ENTSO-E

Research, Development and Innovation (RDI) Implementation Plan 2026–2030

Research, Development & Innovation Committee (RDIC) under leadership of Working Group Research, Development & Innovation Planning (WG RDIP)

CONNECTING EUROPE,
ELECTRIFYING THE FUTURE

Mission Statement

ENTSO-E – the European Network of Transmission System Operators for Electricity – brings together 40 electricity Transmission System Operators (TSOs) from 36 countries. ENTSO-E members are responsible for the secure and coordinated operation of Europe's electricity system. Together, they operate a system of around 500,000 km of power lines **– the largest interconnected electrical grid in the world –** and serve about 520 million citizens.

Electricity is not merely a market commodity, it is an essential service, and TSOs are fully regulated public service entities whose work is essential to powering Europe. The grid is the backbone of the electricity system and has extended over the whole Continent, beyond the borders of the EU. TSOs working together guarantee a functioning infrastructure that makes the trade of electricity possible, contributes to decarbonisation goals, and ensures a reliable and efficient power supply for all members of society.

These shared public service responsibilities need close cooperation beyond national borders, which led to the creation of ENTSO-E. Today, the association serves two main complementary purposes:

1. Cooperation of European TSOs

The foundations of this cooperation date back to the 1950s with the creation of electrical synchronous areas and interconnections, which laid the groundwork for today's interconnected European power system. TSOs established associations to work together on their own mandates and missions, that came together into what today is ENTSO-E. The European electricity system is one of the most stable and reliable grids in the world and is supported by the cooperation and coordination of TSOs both within the European Union and closely interconnected European countries. ENTSO-E strives to build consensus for decision-making amongst its member TSOs as this forms the strongest foundation for cooperation.

2. Fulfilling EU legal mandates

With the adoption of the Third Energy Package in 2009, ENTSO-E's role was formally recognised by European institutions. ENTSO-E was granted legally mandated tasks to further develop the European interconnected grid and to facilitate the integration of European electricity markets. These mandates cover a large spectrum of tasks, including system operation, system development, market integration, information technologies, R&D and innovation.

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Executive summary

This Research, Development, and Innovation (RDI) Implementation Plan 2026–2030[1] translates missions and milestones of the ENTSO-E Research, Development, and Innovation (RDI) Roadmap 2024–2034 into concrete, high-level guidelines for innovation project proposals. It serves as a catalyst for transformative change across Europe's power sector, fostering collaboration led by European transmission system operators (TSOs), promoting investment through private and EU funding instruments, and supporting the modernisation of the European electricity system. **The plan defines 13 Project Concepts (PCs), jointly developed by TSOs, which provide blueprints for future collaborative projects.**

ENTSO-E Mission & Mandate

For ENTSO-E, innovation is imperative, because it powers Europe's energy transition while upholding the association's role of promoting the security, decarbonisation, affordability, and cost-effectiveness of the European electricity system. This Implementation Plan, developed in accordance with Article 30(1)(i) of the **Regulation (EU) 2019/943**, complements the Research, Development, and Innovation (RDI) Roadmap 2024–2034 and translates its missions and milestones into an efficient research programme for its delivery.

The Implementation Plan is aligned with ENTSO-E missions, its **Strategic Roadmap**, and key European policy frameworks.

13 PCs as high-level project blueprints

The 13 PCs outlined below focus on key areas for the future operation and development of the power system, including integrating new technologies, enhancing digitalisation, improving interoperability, and strengthening the resilience of the electricity grid.

Topics include interoperable high-voltage direct current (HVDC) systems, grid digital twins, artificial intelligence (AI)-based decision support tools, and solutions to strengthen system resilience against extreme events and cyber threats.

The objective is to advance innovative solutions towards higher technology readiness levels (TRLs), enabling deployment of real-life, innovative projects. Each PC identifies key system challenges, outlines the innovation needs required to address them, and provides a common basis for launching concrete projects with relevant stakeholders. In addition to PCs, the Implementation Plan highlights ongoing and recently completed projects demonstrating already attained TRLs. The PCs build on those examples and propose project blueprints that go beyond the current state-of-the-art baseline.

Collaboration is at the heart of innovation

The Implementation Plan promotes close collaboration between TSOs and accounts for the role of other energy sector stakeholders – such as distribution system operators (DSOs), technology providers, manufacturers, market participants, research institutions, regulators, and policymakers – in addressing barriers that currently slow deployment of innovative solutions in the electricity grid.

Delivering projects envisioned in this plan will require sustained collaboration, supportive regulatory frameworks, and stable long-term funding. European funding instruments such as Horizon Europe, together with national programmes and TSO resources, will continue to play a key role in supporting the development of demonstrators, pilots, and large-scale projects.

1 Hereinafter "Implementation Plan" or "RDI Implementation Plan".

1 Introduction

For ENTSO-E, innovation is imperative: it powers Europe's energy transition while upholding TSOs' core responsibilities. In fact, the ambitious European Union (EU) goal of achieving net-zero emissions by 2050, coupled with the current international context, demands impactful and effective solutions to maintain a secure, decarbonised, affordable, and cost-effective power system. This RDI Implementation Plan 2026 – 2030 is built on a set of key milestones established by the RDI Roadmap 2024 – 2034. Its purpose is to transition from the strategy defined in the Roadmap to concrete PCs, enabling efficient and practical implementation of the key milestones of the RDI missions.

The Implementation Plan within European energy policy landscape

This Implementation Plan is designed in a policy landscape where the European Commission has significantly heightened its focus on grid modernisation, expansion and digitalisation. **The EU Action Plan for Grids (2023)** identified the urgent need to double cross-border transmission capacity over the next decade and accelerate network development to integrate growing shares of renewable electricity while enhancing resilience and system flexibility. Building on this, the **European Grids Package (2025)** proposes key legislative measures such as **revisions to the TEN-E Regulation** and permitting simplification under the **Renewable Energy Directive and Electricity Market Design reforms** to accelerate grid deployment, optimise use of existing assets and enable more efficient cost-sharing and planning across borders. The forthcoming **Strategic Roadmap for Digitalisation and AI in Energy (2026)** will further accelerate the deployment of AI-enabled solutions for grid optimisation, demand-side flexibility, forecasting and secure data sharing - areas central to ENTSO-E RDI missions. Together, these initiatives create a strong alignment between EU policy priorities and the focus areas of the ENTSO-E RDI Implementation Plan, reinforcing the need for coordinated, innovation-driven action by TSOs.

The Implementation Plan's main scope and target audience

The ENTSO-E RDI Implementation Plan 2026–2030 is a strategic document that identifies and elaborates the next concrete steps necessary to advance the RDI priorities of the European power system. The document delivers a set of PCs as supporting tools to structure and guide the coordinated deployment of innovation projects in line with the missions and milestones defined in the ENTSO-E RDI Roadmap 2024–2034. The 13 PCs were developed collaboratively by ENTSOE TSOs, drawing on the latest outcomes of ongoing and recently completed innovation projects, whether national, TSO-led, or EU-funded. These are also summarised in this document as selected ongoing projects that provide the background for the development of the PCs. This joint effort ensures that PCs are built on the most relevant available results while avoiding duplication of efforts across TSOs.

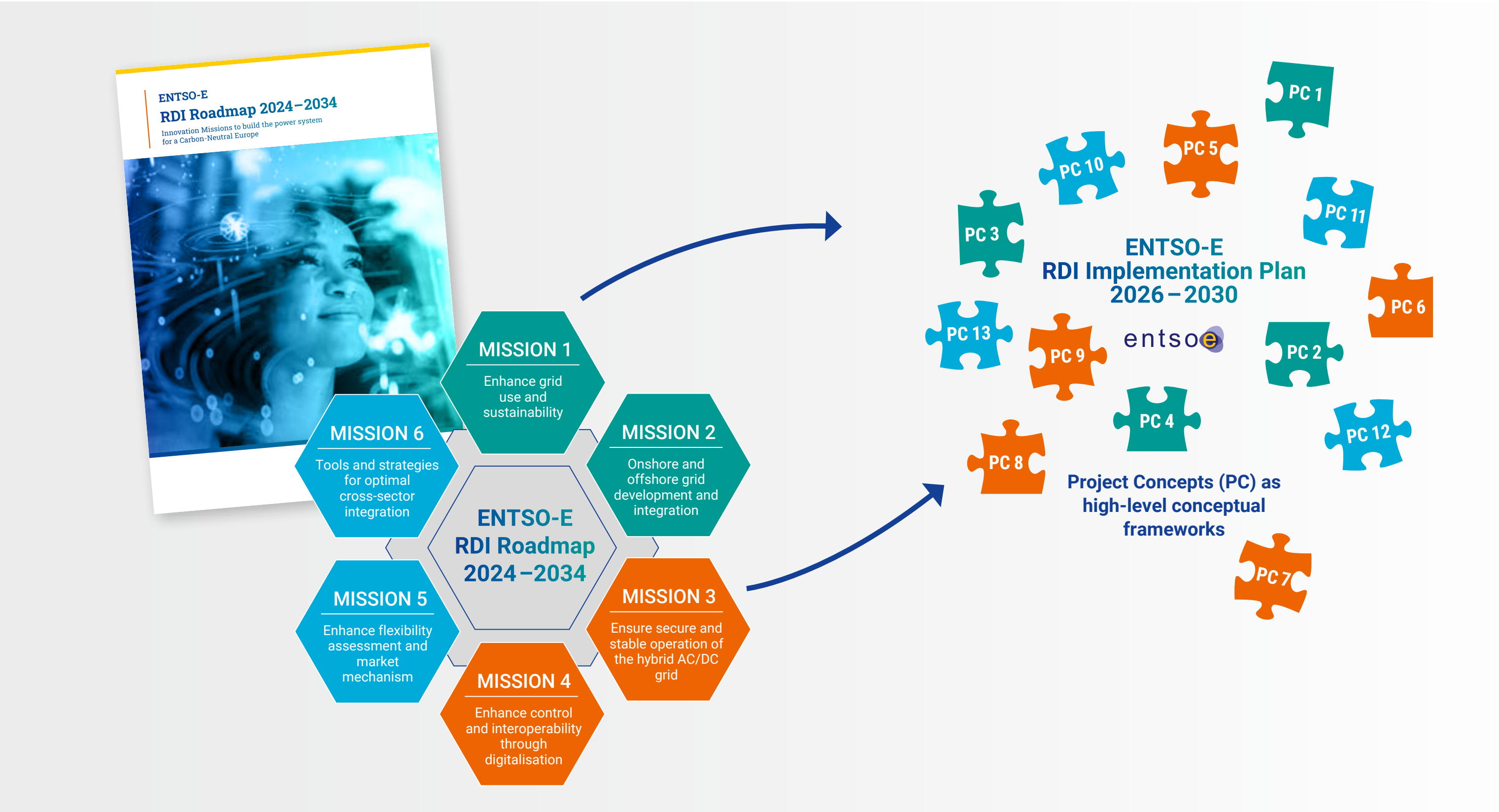


Figure 1: The ENTSO-E Implementation Plan approach

The primary audience for this Implementation Plan comprises, but is not limited to:

TSOs, to support their efforts towards common goals and establish the basis for their topic-specific collaboration. TSOs are committed to sharing results and leveraging the outcomes obtained in different contexts and climates. This collaborative approach will enable the transition from single TSO-led pilots to the development of interoperable, inter-TSO, pan-European solutions.

- **The European Commission (EC)**, to provide strategic ideas as well as substantial, readily accessible EU funding opportunities for. This will empower TSOs to realise the EU's long-term strategy for accelerating the decarbonisation of the EU energy system while ensuring that the transition remains affordable for European society.
- **Research and industry innovation ecosystem**, including manufacturers, research institutions, universities, etc., to share the main TSOs' RDI priorities, while leveraging private sector capacity to bring innovative solutions to market and the research community's ability to deliver breakthrough innovations.

The ENTSO-E RDI cycle

The ENTSO-E RDI cycle is a systematic framework for driving innovation within the European electricity transmission system.

The cycle starts with the development of the **RDI Roadmap**, a crucial and legally mandated strategic document that outlines the long-term vision for European TSOs, effectively shaping RDI policies to align with the EU's objectives for the energy sector.

The strategy outlined in the RDI Roadmap is then detailed in the **RDI Implementation Plan**, translating overarching strategic objectives into concrete PCs to efficiently foster the implementation of the necessary innovative solutions.

Progress is then tracked by the **RDI Monitoring Report**, which assesses ongoing TSOs' RDI projects and identifies gaps against the RDI Roadmap. This feedback loop delivers valuable lessons and data from ongoing projects back into the RDI Roadmap planning process, allowing future Roadmaps to be continuously updated based on real-world outcomes, technological progress, and evolving challenges. By systematically integrating results, trends, and unexpected effects, the ENTSO-E RDI cycle supports a truly dynamic and adaptive strategy for the energy transition, helping decision-makers refine policy, accelerate innovation, and address emerging barriers with agility.

