare interoperability functional specification and system studies for extendable multi-terminal multi-vendor HVDC systems. › Develop a control and protection functional framework and integration tests to cope with interoperable HVDC systems. This includes preparations for new functional capabilities such as GFC included in Network Code amendments as well as functional capabilities for the DC system side (for multi-terminal HVDC as well as other power electronic interfaced devices). › Prepare planning and implementation processes for a real commercial full-scale multi-vendor and multi-terminal HVDC demonstrator. › Develop a multi-vendor cooperation framework and governance to account for future expansions, generic/detailed model sharing, model retuning, dynamic assessments of system interactions, control and protection, and future liabilities and warranties. › Set up a strategy for network planning, project financing and procurement This interoperability framework is generally concerned with 'project de-risking' before commencing an actual commercial tender for a multi-vendor multi-terminal HVDC system (see 'P8 / Real commercial offshore full-scale multi-vendor & multi-terminal HVDC demonstrator').
Expected impact	This project will create incentives for investment and economies of scale in offshore energy, bringing down costs and create new business models and services. The envisaged 300 GW deployment of offshore renewable energy (largely wind, partly others) by 2050 are projected to require € 800 billion, of which around two thirds fund the associated grid infrastructure and one third the offshore generation. This demonstrates the value of maximising cost efficiencies via hybrid projects, coordinated HVDC planning, economies of scale, effective supply chains and efficient modular procurement options that mitigate lock-in situations. The approaches for multi-vendor interoperability could also be applied in other developments onshore.
Barriers	The main barrier as experienced in earlier projects are around two areas: (1) Technical issues, like functional and operational requirements, demonstration in target environment, power system engineering and planning, and standardisation of systems and equipment; (2) Legal issues, like the confidential nature of HVDC controls, current contractual relations and warranties as well as national and EU regulation and legal frameworks. This project puts this challenge at the core and aims for clear procedures to address contractual/legal issues and ensure technical interoperability validations.

Flagship 4 – Enable large-scale offshore wind energy into the grid	
Policy context	This project is a critical element in the European offshore strategy. It also fits with the ambition of the draft TEN-E regulation that aims for coordinated offshore planning and can provide incentives to accelerate **[24]**.
State of the art	Progress on the massive integration of wind, power electronics, multi-terminal and meshed DC systems has been achieved via projects such as Best Paths, Promotion and Migrate, which have contributed to various wind integration building blocks. These projects have confirmed there are no major showstoppers identified for large-scale offshore wind roll-outs, but have still highlighted some technical and legal issues among which is multi-vendor interoperability, which so far remains discussed only at the conceptual level (TRL 2)
TRL now/target	The project aims to demonstrate and validate control and protection prototypes for multi-vendor multi-terminal HVDC (TRL 6). The project paves the way for a full-scale demonstrator which brings the concept to TRL 9.
Proposed Timeline	2021 – 2026
Estimated Budget	€15 to 20 million
Funding Scheme	This project fits the European Green Deal call 'LC-GD-2-1-2020 subtopic 2: Demonstration of innovative technologies to enable future large-scale deployment of offshore renewable energy' under Horizon 2020. The concept could also fit under future Horizon Europe calls that aim for the interoperability of multi-terminal multi-vendor HVDC systems and other power electronic interfaced devices.