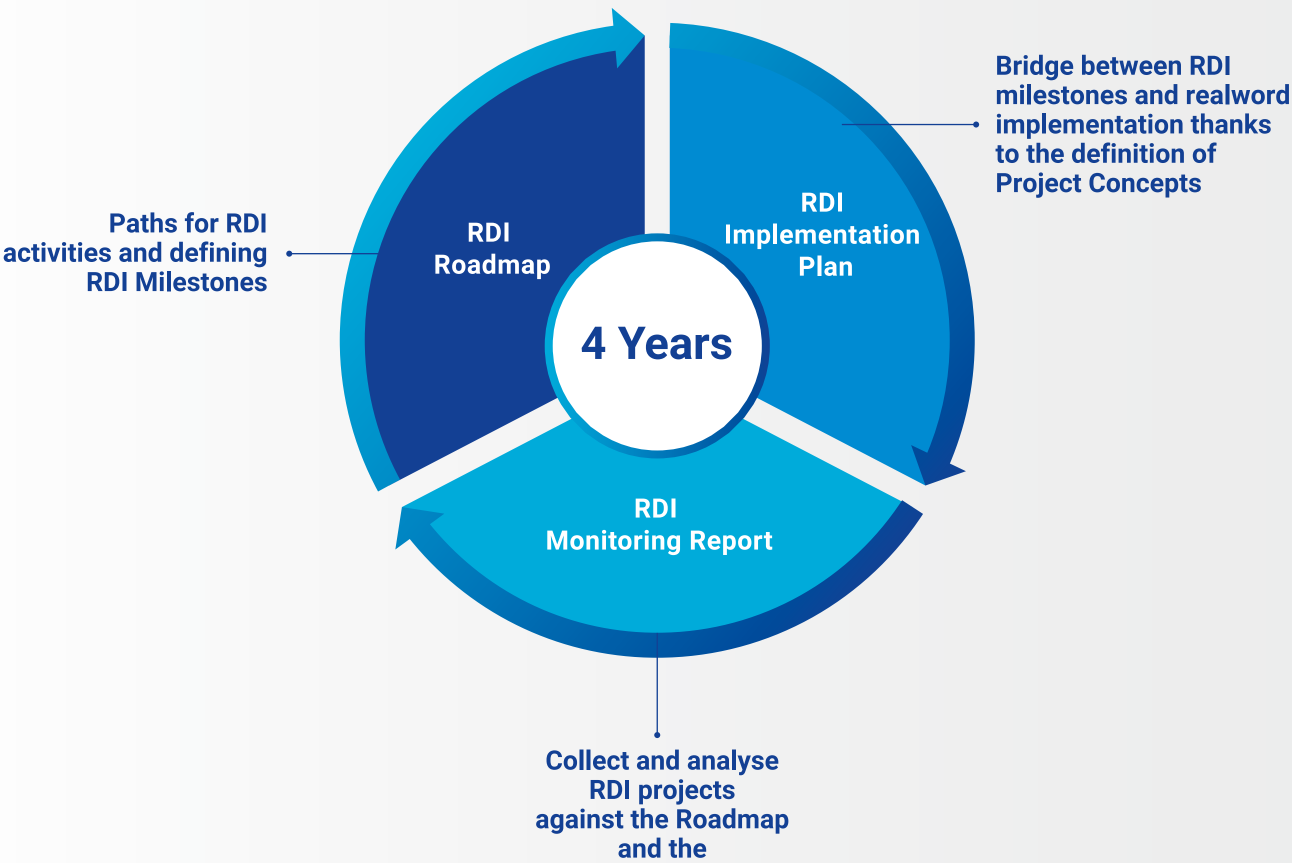


Figure 2: The ENTSO-E RDI cycle

Missions and themes of the RDI Roadmap 2024–2034

The RDI Roadmap, and inherently this Implementation Plan, are aligned with the ENTSO-E Strategic Roadmap and its two pillars: the future of the power grid and the current management of the power grid. Based on these two pillars, the RDI Roadmap identified innovation areas organised into three thematic clusters, as pictured in Figure 3.

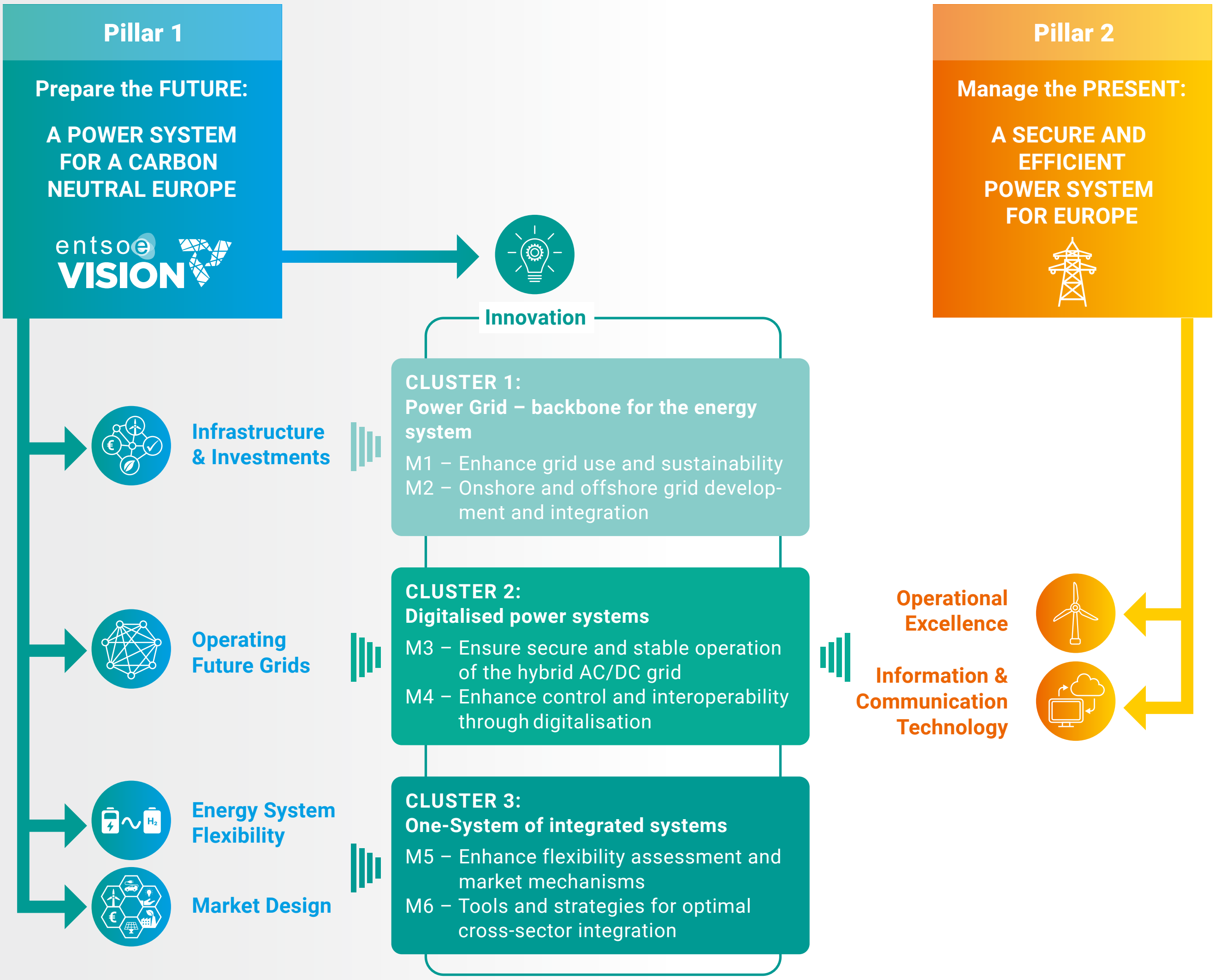


Figure 3: ENTSO-E Roadmap 2024 – 2034 in the framework of the ENTSO-E Strategic Roadmap

Each cluster is supported by additional specific missions and milestones. By defining six RDI missions and over 90 milestones essential to achieving the clean-energy transition of Europe's power system, the ENTSO-E RDI Roadmap 2024 – 2034 places strong emphasis on developing, demonstrating, and scaling the necessary innovative solutions on the path to carbon neutrality.

The RDI Roadmap targets evolving flexibility needs and supports the timely deployment of multiple carbon-neutral flexibility resources – including flexible generation, active demand, storage, sector integration, and flexible grid use – while reinforcing future TSO core activities within an increasingly interdependent "system of systems". To that end, RDI activities are designed as integrated and coordinated efforts that span asset optimisation and digitalisation, enhance system operation, enable flexibility assessment across all time scales, accelerate the integration and utilisation of new flexibility resources, and guide the gradual transition to hybrid AC / DC systems through expanded HVDC links and inverter-based resources (IBR). In parallel, cross-sector integration in planning and developing a holistic energy system, together with market-based interactions, is seen as essential to addressing the challenges ahead.

In short, the ENTSO-E RDI Roadmap outlines the main strategy and key objectives for the next 10 years to make power systems the backbone of the integrated and clean energy system of the future.

Figure 4 shows the six missions and related RDI themes on which the development of the present Implementation Plan is based.

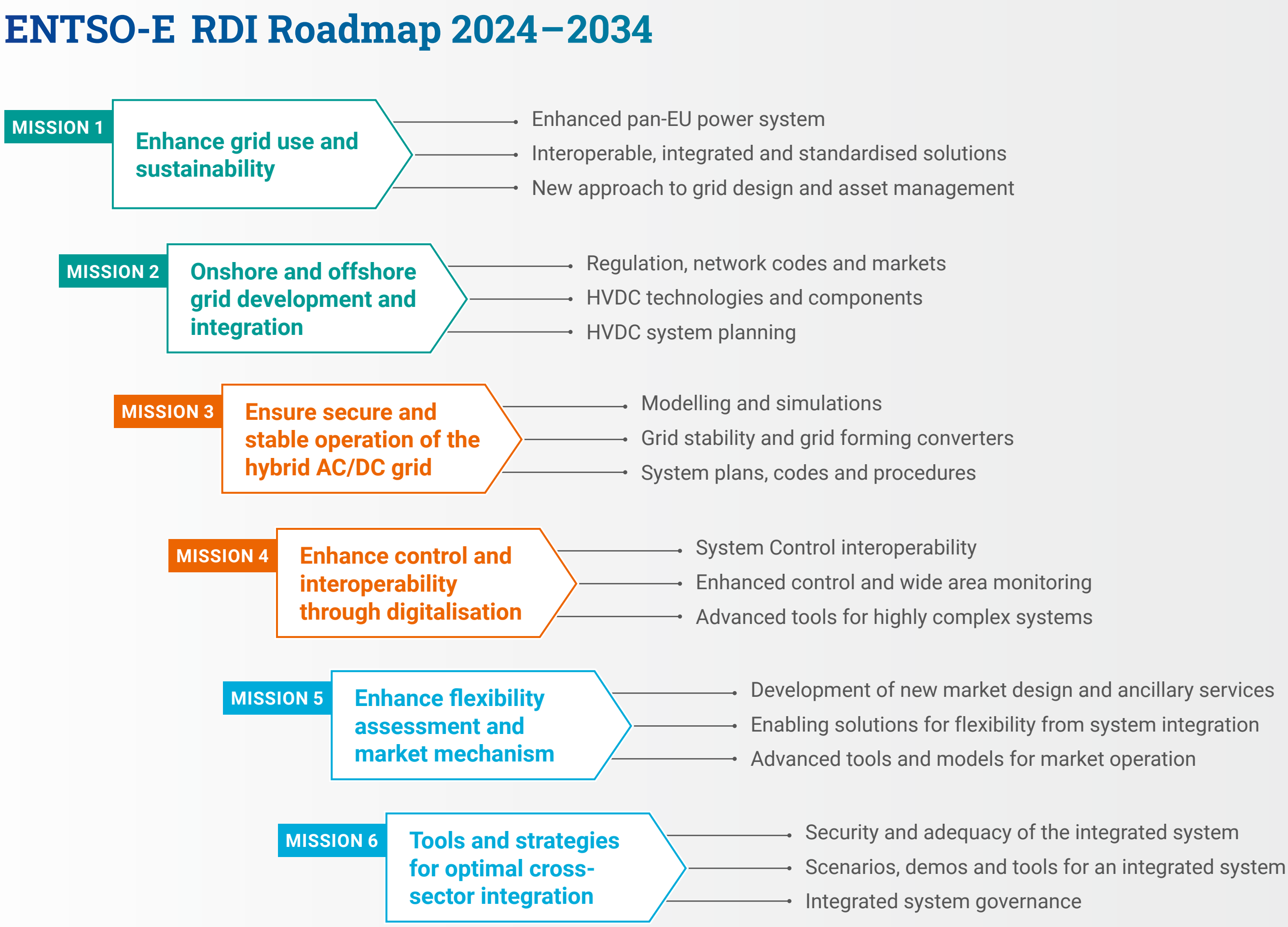


Figure 4: RDI missions and themes of the ENTSO-E RDI Roadmap 2024 – 2034

2 Innovation PCs for the grid of tomorrow

The transition towards a smarter and interconnected power system demands a **structured and forward-looking approach** to RDI activities. Through the present Implementation Plan 2026 – 2030, **ENTSO-E presents 13 PCs** aligned with the milestones of the RDI Roadmap 2024 – 2034 and designed to support transformative progress in the power sector over the next implementation period.

PCs as high-level conceptual frameworks

PCs represent a high-level conceptual framework designed to guide, inspire, and accelerate the development and execution of projects, with the overarching objective of achieving a clearly defined set of milestones for the referenced RDI Roadmap. Each PC includes detailed information that clearly outlines its motivations, scope, and goals. This level of detail enables TSOs to identify and prioritise relevant projects, thereby facilitating informed investment decisions and targeted innovation actions.

The present RDI Implementation Plan proposes 13 PCs, serving as a strategic interface between the milestones defined in the RDI Roadmap 2024 – 2034 and their implementation in the real world.

These PCs have a strong focus and are concretely defined, reflecting a shift towards actionable and impactful research and innovation efforts. By bringing these innovative ideas closer to fruition, the Implementation Plan supports TSOs and their stakeholders in advancing projects to higher technology readiness and operational uptake, ensuring progress towards a secure, flexible, and cost-effective energy transition for Europe.

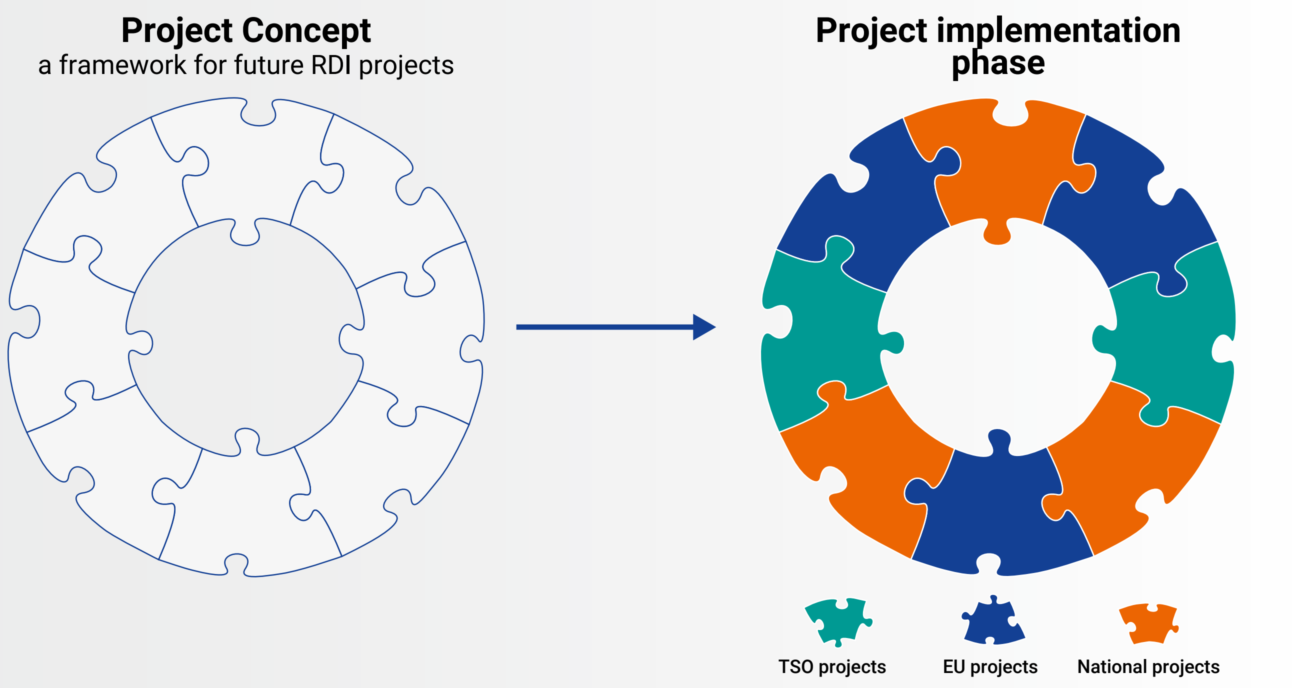


Figure 5: PCs: A high-level conceptual framework

PCs for all RDI missions

PCs are directly linked with select RDI milestones from the RDI Roadmap, ensuring that each initiative is both relevant and strategically timed for the 2026 – 2030 implementation period. Furthermore, distinct but mutually reinforcing PCs have been designed for every RDI mission.

Each PC addresses a specific challenge and stands independently, though some strategic overlap may occur to ensure coverage of interdisciplinary and emerging issues. This structure creates a comprehensive RDI package that spans the entire spectrum of research, development, and innovation pertinent to TSOs. By connecting high-level scientific efforts with tangible, innovation-driven actions, the PCs lay the groundwork for practical impact and measurable progress in the power sector.

As a result, PCs aim to accelerate the translation of new knowledge into solutions, facilitate collaboration among stakeholders, and promote the adoption of advanced technologies and practices. Figure 6 illustrates the PCs together with their connections to the respective missions of the ENTSO-E RDI Roadmap, highlighting their role as a bridge between the RDI Roadmap's milestones and real-world transformation across Europe's power systems.

Four projects have a broader scope and address milestones spanning multiple missions, although each remains primarily linked to a single mission. In Figure 6, the hexagons associated with each PC visually represent these links.

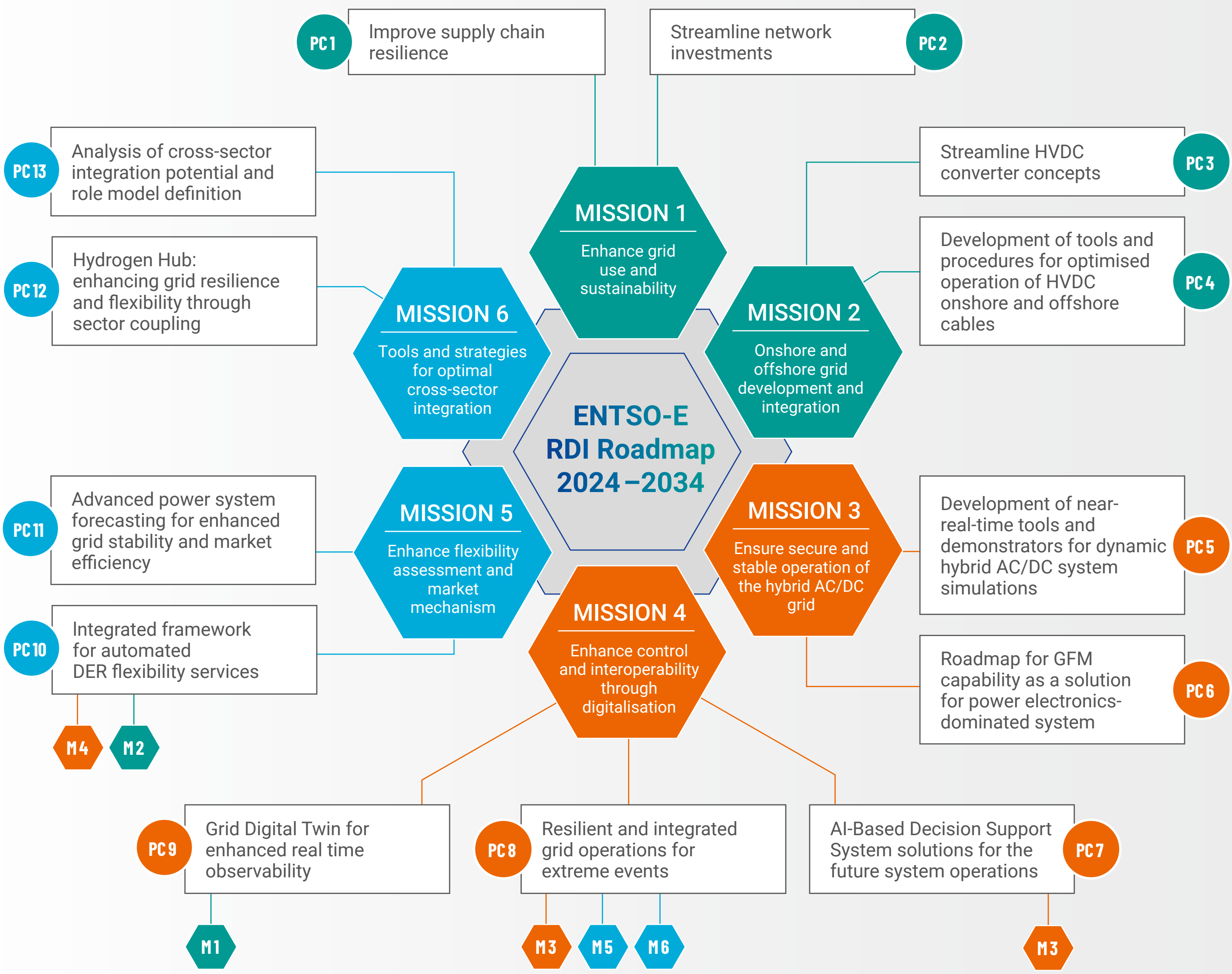


Figure 6: PCs identified by the ENTSO-E Implementation Plan 2026 – 2030 and associated RDI missions

Pathways to a modern, reliable, and flexible power system

The EU is actively striving to enhance its energy independence, with renewable energy at the centre of this transition. As the electricity system adapts to increased weather-dependent generation and rapidly evolving demand patterns – including the rise of AI-driven industries and widespread electrification – unprecedented challenges emerge in grid modernisation and cross-sector integration, necessitating innovative processes and mechanisms to ensure the power grid's resilience, security, stability, reliability, and long-term sustainability.

In this view, **supply chain resilience and standardised asset management** emerge as foundational priorities for grid transformation. Europe's race to upgrade transmission networks faces bottlenecks due to strained supply chains and extended delivery times for essential equipment. Addressing these challenges requires standardising critical components such as transformers, switchgears, and HVDC systems, coupled with synchronised asset management strategies across TSOs.

HVDC technology integration represents another critical pillar for Europe's energy infrastructure. **The expansion towards meshed large-scale HVDC grids** necessitates cross-manufacturer compatibility through the development of multi-vendor (MV), multi-terminal (MT) systems. Key actions include establishing unified requirements and standards for HVDC control and monitoring systems. Additionally, simulation tools for large-scale HVDC systems must be developed alongside converter models and decentralised DC grid controllers to ensure stability, resilience, and security in MV environments.

Developing **digital solutions to enhance power system operations** becomes crucial to manage the increasing complexity from IBR and variable renewable generation. **Grid digital twin** implementation is a transformative priority for modern power system management, as well as deploying comprehensive **wide area monitoring systems (WAMS)**, expanding Internet of Things (IoT) sensor networks across grid infrastructure, and developing **real-time dynamic security assessment (DSA)** capabilities. These will provide enhanced grid observability, supporting both operational decision-making and predictive maintenance strategies.

Grid-forming (GFM) capability development emerges as critical for power electronics–dominated systems. As conventional synchronous generators are gradually phased out, demonstrations in relevant operational environments must be implemented, and consistent GFM requirements and standards must be established across the system. The integration of distributed energy resources (DER) requires improved flexibility operations through the effective implementation of coordination mechanisms between TSOs and DSOs. Critical actions include developing **advanced information and communication technology (ICT) platforms for widespread DER deployment**, implementing standardised data exchange protocols, and creating vendor-agnostic control solutions. The framework must enable participation in national and cross-EU ancillary services markets while addressing challenges in baseline calculation, rebound effect management, and enhanced TSO–DSO coordination schemes. **Advanced power system forecasting** becomes essential as DER penetration increases system complexity.

Resilience to extreme weather events has become paramount as climate events intensify and threaten grid stability. Essential actions include advanced forecasting system development, comprehensive modelling of extreme scenarios, and identification of preventative strategies. This includes implementing real-time adaptive response capabilities, enhanced cybersecurity measures, and rapid system recovery protocols.