P9 / Real commercial offshore full-scale multi-vendor & multi-terminal HVDC demonstrator	
Needs addressed	With most technical, economic and regulatory issues addressed in earlier projects, there is a need to **demonstrate a full-scale multi-vendor multi-terminal HVDC project for offshore wind integration** in the power grids so it can upscale the levels of wind connected to the European energy system in a cost-effective and reliable manner **[23]**.
Scope	The overall objective of this project is to develop a real pilot project, building on the interoperability framework developed in the previous project ('P7 / Development of multi-vendor HVDC systems and other power electronics interfaced devices'): › Project planning in line with TYNDP process and relevant national planning processes › Procurement and contractual arrangements (IP, warranties, obligations during operation) › Project development and commissioning › Field validation and continuing assessment / control retuning › Technical and regulatory recommendations for further upscaling towards 300 GW offshore energy
Expected impact	This project is expected to provide full confidence to manufacturers, developers and TSOs for a wide-spread roll-out of interoperable multi-terminal HVDC. HVDC multi-terminal planning can be considered state-of-the-art and market-ready after successful completion.
Barriers	As a first-of-its-kind project, the remaining risk levels of the project needs to be covered by policy/regulatory support to enable investment by regulated system operators via commercial procurements.
Policy context	This project is a critical element in the European offshore strategy. It also fits with the ambition of the draft TEN-E regulation that aims for coordinated offshore planning and can provide incentives to accelerate **[13]**.
State of the art	This is a first-of-its-kind project globally.
TRL now/target	Project 'P7 / Development of multi-vendor HVDC systems and other power electronics interfaced devices' should bring TRL to 6. This demonstrator needs to push towards TRL 9.
Proposed Timeline	Commencing in 2025
Estimated Budget to facilitate TSOs efforts	This project involves the development of an actual multi-terminal HVDC system with multiple vendors, which has a typical budget orders of magnitude beyond that of other projects proposed in this Implementation Report.
Funding Scheme	The Connecting Europe Facility (CEF) can leverage this demonstrator by supporting the innovative aspects and covering the risk element in project financing. This would have to follow the TEN-E process for project of common interest (PCI) status and possible grants for studies and works. The TEN-E regulation is presently being reviewed. In addition, the Innovation Fund could leverage the investment of this demonstration of a first-of-a-kind highly innovative project.

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

P10 / Stability management in power electronics dominated systems

Needs addressed

The European AC power system is seeing a surge of power electronic coupled devices in supply (solar PV and wind), load (EVs, industrial electric drives), storage (batteries), sector coupling (electrolysers) and interconnections (DC links). Such transition necessitates new operational tools to manage low inertia systems and stability risks[2]. Such tools allow for improved planning and operational procedures. Recent years have shown progress in technological options from power electronic coupled sources to support the future system, most notably in the field of GFCs **[26, 36]**. There is an urgent need for TSOs to **develop, test and implement a new stability management approach**. This also needs to be covered by clear requirements for operation, market and connections to establish a stability management scheme with GFC sources and other assets.

Scope

The overall objective is to develop and test methodologies and procedures for stability management by GFCs (solar PV, wind, batteries, EVs, HVDC) at system-wide level. System management rules and a demo of several distributed units are tested in a relevant environment.

- Review state-of-the-art knowledge from Europe and abroad on how to cope with systems with high level of power electronic coupled sources, including present system management approaches and technology options
- Develop the required fast system frequency change (RoCoF) identification methodologies and models based on existing monitoring infrastructure, and scope future options and performance needs.
- Assess impact on protection systems, develop appropriate models and identify enhanced fit-for-purpose protection schemes.
- Develop common frequency and voltage distortion limits depending on local system characteristics, synchronous area characteristics, interconnectors and existing grid codes.
- Assess the impact of power electronic interfaced devices on existing and new inter-area modes for small signal stability and develop wide area monitoring and control schemes.
- Assess the current and future (next 10 years) technology capabilities and costs for stability management from power electronic interfaced devices in cooperation with manufacturers, research institutions and service providers, considering the process for setting up relevant connection code requirements.
- Develop methodologies for operational planning, forecasting of frequency response services needed and spatial distribution of units qualified to deliver GFC functionalities. Consider all possible sources and loads, from high-voltage transmission level to distribution connected assets. This includes a cost benefit approach for stability management options by GFC and alternatives (e.g. synchronous condensers).
- Identify ancillary service products, market approaches, coordination schemes and their impact on wider operational rules for TSOs and DSOs, as well the potential needs for new capabilities of other grid users such as synchronous generators.
- Set up a stability management demonstrator of several distributed units with GFC capabilities (asset type, location, voltage level connection, and other parameters to be defined).