Addressing these complex challenges requires the deployment of novel AI tools for the power system. In particular, **AI-based decision support systems** offer breakthrough potential to improve grid management. Such systems must address dynamic grid conditions and ensure operational voltage security while supporting routine activities through continuous reporting and detailed network analysis.

Cross-sector integration and development of hydrogen technologies could provide strategic flexibility for long-term system optimisation. In this respect, key actions involve developing sector coupling strategies across heating, transportation, and industrial sectors, and creating market frameworks that enable hydrogen's role in hard-to-abate industrial sectors.

Finally, the successful execution of all these priorities requires **coordinated action across multiple stakeholders**, including TSOs, DSOs, regulatory authorities, and technology providers. **Streamlined investment methodologies** must be developed to identify and assess critical infrastructure projects while ensuring fair cost and benefit distribution among stakeholders. This includes **innovative financing mechanisms**, accelerated implementation timelines, and effective integration of renewable energy sources (RES) through increased price convergence and enhanced security of supply.

The transformation towards a sustainable, reliable, and resilient electrical power system demands immediate and coordinated action. Success will depend on industry-wide collaboration, regulatory alignment, and sustained investment in both physical infrastructure and digital capabilities that will define Europe's energy future.

3 Framework for PC implementation

The PCs address a broad set of RDI milestones from the ENTSOE Roadmap 2024–2034 and have been structured to overcome key innovation barriers. Building on current TSO activities, they aim to advance promising solutions through coordinated development. The Implementation Plan highlights the importance of sustained political and financial support, notably through EU programs like Horizon Europe, and intends to foster strong collaboration across the energy value chain to deliver scalable innovations driving Europe's clean energy transition.

RDI milestones covered by PCs

Figure 7 provides a comprehensive summary of the RDI milestones addressed by each PC. The result of this analysis shows the strong alignment and link between the RDI Implementation Plan 2026–2030 and the RDI Roadmap 2024–2034.

The number of milestones covered by each PC varies, reflecting the distinct characteristics, specific objectives, and peculiar scope of each individual PC. These differences highlight how each PC contributes uniquely to the overall RDI strategy, ensuring a diverse yet coordinated approach to achieving the research, development, and innovation goals within the defined timeline.

A total of 61 links have been identified between RDI milestones and PCs, encompassing 56 specific RDI milestones, which represent approximately 60% of the 93 milestones defined in the RDI Roadmap. This demonstrates the broad range of RDI milestones addressed by the PCs, with very few duplications among the covered RDI milestones.

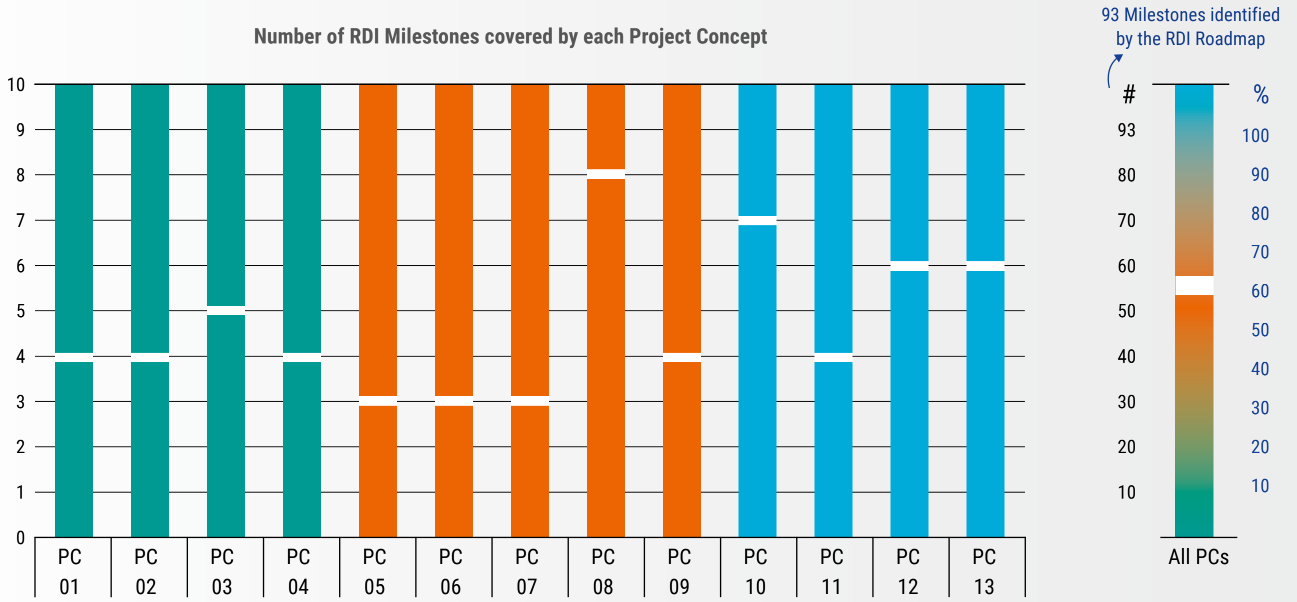


Figure 7: RDI milestones addressed by each individual PC within the RDI Implementation Plan 2026–2030, and the total number of RDI milestones covered

Leveraging the temporal placement of milestones defined in the RDI Roadmap, a more detailed analysis was conducted to identify the specific time frame within the 10-year span of the RDI Roadmap in which the milestones addressed by PCs are positioned. The results of the analysis, presented in Figure 8, show strong coverage of RDI milestones in the 2024 – 2027 period, with PCs addressing around 72 % of the identified milestones. Coverage decreases in the subsequent periods, to around 55 % for 2028 – 2031 and 39 % for 2032 – 2034. This aligns closely with the core objective of the PCs, which is to stimulate the development of projects that aim to address the most urgent and high-priority milestones.

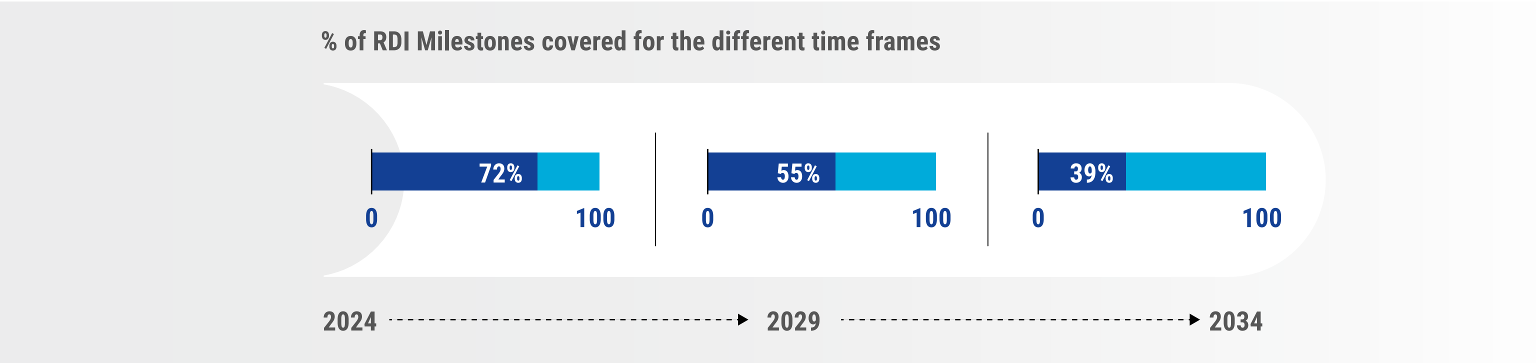


Figure 8: Percentage of RDI milestones covered and addressed by all the PCs in the different time frames according to the RDI milestone distribution presented in the RDI Roadmap 2024 – 2034

Enablers and limiting factors

For each of the 13 PCs identified, the main limiting factors hindering their successful implementation have been assessed to determine how to overcome them. While some obstacles are specific to individual PCs, others recur across multiple ones.

For instance, the limited access to real-time, high-quality data from diverse sources and the lack of harmonised data structures constrain the development of simulation models, tailored software, and digital platforms. At the same time, the integration of new technologies and communication infrastructures introduces cybersecurity and operational risks, which require careful management through phased integration, certification schemes, and coordinated transition strategies. These challenges are further compounded by the need to ensure alignment with privacy regulations and adopt standardised cybersecurity solutions. To address these interconnected issues, the proposed PCs promote harmonised standards, open interfaces, interoperability testing facilities, and secure data exchange frameworks with clear access rights and synthetic data generation, to safeguard privacy and enhance the reliability of digital solutions.

Beyond technical aspects, future projects must also tackle organisational and regulatory barriers. Integrating innovative forecasting and operational tools into existing grid management systems often requires attention and care due to the impact on critical processes and systems. Regulatory and policy conditions further influence deployment, as long approval procedures for new technologies delay the effective delivery of solutions. Fast-track permitting schemes and adaptable regulation can significantly reduce such delays and foster the timely achievement of RDI targets.

Technological complexity adds another layer of challenge, as developing models that accurately represent modern power systems demands both interoperability and advanced skills across stakeholders. Efforts should therefore combine the creation of effective yet easy-to-implement solutions with targeted training to strengthen operators' capabilities. At the same time, financial and resource constraints limit technology uptake. The absence of proven business models and market mechanisms further slows adoption.

The coordinated ENTSO-E RDI cycle helps counter these challenges by fostering a shared TSO vision and reducing duplicated efforts.

Large-scale deployments may also face public and stakeholder acceptance hurdles, which can be mitigated through transparent communication about the benefits and trade-offs of proposed solutions.

Addressing these diverse barriers requires a coordinated approach to data management, regulatory alignment, stakeholder engagement, and technological innovation to achieve the milestones stated in the RDI Roadmap and the overall goal of energy system decarbonisation.

Policy framework

This Implementation Plan duly considers and aligns with the main documents constituting the policy framework for energy system research, development, and innovation. This includes the TEN-E Regulation, which prioritises cross-border infrastructure and interoperability to strengthen the internal energy market and security of supply, the EU Grid Action Plan, which aims to accelerate grid expansion and modernisation to integrate renewables and support electrification, and the REPowerEU Plan, which emphasises energy independence and rapid deployment of clean technologies to reduce reliance on fossil fuels. Complementing these, PCs duly consider digitalisation in line with the EU Action Plan on Digitalising the Energy System, which promotes smart grids, data-driven solutions, and cybersecurity to enable a flexible, efficient, and resilient electricity network. The European Energy Data Space has been an enabler for many PCs, especially for those focused on system digitalisation and interoperability.

The development of PCs also reflects and duly considers key recommendations from the Net Zero Industry Act and the Critical Raw Material Act. In particular, the Net Zero Industry Act acknowledges that achieving EU decarbonisation objectives requires massive expansion of electricity grids at both the transmission and distribution levels. It recognises that without grid connections, there can be no net-zero industry, emphasising the critical role of electricity infrastructure in the clean energy transition. Accordingly, ENTSO-E recommends including industry stakeholders in future RDI projects, streamlining permitting to ensure the timely emergence of European manufacturing capacities, clarifying public procurement, and establishing a coherent regulatory framework to incentivise grid technology innovation.

On the other hand, ENTSO-E also acknowledges the relevance of the Critical Raw Material Act, which aims to ensure secure, sustainable, and resilient supply chains for materials essential to electric infrastructure – such as copper, lithium, rare earth metals, and others – which are fundamental for batteries, wind turbines, solar panels, and grid technologies.

While developing PC descriptions, ENTSO-E also considered recent European AI strategies, given the growing importance of this technology. In this context, the EC recently published the Apply AI Strategy and the AI in Science Strategy. These documents align with the EU'S AI Continent Action Plan and aim to facilitate AI adoption across various sectors, as well as to promote the use of AI in research activities. In the power sector in particular, AI plays a crucial role in advancing grid management and renewable integration through the development of AI models that improve forecasting, optimisation, digital twins, and system balancing within the energy system.

Finally, to translate PCs into tangible outcomes, it is essential to underscore the critical need to de-risk grid investments. Establishing coherent strategies that demonstrate the strategic importance of grid infrastructures and the corresponding need for sustained political commitment would provide credible, stable signals to investors, thereby boosting confidence and fostering greater engagement in projects aligned with the clean energy transition.

The PCs developed in this Implementation Plan are designed to pursue these objectives, offering a structured approach that supports both policy goals and practical advances in grid development.

Funding

A key success factor for TSOs' innovation activities is the ability to access national and European funding programs, which, along with their own resources, enable the achievement of ambitious research and innovation goals. National initiatives and EC instruments such as Horizon Europe play a key role in supporting projects that address the most pressing technological, operational, and regulatory challenges for the power system. These funding mechanisms not only sustain the development of breakthrough solutions but also foster collaboration across countries and sectors, ensuring that innovation responds to common priorities. Leveraging such financial support is essential to complement regulated budgets, bridge the gap between research and deployment, and accelerate the transition towards a smarter, more resilient, and sustainable European energy system.

Collaboration with other actors

TSOs advance research and innovation by engaging a broad spectrum of stakeholders integral to the development and implementation of new projects. These stakeholders include energy service providers, energy suppliers, authorities, regulators, and DSOs, who play direct and essential roles in system operation and regulation. TSOs also collaborate extensively with manufacturers, software developers, ICT service providers, universities, and research and technology organisations, leveraging their technical expertise and innovative solutions. Additionally, effective project delivery requires alignment with associations and local communities, end users, and standardisation bodies, whose perspectives ensure that initiatives address broader societal needs and regulatory requirements.

Figure 9 provides a visual representation of this collaborative approach, employing concentric circles to illustrate the varying degrees of strategic relevance among different energy system stakeholders with respect to the launching of RDI projects. The diagram highlights the actors whose engagement is most critical for TSOs when developing projects stemming from the established PCs. By visually emphasising the priority stakeholders, the figure supports a targeted cooperation strategy that enhances the effectiveness and impact of project implementation, fostering a more integrated and resilient energy system.

Such collaboration ensures that innovation addresses not only technical challenges but also market integration, regulatory compliance, and consumer needs. By pooling expertise from these varied actors, TSOs can tackle complex, multidisciplinary issues and accelerate the deployment of interoperable, scalable solutions. At the same time, TSOs rely on dedicated innovation departments, laboratories, or cross-unit collaboration to manage all phases of innovation internally. The choice between internal development and external partnerships depends on the legal requirements, budget, urgency, and timeline, but the trend is clear: innovation success increasingly hinges on strong, systemic collaboration across the full energy ecosystem.

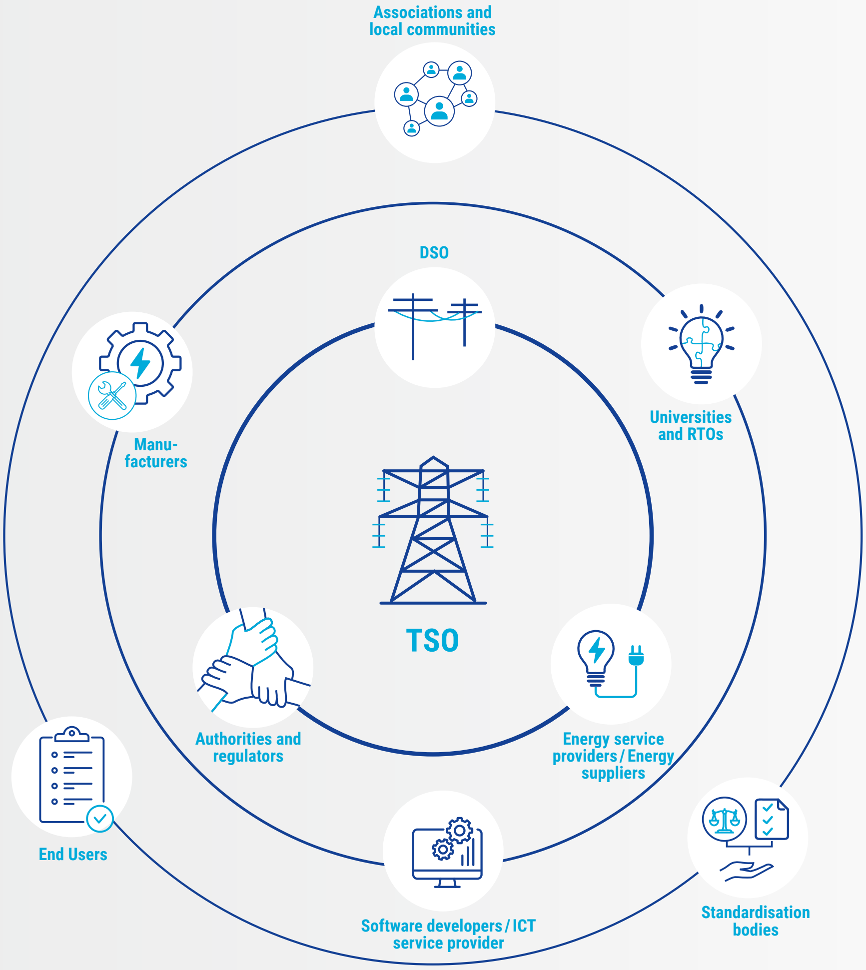


Figure 9: Expected main partners of RDI projects implementing PCs, from the TSOs' perspective

Ongoing projects: background to developing PCs

A selection of ongoing or recently completed projects was analysed to determine how current RDI initiatives can serve as a solid foundation for developing and deploying innovative PCs. This activity aims to provide transparent and structured information on selected projects led or participated in by TSOs across Europe, facilitating effective exploitation of results in future projects launched within the PC framework.

Project information was provided by TSOs and linked according to their alignment with the RDI Roadmap. Certain projects stand out because the solutions and technologies they develop have a strong potential to support and accelerate the rollout of future projects that address key RDI milestones for advancing the European power system.

Several EU-funded projects were also considered, given their critical role in creating innovative solutions supporting key RDI milestones and serving as an essential reference for new PCs. The overall goal of this activity is to foster transparency, enhance dissemination, and promote greater coordination and collaboration among a wide spectrum of stakeholders, including TSOs, regulators, technology providers, and policymakers.

By presenting clear and structured information, this process is expected to enable more efficient decision-making and targeted progress towards the strategic priorities identified in the RDI Roadmap.

In the following figures, each PC is linked to one or more background projects, many of which are large-scale and whose results can be leveraged across multiple concepts. However, each ongoing project has been associated with the most relevant concepts based on its achievements and expected outcomes. European projects are marked with the EU flag for easy identification.

M1

PC 1: Improve supply chain resilience

Ongoing projects

Autonomous robot in the environment of an electrical substation

Development and deployment of a mobile robotic platform designed for autonomous movement within substation premises. The robot will be capable of performing inspection tasks in high-risk environments.

Figure 10: Ongoing projects behind PC 1: Improve supply chain resilience

M1

PC 2: Streamline network investments

Ongoing projects

Circular economy: re-use of aluminium to forge new ones

Industrial recycling chain for dismantled high-voltage cables, aiming to recover 600 tons of aluminium annually, that can be fully recycled without losing quality, and cut CO_2 emissions by at least 400 tons while ensuring a stable raw material supply.

Cicognes

White stork populations have increased by 700 % since 1974, contributing to 20 % of short circuits on the grid. RTE's project aims to study the dynamics and evolution of nesting white storks' distribution to anticipate consequences, manage future risks, and guide birdlife management policy.

SF6-free alternatives for Gas Insulated Substations (GIS) and Air Insulated Substation (AIS)

The project will pilot SF6 free technologies, considering both Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS) for all voltage levels (145 kV – 420 kV), to gain experience thus allowing to fulfil sustainability goals and to proceed in the installation of these innovative circuit breakers in the grid.

Cassandra

The CASSANDRA project aims to develop a digital platform, for Spain's electricity grid planning, featuring collaborative scenario management, data integration, and comparison tools. It will streamline the creation and updating of planning scenarios through automation and unified workflows.

Monitoring of construction work through satellite imaging

Satellite imaging combined with AI-based analysis to monitor construction activities in the vicinity of RTE's transmission lines, to enable the identification of worksites that are not reported through existing procedures. This can improve situational awareness and prevent potential risks to grid infrastructure.

Figure 11: Ongoing projects behind PC 2: Streamlining network investments

M2

PC3: Streamline HVDC converter concepts

Ongoing projects

DC PROSECCO

The project aims to advance HVDC grid maturity by improving grid protection and congestion management, using a vendor-neutral, model-based approach. The project features four demonstrators across the EU, developing DC protection relays, power flow controllers, and cost-effectiveness tools.

PROMOTioN

Analysed the benefits of joint offshore electricity infrastructure using meshed HVDC grids, covering converter, protection, and HVDC circuit breaker technologies, and worked on planning, regulation, and deployment roadmaps for offshore grids.

Figure 12: Ongoing projects behind PC 3: Streamlining HVDC converter concepts

M2

PC 4: Development of tools and procedures for optimised operation of HVDC onshore and offshore cables

Ongoing projects

Distributed Acoustic Sensing (DAS) System on the "Nordbalt" Interconnection

Litgrid

The project implements Distributed Acoustic Sensing (DAS) technology along the NordBalt HVDC subsea cable to enable real-time monitoring of mechanical stresses and rapid fault location, reducing outage duration and associated financial losses.

InterOPERA

InterOPERA aims to unlock multi-vendor HVDC grids to make future HVDC systems interoperable by design and to enhance the grid forming capabilities of both offshore and onshore converters. It involves TSOs, HVDC vendors, and wind generator manufacturers.

HVDC-WISE

Develops reliability- and resilience-oriented planning tools and concepts for large-scale HVDC grid expansion to improve resilience, reliability, and integration of renewable energy. Different HVDC-based grid architecture concepts will be compared.

Figure 13: Ongoing projects behind PC 4: Development of tools and procedures for optimised operation of HVDC onshore and offshore cables

M3

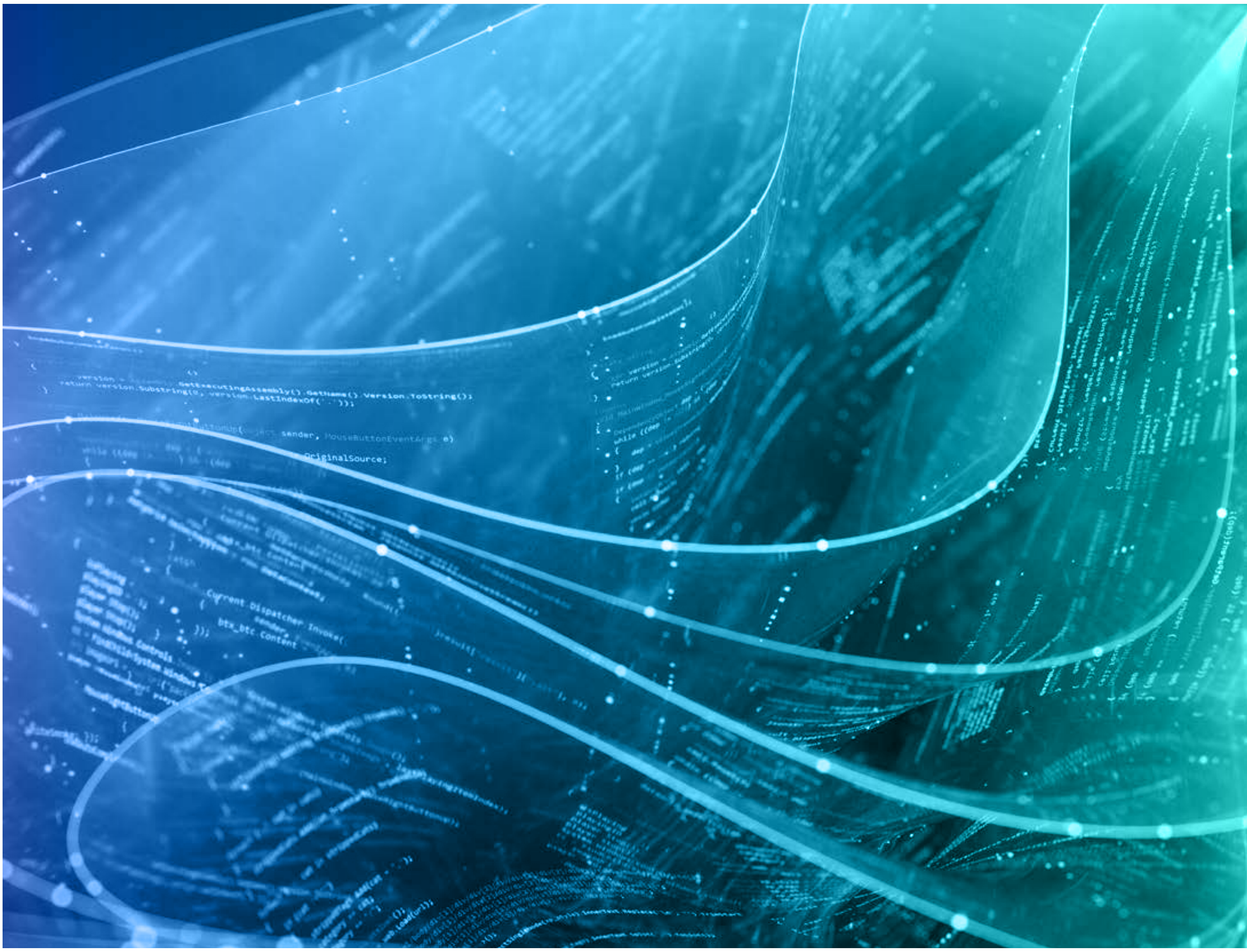
PC 5: Development of near-real-time tools and demonstrators for dynamic hybrid AC/DC system simulations

Ongoing projects

DAEDALOS

The project aims to facilitate the transition of the current power grid towards a novel approach where such AC/DC hybrid systems and MVDC/HVDC grids are foreseen to enable the growth of intermittent renewable energy sources.