Expected impact

Optimised stability management in assessment, planning and operation by GFC schemes could cope securely with higher infeeds of power electronic interfaced sources such as PV and wind at lower societal cost than curtailment or dedicated new assets. The TYNDP scenario analysis shows synchronous area inertia levels from conventional plants broadly dropping by 10–20% towards 2030 in Continental Europe and the Nordics **[25]**. In smaller systems such as Great Britain and Ireland, the lower levels of inertia necessitate action already. Ireland sees ~7% wind curtailment, among others, to respect a maximum simultaneous non-synchronous penetration of 75% **[28]**. National Grid ESO recently contracted services for £ 328 million up to 2026 in a dedicated Stability Pathfinder process, mainly from conventional assets; the ambition is that in a next auction round, stability management by GFCs can also offer similar performance for lower cost **[27]**. The risk-related high levels of converter-based infeed in Continental Europe and the Nordics is especially critical in case of system splits.

Alternative options exist to cope with higher shares of power electronic coupled sources and are already being applied in smaller systems. Novel inertia measurement and fast frequency change detection tools are tested. System operators can develop/procure dedicated fast frequency service products (e.g. from batteries), curtail non-synchronous infeed, and build dedicated assets such as synchronous condensers and flywheels. GFCs rely on different control strategies in existing converters (PV, wind, HVDC, batteries) with a likely extra cost due to higher internal ratings.

For TSOs, the implementation of GFC system management schemes implies changes in long-term planning, connection rules, load-frequency control procedures and the procurement of ancillary services.

Barriers

The development, validation and implementation of a new wide-area system stability management approach, must include clear guidelines for the technical capabilities, system operation, new market rules to facilitate the presence of solutions and revised connections network codes requirements. It is crucial to see this project as an enabler for operating a zero-emission system with higher shares of PV and wind, not as a complicating element that slows integration. As an example, it remains difficult to validate a GFC concept at the level of a large synchronous area.

Policy context

Inertia management and RoCoF identification is receiving increasing attention in network codes (EU level and national). The network code implementation and amendment process has already reviewed this topic in collaboration with relevant stakeholders. A European approach is key to avoid national divergent approaches which complicate system operations and product development.

2 This is often referred to as 'system strength' related issues, which are a combination of low inertia, low short circuit level and voltage stability problems. The project refers in general to stability management.

Flagship 5 – Enable secure operation of widespread hybrid AC/DC grid	
State of the art	Control algorithms and novel approaches for GFC technologies are being tested in collaborative TSO research projects such as MIGRATE (methodology) and Osmose (storage based GFC). This brings GFC TRL from a technology angle to ~7 for some technologies, and the system management TRL to ~4. GFC capabilities are already included in the specification of some HVDC projects (Germany). ENTSO-E and industry actors published a technical report on technology capabilities to cope with high converter infeed levels in early 2020 **[26]**.
TRL now/target	From TRL 4 (conceptual understanding and initial GFC tests) towards 6 (validated methodology in relevant environment to prepare for wide system implementation; possible distributed field demo)
Proposed Timeline	2022 – 2025
Estimated Budget to facilitate TSOs efforts	€ 12 million or more depending on the extent of a demonstrator
Funding Scheme	This project can be linked to CL5-2021-D3-01-02: 'Laying down the basis for the demonstration of a Real Time Demonstrator of Multi-Vendor Multi-Terminal HVDC with Grid Forming Capability: Coordinated action' under Horizon Europe. Future calls may focus on stability management based on GFC capabilities from a wide variety of sources and alternative options.