Figure 14: Ongoing projects behind PC 5: Development of near-real-time tools and demonstrators for dynamic hybrid AC/DC system simulations



M3

PC 6: Roadmap for GFM capability as a solution for power electronics-dominated system

Ongoing projects

VYSINC – Virtual Synchronous compensator

red eléctrica

The project aims to develop and test a 16 MW, 3.45 MWh hybrid synchronous compensator based on lithium-ion batteries and supercapacitors, featuring advanced grid-forming capabilities. This device will enhance the stability and reliability of isolated power systems with a high penetration of renewable energy.

THEUS

Developing and validating advanced grid-forming control for hybrid AC/DC networks and demonstrating it through hardware in the loop (up to TRL 5) considering the existing HV AC/DC link Attica–Crete. Two complementary tools will be developed: a harmonic stability monitoring tool and an active damping strategy.

TIGON

Develops a comprehensive portfolio of power electronics, management software and tools supporting optimised and intelligent DC-based hybrid grids. It will also design a hybrid alternating and direct current microgrid system.

HYNET

Addresses integration of renewables and power electronics into AC systems via new control, protection, and grid forming methods. It also plans to enhance network security, facilitate islanding operations, and support investment planning by incorporating multi-energy modelling.

Figure 15: Ongoing projects behind PC 6: Roadmap for GFM capability as a solution for a power electronics–dominated system

Figure 16: Ongoing projects behind PC 7: AI-based decision support system solutions for future system operations

M4

PC7: AI-Based Decision Support System solutions for the future system operations

Ongoing projects

NAZA

In response to the rising uncontrollable renewable output and resulting grid uncertainties, automated systems are used to keep sub-transmission line currents below safe limits. In this view an optimization algorithm allows to leverage flexibility from power curtailment, batteries, demand response, and grid topology.

Use of disturbance recorders data to support detailed localisation of power quality disturbance sources in the Polish Power System (NPS).

A tool will be developed to enable detailed identification of sources of power quality disturbances in the Polish Power System. This initiative will support the development of new analytical and technical competencies within PSE Group, which can be implemented in operational activities.

DALIA – Digital model of transmisión grid and automatic grid anomalies identification.

The project focuses on developing a platform for automatic supervision and inspection of overhead transmission systems. This involves creating a digital model of the grid utilizing 3D LiDAR data combined with advanced algorithms to enhance engineering and maintenance of the transmission infrastructure.

Inter-Area Oscillations Damping

The project develops a predictive model to identify small-signal oscillations and their damping in the Spanish power system. It analyses the relationship between damping and key system variables to anticipate risks below safety thresholds. Preventive actions are enabled to enhance system stability.

Identification of inter-area oscillations using WAMS

The project will develop a prototype application for identifying inter-area oscillations using data from WAMS. The application will be made available for testing by system operators. The work will result in a prototype algorithm and application (based on openPDC), which will be integrated into dispatcher training sessions.

M4

PC 8: Resilient and integrated grid operations for extreme events

Ongoing projects

NATUREYE – Detection and Simulation of Rural Fires

Integrated platform for monitoring, validating, and predicting rural fires, using about 80 multispectral cameras on very high voltage (VHV) towers (~40 m) that cover over 1 million hectares in mainland Portugal. Images are sent in real time to the Decision Support Centre in Coimbra, where alerts are validated.

A Comprehensive Set of Organisational, Technical and Legal Measures to Ensure Power System Resilience and Security of Supply under Extreme Conditions

The project strengthens physical protection and operational resilience of substations by building protective structures, implementing underground automated control facilities, and ensuring civil protection shelters are fully available by 2028. It also provides backup power and remote communication systems for critical assets.

InterSCADA

The project will develop an open-source, vendor-independent SCADA system. This modular platform will enable operators to quickly adapt to sudden system changes and implement new monitoring functions. Demonstration sites in four countries will test InterSCADA's solutions.

Figure 17: Ongoing projects behind PC 8: Resilient and integrated grid operations for extreme events

M4

PC 9: Grid Digital Twin for enhanced real time observability

Ongoing projects

Crete Valley

The project aims to establish a Renewable Energy Valley (REV) lab on Crete island to shift from carbon-based energy to a renewable, low-carbon system. IPTO will focus on scenario analysis for grid management using a Digital Twin, involving different weather conditions, energy demand profiles and ancillary services provision.

Intelligent monitoring of structural components of power lines using IoT sensors

Asset monitoring of transmission pylons with IoT sensors and statistical evaluation for fault detection. The project aims to install IoT sensors on selected pylons across selected lines, to develop numerical models with parametric studies and to validate models using measurement data.

ASUMO (Advanced substation monitoring)

This project aims to test and select monitoring devices for a wide range of substation equipment to enhance asset management. It will implement a communication architecture that links these devices to a central control center for real-time data collection.

TwinEU

The project aims to create a European data exchange core supported by interfaces to the energy data space currently in development. Leveraging advanced modelling and AI tools, the project seeks to deliver a digital replica of the energy infrastructure that can be tested and activated.

Figure 18: Ongoing projects behind PC 9: Grid digital twin for enhanced real-time observability

M5

PC 10: Integrated framework for automated DER flexibility services

Ongoing projects

GridShield

GridShield is exploring the risk that cyber attacks on Distributed Energy Resources (DERs) pose to system stability to enable a cybersafe integration of residential DERs as a key contributor to the decentralised and flexible energy system.

Granular Certificates for 24/7 Energy Procurement and Transparency

Granular Certificates to enable precise, hourly tracking of renewable energy procurement. By using decentralized technologies such as blockchain and zero-knowledge proofs, this project aim to enhance grid stability, market transparency, and consumer trust with secure, privacy-preserving access to energy data.

Pilot project on TSO-DSO Coordination

Building on the existing static DSO validation process from the "mixed enabled virtual units" (UVAM) Italian pilot, a dynamic "traffic light" system for DSOs is implemented, to signal local grid constraints. This ensures that the flexibility services' activation from distributed resources does not create distribution grid congestions.

ESI Resource Aggregation

The project is a technical trial led by Terna with participants providing resource portfolios to test distributed flexibility under conditions similar to future expected policy scenarios. It aims to assess market readiness, resource availability, price signals, and performance limits in supporting the electricity system flexibility.

Figure 19: Ongoing projects behind PC 10: Integrated framework for automated DER flexibility services

M5

PC11: Advanced power system forecasting for enhanced grid stability and market efficiency

Ongoing projects

Renewable Energy Sources (RES) Management System

Litgrid

Build an automated D-1 real-time platform that sets safe RES operating limits and executes controlled curtailment to prevent transmission overloads and manage system-wide generation surplus. This will results in more RES hosting capacity without major grid reinforcements and improved flexibility and responsiveness of the transmission network.

Figure 20: Ongoing projects behind PC 11: Advanced power system forecasting for enhanced grid stability and market efficiency

M6

PC12: Hydrogen Hub: Enhancing grid resilience and flexibility through sector coupling

Ongoing projects behind PC12

Ecofoss

The project aims to design a modular HV offshore floating substation with zero emissions. It involves researching materials, design, operation, maintenance, and sustainability aspects of the floating substation. Maintenance protocols, monitoring systems, and automated solutions will ensure efficient operation.

Figure 21: Ongoing projects behind PC 12: Hydrogen hub: Enhancing grid resilience and flexibility through sector coupling

M6

PC13: Analysis of cross-sector integration potential and role model definition

Ongoing projects

GreenSwitch

ELES
HOPS

Cross-border smart grid initiative that involves Austria, Croatia, and Slovenia, co-financed by the EU's Connecting Europe Facility. It focuses on modernizing transmission and distribution networks to integrate renewable energy, electric vehicles, heat pumps, and battery storage.

Figure 22: Ongoing projects behind PC 13: Analysis of cross-sector integration potential and role model definition

4 PCs: List and detailed descriptions

This section includes detailed descriptions of 13 PCs that include the following areas:

- **Needs addressed:** The reasoning and motivations behind the PC are highlighted, focusing on its relevance for the European energy sector and why it is needed to accelerate innovation for TSOs.
- **Scope:** This section outlines the PC's high-level goals and the area of innovation that projects based on it must address.
- **Expected outcome:** This section details the desired implications and significant impacts that the successful deployment of the projects is projected to have on transmission systems.
- **Milestones:** The key milestone of the RDI Roadmap 2024–2034 to which the PC is linked.
- **Barriers:** This section presents the issues and restrictions that could hinder project deployment.
- **Policy context:** In this section, the links of the European policy landscape with the scope of the PC are analysed and presented.
- **State of the art:** This section provides an overview of current and past European TSO activities that could serve as a starting point for the development of projects. If possible, links with the ENTSO-E Technopedia are presented.
- **Technology Readiness Level (TRL) current/target:** The actual and target TRL of the PC are identified.
- **Timeline:** The period of implementation for the PC is provided.
- **Expected collaboration with:** Lists the specific partners whose cooperation is essential.

Annex I includes short summaries, in the form of fiches, highlighting key information extracted from the detailed PC descriptions, such as needs addressed, expected outcomes, links to RDI Roadmap milestones, and starting and ending TRL levels.

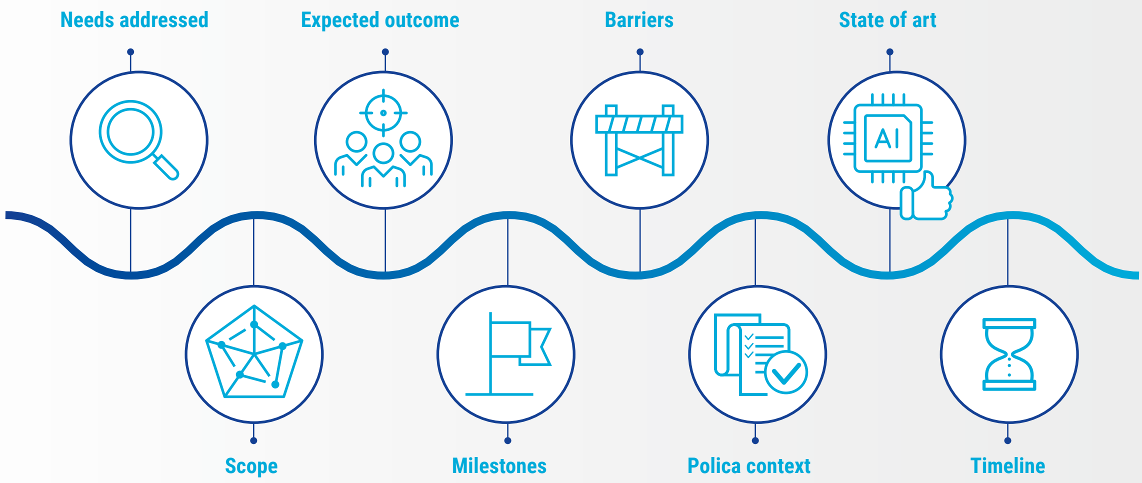


Figure 23: Information collected for each of the PCs

PROJECT CONCEPT 1:
Improve supply chain resilience

MISSION 1 – ENHANCE GRID USE AND SUSTAINABILITY	
PROJECT CONCEPT 1	**IMPROVE SUPPLY CHAIN RESILIENCE**
Needs addressed	Europe is racing to upgrade and expand its grid infrastructure to accommodate rising shares of renewable energy and support the increasing electrification of loads. The reliable operation and timely expansion of the transmission infrastructure are highly dependent on the availability of extra high voltage (EHV) equipment. Thus, supply chains, which are currently a critical bottleneck, are at risk of becoming even more constrained as they are subjected to further pressure due to global disruptions and geopolitical tension. This dramatically increases lead times for essential components such as power transformers, switchgears, and HVDC components, with delivery delays of a year or more becoming commonplace. Aligning asset management strategies and practices for critical components could bring further benefits for TSOs. In fact, aligning condition monitoring, lifetime assessment, spares inventories, and maintenance practices can improve security of supply through increased efficiency and interoperability.
Scope	The projects are expected to explore opportunities to align specifications and designs for certain EHV equipment, review asset management strategies, and develop common approaches. In particular, the following aspects will be addressed: › Analyse current requirements across TSOs and engage with relevant ENTSO-E Task Forces › Identify EHV devices experiencing supply shortcomings and define measures that could help overcome them (e.g. alignment of requirements and / or tests) › Identify areas where alignment is most crucial › Assess best practices for condition monitoring and maintenance › Create common approaches, asset management tools, and indicators such as asset health indices, and develop standardised maintenance strategies › Develop guidelines for harmonising spares strategies and mutual assistance agreements › Design a common data interface between monitoring and asset management
Expected outcome	Project outcomes will expand multi-sourcing options for critical EHV components and harmonise asset management strategies by developing: › A comprehensive assessment of harmonisation potential › An actionable roadmap and a co-created framework for transitioning › An assessment of demonstrable increase in qualified supplier options › Harmonised asset management strategies › Common methodologies and tools for maintenance, condition monitoring, lifetime assessment, and risk management › Aligned maintenance and spares strategies to optimise outage planning and emergency response › A validated framework for harmonising specifications of selected EHV components › Harmonised EHV asset management among multiple TSOs and assessment of benefits for scaling across Europe
Milestones	Projects based on this concept will contribute to reaching the following Mission 1 milestones: › Standardisation of asset management approaches › Development of methods to mitigate risks (e.g. in the supply chain) for European TSOs › SF6-free solutions operating in high voltage and EHV grids › Circular economy and environmentally friendly components included in planning and asset management
Barriers	› Resistance, uncertainties, and long lead times in changing established EHV component specifications (including different operating voltages) and procurement practices › Concerns about compromising asset security and privacy through information sharing › Cultural differences in maintenance approaches

MISSION 1 – ENHANCE GRID USE AND SUSTAINABILITY		
PROJECT CONCEPT 1	**IMPROVE SUPPLY CHAIN RESILIENCE**	
Policy context	The EU's Net-Zero Industry Act aims to bolster European supply chains for key technologies to meet decarbonisation goals. Ensuring robust supply chains for critical transmission components aligns with policies to accelerate energy infrastructure build-out. The EC's 2023 Critical Raw Materials Act also highlights the need to secure reliable access to materials for clean energy technologies, similar to the Industrial Acceleration Act.	
State of the art	**Standardisation of EHV component specifications and designs:** The switchgear and control gear standards (like IEC 61936 and IEC 62271) in force are primarily focused on safety, performance, and testing requirements. However, there are significant differences between TSOs' specifications, which could lead to issues with interoperability and interchangeability. **Harmonised asset management:** ISO 55000 and the IEC 123 series provide a general framework, but the actual implementation varies across TSOs. While there are some early-stage pilots for harmonised approaches and common platforms for sharing best practices, no framework or integrated solutions currently exist.	
Technology Readiness Level (TRL) current/ target	**Harmonisation of EHV component specifications and designs is at TRL 5.** While some standards exist for EHV component performance and testing, harmonised specifications are still in the early research and prototyping stages. **Target TRL: 7**	**Asset management harmonisation for transmission components is at TRL 5.** Some shared methodologies and bilateral agreements exist, but full alignment and integration across TSOs has not yet been operationalised. **Target TRL: 7**
Timeline	2026–2030	
Expected collaboration with	› Manufacturer › Standardisation bodies	

PROJECT CONCEPT 2: Streamline network investments

MISSION 1 – ENHANCE GRID USE AND SUSTAINABILITY	
PROJECT CONCEPT 2	**STREAMLINE NETWORK INVESTMENTS**
Needs addressed	Europe needs to develop streamlined methodologies for the identification of system needs, addressing both cross-border interconnections and internal bottlenecks within Member States to enhance market integration and efficient grid use. These methodologies should support the identification of structural bottlenecks and investment gaps without predetermining solutions or investment decisions. Optimising the use of financial resources and designing appropriate financing frameworks would support the timely implementation of essential infrastructure projects while avoiding distortions or undesired redistribution effects among stakeholders. Close cooperation among TSOs, regulatory authorities, and policymakers will contribute to the effective integration of RES through increased price convergence (i. e. lowering differences in electricity prices between bidding zones) and to security of supply in ENTSO-E.
Scope	The projects will also explore how to streamline network investments through innovative financing frameworks and stakeholder engagement. In particular, the projects aim to: › Develop a streamlined and harmonised methodology to identify, assess, and alleviate cross-border and internal bottlenecks, considering their technical feasibility, socioeconomic benefits, and contribution to market integration › Assess the potential of innovative technologies – such as advanced power flow control devices, dynamic rating systems, and topology optimisation techniques – to optimise grid utilisation › Develop a comprehensive framework for the allocation of financial resources, considering both traditional grid reinforcements and innovative technologies to maximise impact › Engage with other committees (System Development Committee, Market Committee), TSOs, regulatory authorities, and policymakers to build consensus on the proposed methodologies and financing mechanisms to facilitate their adoption and implementation
Expected outcome	The main outcomes of the projects will be: › Enhanced cross-border transmission capacity and improved market integration in Europe › Further developed methodology for planning transmission projects and a targeted investment plan to address cross-border and internal bottlenecks › A balanced and cost-effective approach to allocating financial resources between traditional grid reinforcements and innovative technologies, considering the unique needs and constraints of each investment
Milestones	Projects based on this concept aim to reach the following Mission 1 milestones: › Harmonised methods for coordinated planning of highly loaded networks › Integration of dynamic ratings and AI-based renewable power forecasts › Advanced reconfiguration and control of network and assets › Demonstration of innovative technologies for power flow control and increasing grid efficiency

MISSION 1 – ENHANCE GRID USE AND SUSTAINABILITY	
PROJECT CONCEPT 2	**STREAMLINE NETWORK INVESTMENTS**
Barriers	› Challenges in accurately assessing socioeconomic benefits due to complex interdependencies between national and cross-border grid projects › Various levels of political commitment and differing national energy strategies complicate cross-border project alignment › Financing traditional grid upgrade projects faces challenges as new priorities emerge for resource allocation › Innovative technologies often lack proven business models or established acceptance
Policy context	› European Green Deal and Fit for 55 legislative frameworks pushing for increased RES integration › Regulations and guidelines from ENTSO-E's Ten-Year Network Development Plan (TYNDP) and ACER's cross-border cost allocation (CBCA) regulations › The Competitiveness Fund and the Connecting Europe Facility (CEF) funding programs providing incentives and frameworks for cross-border infrastructure projects › Regulatory frameworks set by ACER and National Regulatory Authorities (NRAs) supporting harmonised market and investment procedures
State of the art	› Existing TYNDP methodologies for identifying infrastructure needs, including scenario planning and cost–benefit analyses › Ongoing development of market coupling and grid planning tools by ENTSO-E and EU institutions to enhance resource allocation and market integration
TRL current / target	An integrated planning methodology / tool, combining conventional grid reinforcement approaches with innovative technologies (dynamic ratings, power flow controllers, and topology optimisation), **currently sits at TRL 5–6**. **A realistic target is TRL 8.** The deliverables would show consistent reliability, proven practicality and clear values, but might still require final refinement, broader deployment, or standardisation before becoming fully "commercial" and being universally adopted by TSOs across Europe.
Timeline	2026–2030
Expected collaboration with	Authorities and regulators

PROJECT CONCEPT 3: Streamline HVDC converter concepts

MISSION 2 – ONSHORE AND OFFSHORE GRID DEVELOPMENT AND INTEGRATION	
PROJECT CONCEPT 3	**STREAMLINE HVDC CONVERTER CONCEPTS**
Needs addressed	HVDC technology is becoming increasingly critical for Europe's energy infrastructure. HVDC is planned for the transmission of large volumes of electricity onshore and to support interconnectivity between European countries. Moreover, HVDC connections will play a major role in integrating large-scale offshore RES into Europe's energy systems. To enable faster expansion of meshed large-scale HVDC grids, a cross-manufacturer approach is required. Therefore, concepts for MV / MT structures are being developed, creating a strong need to align requirements for HVDC converters, cables, and monitoring systems, as well as offshore platform types and reliability and maintenance concepts. Moreover, to allow for a resilient MT HVDC grid, successful development and testing of HVDC breakers at the 525 kV level is needed. The European electric power system is increasingly integrating RES to replace conventional synchronous generator-based plants, resulting in reduced system inertia and lower fault current levels. HVDC converters with GFM and energy storage systems, however, could support the electric power system by providing synthetic inertia. Achieving this requires the timely development of simulation tools for large-scale HVDC systems, along with corresponding converter models and (decentralised) DC grid controllers to test MV / MT DC grids for stability, resilience, redundancy, security, etc.
Scope	The projects are expected to advance HVDC technology by exploring GFM capabilities, creating advanced simulation tools, standardising sensor equipment, and addressing regulatory aspects. Specifically, projects will: › Scale up and test HVDC breakers up to 525 kV › Develop a concept for a pilot MT HVDC converter with GFM capabilities and an energy storage system to supply the AC grid with as much short-circuit current / power as a synchronous machine › Develop HVDC simulation tools to capture dynamic system behaviour and transient phenomena arising from converter characteristics and control mechanisms, which can cause interactions between the AC and DC sides of converters and allow incidents to spread over wider areas › Perform research and alignment of sensor and measurement equipment and practices to verify converter models and enable failure root analysis › Address governmental aspects regarding MV / MT DC grids owned by multiple TSOs
Expected outcome	Projects are expected to contribute to the following outcomes: › Aligned requirements among TSOs, enabling faster production of HVDC components and deployment of HVDC grids both onshore and offshore › Development and testing of HVDC breakers at the 525 kV level, enabling MT HVDC grid deployment › Development of an HVDC converter concept combined with GFM and energy storage systems, allowing faster deployment of the HVDC grid with the required functionalities, which would help stabilise the short-term volatility of the electric power system and market and allow for faster integration of RES in theEU › Development of methods and tools to identify interaction among power electronic interfaced devices (PEID), applied in grid simulations with up to 100 nodes and at least 50 different PEID › Development of solutions to measure and record faults with the accuracy and time resolution needed to monitor travelling wave effects in DC grids, validate fault identification and derived selectivity methods, and other side effects of DC grid dynamics

MISSION 2 – ONSHORE AND OFFSHORE GRID DEVELOPMENT AND INTEGRATION	
PROJECT CONCEPT 3	**STREAMLINE HVDC CONVERTER CONCEPTS**
Milestones	Projects based on this concept will contribute to reaching the following Mission 2 milestones: › Alignment of requirements for HVDC, cable, and monitoring systems › Alignment of reliability and maintenance concepts › Alignment of offshore platform types › Critical MT HVDC components developed and tested › Simulation tools, compliance tests, and test facilities for HVDC converters
Barriers	› Different TSOs have varying design requirements, making it challenging to achieve common alignment › Finding constructive ways to cooperate with HVDC suppliers › Obtaining access to converter control models › Future HVDC grids in Europe are mainly planned at the 525 kV level, and scaling HVDC breakers from 320 kV to 525 kV is not a straightforward task
Policy context	Relevant policy documents, such as the TEN-E Regulation, the Grid Action Plan, and the REPowerEU Plan, support interoperability, standardisation, and operational excellence in HVDC converter concepts, advancing the EU's energy transition and grid modernisation efforts.
State of the art	HVDC breakers, which are crucial for developing resilient large-scale HVDC grids, have been recently tested at 320 kV in the PROMOTioN project. The development of MT capabilities for large-scale HVDC grids can be accelerated by leveraging lessons learned and best practices from previous projects, such as InterOpera and Ready4DC. Technologies with GFM capabilities and energy storage concepts / products are currently available. Simulation software is available, but models of large hybrid AC and DC systems must be developed. The following Technopedia fact sheets are related to this PC: › HVDC circuit breakers › Large-scale DC overlay grid › Voltage source converters (VSC)
TRL current / target	**Current TRL: 6** **Target TRL: 7**
Timeline	2026 – 2030
Expected collaboration with	› Manufacturers › Universities and RTOs

PROJECT CONCEPT 4: Development of tools and procedures to optimise the operation of HVDC onshore and offshore cables