P11 / Assessment of a widespread hybrid AC/DC system	
Needs addressed	The power system has a long history of HVDC connections between synchronous AC systems and DC connected offshore wind. Larger DC systems are increasingly being integrated into the AC system via larger (meshed) DC offshore systems and embedded HVDC corridors **[29]**. This calls for new **modelling methods and tools** that enable the **assessment of security, controllability and dynamic stability** of the future system and **mitigate adverse interactions between AC and DC parts of hybrid AC/DC systems**.
Scope	The overall objective is to develop methodologies for the security, controllability and dynamic stability assessment of hybrid AC/DC transmission systems and develop/validate simulation models for specific use-case applications. This enhances the toolkit for security assessments of widespread hybrid AC/DC systems, considering the proprietary nature of DC controls. This is critical for a full assessment and de-risking of meshed DC systems and their interaction with the AC system prior to full-scale deployment. This project is an enabling step with some prototype pilots, before actual modelling tools are developed and validated (incl. software design, standardisation, interoperability tests, integration tests, acceptance tests, etc) Establish AC-side and DC-side modelling requirements and define information exchanges for various (new) designs of DC systems, including boundary conditions, specifications, data needs and validation. Apply benchmarking based on existing DC connections. Develop descriptive/predictive/prescriptive data processes and modelling methods for various use cases. › Use case 1: interaction modelling (based on collaboration/governance schemes as set out in project 'Development of multi-vendor HVDC systems and other power electronics interfaced devices'), including impact, source identification, and propagation paths. › Use case 2: compatible models for wide area controllability and stability assessment, including probabilistic dynamic security assessments. › Use case 3: modelling and assessment of different HVDC grid protection schemes. › Use case 4: assess how present services by Regional Security Coordinators can be improved with enhanced hybrid AC/DC assessments, as well as how this can feed into the development of future Regional Coordination Centre services. › Use case 5: develop recommendations for the harmonised assessment methodologies of hybrid AC/DC systems stability aspects, consequential amendments proposals for the relevant network codes and improved grid planning guidance.
Expected impact	The Continental European system sees already almost a dozen embedded HVDC links in operation or under construction. An increasing number of DC hubs and hybrid projects are moving towards offshore wind and crossing synchronous areas **[30]**. Planned HVDC interconnectors (embedded and radial) in the most recent TYNDP account for over half of all projects, whereas in the past this was mainly AC-project dominated **[6]**. The TYNDP2020 portfolio unlocks approximately € 10 billion per year, for which a resilient and timely development of the AC/DC portfolio is essential. As the hybrid AC/DC grid emerges, this project is required to advance TSOs' capabilities to assess such system, de-risk investments and ensure that what looks promising from an initial techno-economic assessment can be realised in a secure manner for the entire system. Not having this capability to validate system impact and take appropriate action implies reducing transfer capacities, higher balancing costs and developing additional assets (e.g. phase-shifting transformers [PSTs]) to mitigate risks. This TSO-driven development of methodologies and models enable further tool development, either as open source or by vendors.
Barriers	Lack of transparency, compatibility and interoperability of electrical simulation models, data types and platforms. Lack of requirements and agreements for information exchange. Lack of model updates of existing generators units (refurbishment of current model portfolio).
Policy context	EU Regulation 2017/1485 System Operation Guidelines (e.g. Art 38 – 39, 79 – 81)

Flagship 5 – Enable secure operation of widespread hybrid AC/DC grid	
State of the art	TSOs conduct extensive feasibility studies for all new connections. Recent research projects (Migrate, BestPaths, iTesla) have already advanced the methodologies and modelling capabilities for an increasingly complex system on a conceptual level. In today's Regional Security Coordinator services, HVDC systems are usually represented with basic static models.
TRL now/target	From TRL 3 (general concept and initial scientific research for hybrid systems) towards 6 for the main use cases (models that are benchmarked and validated to the extent possible)
Proposed Timeline	2022 – 2024
Estimated Budget to facilitate TSOs efforts	€11 million
Funding Scheme	Some tasks could be part of a project following the Horizon Europe call CL5-2022-D3-01-09 on 'Real Time Demonstrator of Multi-Vendor Multi-Terminal VSC-HVDC with Grid Forming Capability (in support of the offshore strategy)', the call CL5-2022-D3-01-13 on 'Energy system modelling, optimisation and planning tools', the call CL5-2021-D3-02-08: 'Electricity system reliability and resilience by design: High-Voltage, Direct Current (HVDC)-based systems and solutions', or another future call with a stronger one-on-one match to this project scope

Flagship 6 – Enhance control centres' operation and interoperability	
P12 / Cyber resilience in the future control centre	
Needs addressed	Security of supply in the future cyberphysical grid **[34]** will not only rely on clear planning, connection and operational measures of the electrical grid, but require **increasing attention to cyber resilience across all stakeholders. In this system of systems, control centres are a critical cornerstone** due to potential real-time cascading effects. As physical and digital worlds converge in power systems and the number of cyber connected systems increases, cyber resilience becomes as important as operational security.
Research objectives	The overall objective of the project is to develop risk assessment methodologies for control centre cyber resilience, develop collaboration schemes and joint emergency exercises. The focus is not on specific identification and defence tools or a detailed standardisation of communication interfaces, but rather on adapting cyber hygiene measures to control centre interactions. The aim is also without prejudice to obligations TSOs already have, subject to national and EU legislation. The work includes: › Identify future risk scenarios. Apply in vulnerability assessment. › Develop maturity framework / metrics for control centre interactions (national–regional, TSO-external, inter-TSO), based on the existing, more general cyber resilience maturity models. (Note: a maturity framework is a supporting tool not a compliance check.) Apply the logic not only to today's system but also identify issues with the envisaged control centre of the future (2030) and its evolved architecture and applications › Set up information sharing process, fast response schemes across TSOs and fast recovery procedures, › Run emergency exercises and adapt proposed tools and training. › Implement pilot projects as anticipated with the future implementation of an EU network code on cybersecurity.
Expected impact	Over recent years, the investments in digitalisation of the power sector have doubled while grid investments in transmission and distribution have declined **[31]**. Recent surveys show how globally, over half of all utilities experienced a loss of information or operational technology (OT) outage due to cyber issues in 2019, whereas an estimated one third of OT attacks go undetected **[32]**. Leading organisations are able to remediate security breaches in 1 – 2 weeks max or often sooner, whereas the majority of other organisations take at least two weeks **[33]**. Control centres transition from a system based on strict closed-loop automation with proper cyber defence perimeters towards a control centre that needs to securely communicate with an increasing number of digital substations, other system operators and external platforms. It is impossible to completely prevent cyber incidents nor estimate how frequent or impactful they might become. Nevertheless, innovation in cyber resilience for control centres will enable a faster identification of issues, better preparedness, a swift recovery in the event of incidents through enhanced collaboration, and overall a stronger embedding of cyber resilience practices across the organisation and in staff training.
Barriers	As in all cyber resilience collaborations, the key is trustful partnerships to navigate sensitive and confidential business information. The project focuses on advancing collaborative processes, promoting a common understanding and incentivising joint emergency exercises. It does not cover actual technical cyber resilience infrastructure and software solutions at the TSO level.

Flagship 6 – Enhance control centres' operation and interoperability	
Policy context	Various European policies focus on this topic, including the risk preparedness regulation, system operation guidelines, the network and information security (NIS) directive, the EU cyber strategy, a future network code on cybersecurity and national legislation on critical infrastructure (often linked to NIS implementation). Although cyber resilience receives increasing policy attention, there is a common understanding regulation can and should not be fully prescriptive but rather incentive and outcome-based. This implies the initiative for best practices needs to come from industry.
State of the art	TSOs are designated as operators of essential services under national NIS directive implementation. Specific processes to be followed are often national. ENTSO-E focuses extensively on cyber resilience in its digital committee and was an active contributor to the EC's Smart Grid Task Force on Cybersecurity together with DSOs and industry. Cyber resilience at the national level is deemed well advanced, but collaborative processes (apart from valuable but general knowledge exchange such as information sharing and analysis centres [ISACs]) are in the early phases only.
TRL now/target	From TRL 3 (concepts for collaboration) and high TRL for national implementations to TRL 6 (operational processes for control centres and their cooperation)
Proposed Timeline	2023 – 2025, also considering future network code on cybersecurity tasks
Estimated Budget to facilitate TSOs efforts	€ 6 million
Funding Scheme	This can be linked to CL5-2021-D3-02-07: 'Reliability and resilience of the grid: Measures for cybersecurity, vulnerabilities, failures, risks and privacy' under Horizon Europe. It might also align with the Digital Europe Programme 2021 – 2027

P13 / Secure, robust, AI-enabled and open IT solutions for the future control centres	
Needs addressed	The suite of applications used in TSO control centres for advanced monitoring, real-time assessments, communication and control is ever expanding, as is the set of cyber connected devices and external platforms. Historically, supervisory control and data acquisition (SCADA)/energy management system (EMS) systems were monolithic solutions with the operator interface, central communication architecture and database strongly driven by single vendors. The future control centres will see additional functionalities emerge. They need a much more **modular approach allowing for multi-vendor and open source applications** to be integrated and maintained, which can communicate in a secure and robust manner with various own remote gateways and external platforms.
Scope	The overall objective of this project is to develop a framework for accommodating vendor-independent modules for communications and data processing ('hybrid open source') in the control room's existing SCADA/EMS. This approach is tested and validated for specific applications. › Establish target concept for control centre of the future › Identify barriers for open modules based on use case elaboration › Develop a cooperation framework and governance for TSOs and vendors that enables interoperability by accounting for future control centre functionality expansions, generic/detailed model sharing, model adaptations to plug in new modules, and future liabilities and warranties › Develop modules using AI and optimization algorithms to support decision making in system operation. The modules have enable the implementation of a probabilistic risk approach as the one which has been proposed in European project like GARPUR › Define services to reach an open community and continuous maintenance/support › Assess impact on internal TSO procedures and regulatory compliance › Develop and test a number of open applications as actual demo of the idea. This can include WAM applications, individual grid model (IGM) export, distributed energy resources management system (DERMS) interaction, outage planning module, real-time security analysis, or others.
Expected impact	Moving towards (hybrid) open source solutions or modular approaches for system integration allows for faster innovation cycles and provides higher agility in improving control centre tools. It can improve resilience in a further digitalized power system with higher levels of automation and distributed intelligence. A direct benefit is that avoiding vendor lock-in can reduce longer term investment costs by TSOs which is in the interest of all grid users. In other sectors, open source strategies deliver 20–55 % cost reductions to organisations. This is likely less in a critical infrastructure environment, but even a reduction of a few percent implies relevant benefits for the end consumer bill.
Barriers	Vendor participation is necessary to develop a cooperation framework and governance that enables future interoperability. Adoption will require an ecosystem of service providers to support maintenance (as is the case already in other ICT branches). In case of open-source solutions, particular business case for some of the vendors to support it might not be clear. Intellectual property related aspect has also to be solved. In addition, higher agility of control centre applications also requires simultaneous improvement of processes and continuous attention to staff training.

Flagship 6 – Enhance control centres' operation and interoperability	
Policy context	There is no specific policy addressing open modules for TSOs, apart from a general obligation to deliver value at lowest costs to consumers while ensuring operational and cyber resilience at all timeframes.
State of the art	Initial steps are taken for open source applications in the control room or applications from other vendors than the main SCADA/EMS. This covers mostly meter data acquisition and simulation tools but are not integrated in key applications. Some initiatives exist to promote open source approach in the TSO community.
TRL now/target	For some applications in the control centre, TSOs already adopt open source tools (e.g. openPDC). Apart from these trials, the TRL on open source modules fully integrated in SCADA/EMS is generally very low. The aim of the project is to come at least to TRL 3 in terms of target concept, and with some demo applications to TRL 6.
Proposed Timeline	2024 – 2026
Estimated Budget to facilitate TSOs efforts	€ 10 million
Funding Scheme	This can be linked to Horizon Europe call CL5-2021-D3-01-01 on 'Establish the grounds for a common European energy data space', or another call in the same programme at a later stage.

Annex II:

TRL definitions applied to TSO RDI actions

TRLs are key indicators for planning innovation projects and measuring state-of-play. They are commonly used in European funding programmes as well as in ENTSO-E's own RDI work. Initial TRL definitions stem from NASA and the terminology is still very much technology centric and aimed at market viability. In other domains such as the scope of this RDI Implementation Report, methodologies, ICT schemes, standardisation, operational procedures, etc are also targeted. The following table lists the reference TRL definitions, as well as the interpretation in ENTSO-E's Technopedia and some example terminology from this Implementation Report.

Level	Basic Definition	ENTSO-E Technopedia	Example outcomes for non-technology centric projects
TRL 1	Basic principles observed	Basic research: basic principles are observed and reported	Early scoping defined; standard scope defined
TRL 2	Technology concept formulated	Applied research: technology concept and/or application formulated	Methodology described; KPIs defined; standardisation process launched
TRL 3	Experimental proof of concept	Critical function, proof of concept established	Assessment methodology developed; offline simulations of new technology performed; draft standard developed
TRL 4	Technology validated in lab	Laboratory testing of prototype component or process	Assessments methodology applied for generic case study; early prototype developed and tested; draft standard validation and amendment
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Laboratory testing of integrated system	Field demo of assets communication architecture, operational platform showing reliable fit-for-purpose performance; analytical system studies on limited scale using prototype methods, not using full real-world data set; draft standard validation and amendment
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Prototype system verified	Field demo of asset, communication architecture, operational platform to drive benefits; Assessment methodology fully tested, but not on critical path of normal operations; draft standard validation and amendment
TRL 7	System prototype demonstration in operational environment	Integrated pilot system demonstrated	Assessment methodology fully tested, driving operational/market/investment decisions; Field demo of asset, communication architecture, operational platform fully demonstrated in operational environment; draft standard validation and amendment
TRL 8	System complete and qualified	System incorporated in commercial design	Approach is standardised in an international standard.
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	System ready for full-scale deployment	System ready for full-scale deployment

Abbreviations

AI	Artificial Intelligence
BIM	Building Information Model
CBA	Cost Benefit Analysis
CBCA	Cross-Border Cost Allocation
CEF	Connecting Europe Facility
CIM	Common Information Model
DERMS	Distributed Energy Resources Management System
DSO	Distribution System Operator
EC	European Commission
EMS	Energy Management System
ENTSO-E	European Network for Transmission System Operators in Electricity
ENTSO-G	European Network for Transmission System Operators in Gas
ERAA	European Resource Adequacy Assessment
EV	Electric Vehicle
FFR	Fast Frequency Response
FTE	Full-Time Equivalent
GFC	Grid-Forming Converter
H2020	Horizon 2020
HVDC	High Voltage Direct Current
IGM	Individual Grid Model
ISAC	Information Sharing and Analysis Centre
IT	Information Technology
MSPS	Multi-Sectorial Planning Support
NIS	Network and Information Security
NUTS	Nomenclature des Unités Territoriales Statistiques
OT	Operational Technology
P2X	This refers to all power conversion options in general
PCI	Project of Common Interest
PMU	Phasor Measurement Unit
RDI	Research, Development and Innovation
RoCoF	Rate of Change of Frequency
RE	Renewable Energy
SCADA	Supervisory Control And Data Acquisition
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European Networks for Transport
TRL	Technology Readiness Level
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
V2G	Vehicle to Grid
W3C	World Wide Web Consortium

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