MISSION 2 – ONSHORE AND OFFSHORE GRID DEVELOPMENT AND INTEGRATION	
PROJECT CONCEPT 4	**DEVELOPMENT OF TOOLS AND PROCEDURES TO OPTIMISE THE OPERATION OF HVDC ONSHORE AND OFFSHORE CABLES**
Needs addressed	The restructuring of the energy sector is driving the expansion of offshore energy transmission through HVDC projects. TSO requirements regarding planning, construction, and operation are chosen according to the "fit for purpose" rule and hence can vary significantly. This can lead to operational challenges, especially when the same offshore or onshore service provider is used for maintenance or repair. Aligning procedures could simplify processes, reduce effort for manufacturers and operators, and accelerate completion. On the other hand, it is difficult to find optimal solutions with only limited service experience. For this reason, it is necessary to investigate different options in labs, demonstrators, and real-world projects to pave the way for future optimised HVDC cable systems.
Scope	This PC addresses challenges in the development and operation of HVDC cables and their infrastructure, including: › Optimisation of repair and maintenance procedures for HVDC cables › Development of submarine cable monitoring technologies for maintenance and surveillance › Development of electrical, thermal, and mechanical properties for cable models › Assessment of legal aspects of maritime law and cooperation with defence forces for cable and platform protection › Identification of potential for HVDC cable testing procedures and cross-sections for improved inter-grid connections › Investigation of potential for optimised, flexible offshore platform designs › Investigation of opportunities to optimise procedures, auxiliary equipment, and vehicles during construction work › Investigation of recyclability and sustainable materials for cables
Expected outcome	Integrating tools and procedures for HVDC systems will result in: › Reduced environmental impacts › Improved security against infrastructure damage or sabotage › Enhanced performance and reliability › Easier grid interconnections across Europe › Enhanced availability of components and skilled personnel through reduced system and component complexity
Milestones	Projects based on this concept will contribute to reaching the following Mission 2 milestones: › Alignment of reliability and maintenance concepts › Alignment of offshore platform types › Alignment of requirements for HVDC, cable, and monitoring systems › HVDC system planning criteria and identification of possible new interconnectors

MISSION 2 – ONSHORE AND OFFSHORE GRID DEVELOPMENT AND INTEGRATION	
PROJECT CONCEPT 4	**DEVELOPMENT OF TOOLS AND PROCEDURES TO OPTIMISE THE OPERATION OF HVDC ONSHORE AND OFFSHORE CABLES**
Barriers	› Overcoming interdisciplinary boundaries › Coping with different maintenance practices among TSOs operating offshore grids › Difficulty reaching agreement on standardised protocols and testing standards › Potential need for investments in new technologies and equipment › Technical challenges of ensuring reliable performance with new materials › Difficulty measuring project outcomes to demonstrate the benefits of alignment
Policy context	Relevant policy documents, such as the TEN-E Regulation, the Grid Action Plan, and the REPowerEU Plan, foster the development of harmonised operational tools, procedures, interoperability, and reliability for future HVDC onshore and offshore cable systems in the European grid.
State of the art	Condition monitoring: Technologies are available (e. g. distributed acoustic sensing), but operation concepts and collaboration on further technology development must be promoted (e. g. with marine services, drones, etc.). Procedures and auxiliaries: Varying maintenance practices exist, but must be harmonised. Sustainability: Limited use of recycled materials in HVDC cables. Research on alternative materials and designs for sustainable cables is ongoing. Technology: Existing standardised voltage levels for HVDC systems (up to 640 kV) need future-proof standards for higher capacities. › The following Technopedia fact sheets are related to this PC: › Asset management (processes, tools, and procedures) › Interoperability
TRL current/target	**Current TRL: 6** **Target TRL: 7** The TRL for separate technologies is high, but interoperability must be enhanced.
Timeline	2026 – 2030
Expected collaboration with	Manufacturers

PROJECT CONCEPT 5: Development of near-real-time tools and demonstrators for dynamic hybrid AC/DC system simulations

MISSION 3 – ENSURE SECURE AND STABLE OPERATION OF THE HYBRID AC / DC GRID	
PROJECT CONCEPT 5	**DEVELOPMENT OF NEAR-REAL-TIME TOOLS AND DEMONSTRATORS FOR DYNAMIC HYBRID AC / DC SYSTEM SIMULATIONS**
Needs addressed	In the context of the energy transition, an increasing number of IBRs – such as HVDC converters, STATCOMS, battery energy storage systems (BESSs), or large loads as data centres and electrolysers – are being installed in the system. The different characteristics of IBR resources, compared to synchronous generators, affect system operation and may lead to unwanted interactions. Therefore, system operators require appropriate tools for measurement, analysis, testing, and visualisation of system stability, enabling them to prepare and take appropriate countermeasures. One possible solution is the design and development of powerful near-real-time analytical platforms to assess the system's dynamic properties and simulate dynamic behaviour in a hybrid AC / DC system under different conditions.
Scope	Projects implemented under this concept will develop tools and interfaces for assessing the safety, controllability, and dynamic stability of AC / DC hybrid transmission systems, as well as for validating simulation models for specific applications. Specifically, projects will contribute to the: › Recognition, development, and verification of near-real-time tools (including software design, interoperability testing, integration testing, acceptance testing, etc.) › Determination of recommended models and parameters used for existing and developing solutions › Development of a methodology to reduce the complexity of large networks into models that can be effectively simulated › Setting up a stability management demonstrator and evaluating integration into existing DSA tools › Validation and benchmarking based on available data › Validation of simulation results using real grid measurements › Development of indicators and methods for automatic identification of unstable system conditions › Proposals for harmonised interfaces between tools to enable efficient simulations and analyses › Analysis of opportunities to enhance the performance of computation platforms
Expected outcome	The development of near-real-time simulation tools will enable better management of hybrid AC / DC networks, increasing the efficiency of the holistic power system. Examples of expected outcomes from projects exploring this concept include: › Efficiency improvements fully in line with security frameworks, maintaining defined quality standards, and continuous power supply › Enhanced system controllability and observability › Implemented real-time monitoring and verification capabilities for a hybrid AC / DC system to control unexpected events and cover current imbalances › Updated long-term planning procedures, connection requirements, stability, and frequency control procedures for integrating IBR resources › Developed and deployed new methodologies, standards, and tools that enable the transformation and modernisation of the power system

MISSION 3 – ENSURE SECURE AND STABLE OPERATION OF THE HYBRID AC/DC GRID	
PROJECT CONCEPT 5	**DEVELOPMENT OF NEAR-REAL-TIME TOOLS AND DEMONSTRATORS FOR DYNAMIC HYBRID AC/DC SYSTEM SIMULATIONS**
Milestones	Projects based on this concept will contribute to reaching the following Mission 3 milestones: › Standardisation of simulation tools interfaces › Development of near-real-time platforms for dynamic system simulations (e.g. DSA) › Facilitation of large-scale, pan-EU dynamic analysis
Barriers	› Lack of transparency, compatibility, and interoperability among power system simulation models, data types, and platforms › Limited know-how of software manufacturers › Sophisticated expertise required to model dynamic states in the power system
Policy context	› Relevant policy documents, such as the TEN-E Regulation, the EU Grid Action Plan, and the REPowerEU Plan, promote interoperable, validated, and near-real-time tool development for dynamic simulation of hybrid AC/DC grids to meet Europe's energy transition and grid modernisation targets.
State of the art	› TSOs conduct extensive analyses, including the study of dynamic states using a diverse range of models and software tools. This diversity prevents the use of common databases and can result in outcomes that are difficult to compare, limiting actionable insights and the efficient pan-EU management of combined hybrid AC/DC systems.
TRL current/target	**Current TRL: 7** **Target TRL: 8**
Timeline	2026–2030
Expected collaboration with	› Software developers/ICT service providers › Universities and RTOs, CIGRE C2

PROJECT CONCEPT 6: Roadmap for GFM capability as a solution for a power electronics-dominated system

MISSION 3 – ENSURE SECURE AND STABLE OPERATION OF THE HYBRID AC/DC GRID	
PROJECT CONCEPT 6	**ROADMAP FOR GFM CAPABILITY AS A SOLUTION FOR A POWER ELECTRONICS-DOMINATED SYSTEM**
Needs addressed	The significant increase in power electronic devices connected to the transmission grid as well distribution grid, along with the progressive phase-out of conventional generation sources, creates the need to develop new capabilities and consistent requirements, particularly power system supporting requirements like GFM capability. This increases the security of power supply, supports energy quality and system stability, and promotes the development of new market opportunities for manufacturers. The next step in establishing this technology is its demonstration in relevant environments.
Scope	The scope of the projects developed under this concept includes: › Review of the latest knowledge from Europe and abroad on solutions and applied standards, including set-ups and current approaches to system management and technological requirement options › Assessment of current and future (over the next 10 years) needs and technological possibilities for managing the stability of PEID in cooperation with manufacturers, research institutions, and service providers › Development and validation of GFM models for various devices › Investigation of the possibility of transferring GFM for extended applications › Investigation of interactions between different GFM devices connected in the same electrical area › Demonstration of interoperability of different GFM in equivalent environments (e.g. hardware in the loop)
Expected outcome	Projects that implement GFM as a potential solution for PEID-dominated power systems are expected to: › Address the diversity of manufacturers and resolve the ambiguous understanding of GFM to prevent incompatible solutions from appearing in user systems › Ensure consistent implementation of different functions and necessary features across GFM devices › Achieve common safety goals and enhance device synergy effects for effective network management at both the transmission and distribution levels › Accelerate the energy transformation process through standardised device requirements › Reduce development costs › Increase overall system capabilities and performance › Enhance operational security and resiliency of energy systems › Support innovation activities at the distribution node level to enable transmission-level outcomes
Milestones	Projects based on this concept will contribute to reaching the following Mission 3 milestones: › Stability margins measure and assessment for PEID-dominated systems › Development of GFM demonstrators for moderate levels of PEID penetration › Development of GFM demonstrators for high levels of PEID penetration in specific areas

MISSION 3 – ENSURE SECURE AND STABLE OPERATION OF THE HYBRID AC/DC GRID	
PROJECT CONCEPT 6	**ROADMAP FOR GFM CAPABILITY AS A SOLUTION FOR A POWER ELECTRONICS-DOMINATED SYSTEM**
Barriers	› The development, validation, and implementation of a new approach to devices used to manage stability in large-scale systems would benefit from clear guidance on technical capabilities, system operation, and new market rules that facilitate the deployment of these solutions in line with ACER's recommended revisions to grid code requirements. › Lack of access to appropriate control system models for PEID makes it difficult to perform power system simulations and, consequently, to design both the required device capabilities and overall power system stability management. › Obtaining pan-EU aligned power system design criteria can be challenging.
Policy context	Relevant policy documents, such as the TEN-E Regulation, the EU Grid Action Plan, and the REPowerEU Plan, underscore the strategic pathway for implementing GFM capability as a solution for the reliable operation of future power systems with high shares of power electronics interfaces and renewables.
State of the art	TSOs are testing guidelines for control algorithms and approaches to GFM technology. On this basis, and as a result of joint projects, joint guidelines can already be formulated, which will serve as input to the Roadmap. Since GFM capabilities are already included in the specifications of some HVDC projects, ENTSO-E and industry stakeholders are substantively prepared to harmonise the guidelines for GFM solutions.
TRL current/target	**Current TRL: 5** **Target TRL: 7**
Timeline	2026 – 2030
Expected collaboration with	› Manufacturers › Universities and RTOs, CIGRE C4

PROJECT CONCEPT 7: AI-Based Decision Support System solutions for future system operations

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 7	**AI-BASED DECISION SUPPORT SYSTEM SOLUTIONS FOR FUTURE SYSTEM OPERATIONS**
Needs addressed	AI-based technologies are expected to provide breakthrough innovation and will be leveraged to make control room operations more efficient, starting from routine activities such as producing continuous and periodic reports, in addition to enabling a detailed analysis of network status. In the longer term, AI will also be introduced in decision support systems, thus providing direct support to real-time system operation. This PC specifically addresses the need to manage grid overloads in a dynamic context, minimising current flows and ensuring operational voltage security.
Scope	The projects based on this concept will develop and implement AI-based systems that support operational decisions in managing current flows on high and EHV grids, addressing several key aspects, including: › Analysis, also based on surveys about tools and techniques currently in use at the EU level, of the current and voltage dynamics of the grid, with particular attention to new interactions between the transmission and distribution networks, such as the behaviour of primary substations that are beginning to inject power back into the grid › Creation of dedicated TSO-level databases, harmonised and shared at the EU level for training AI algorithms, integrating both regularly saved historical data and synthetic data generated to reflect the characteristics of the evolving behaviour of current and future grids › Development of advanced tools and data consistency methods for grid simulation and optimisation (based on a comprehensive assessment of existing tools), capable of considering complex scenarios and providing optimal configurations to reduce violations of electrical quantities › Validation of solutions through pilot demonstrations and on critical sections of the grid › Development of new, dedicated training scenarios for system operators to start working with new AI-based tools › Definition of operational guidelines for large-scale implementation › Assessment of potential conflicts between AI-driven recommendations and operator decisions by designing clear protocols and guidelines to ensure the optimal combination of system and human expertise
Expected outcome	The projects are expected to deliver results that will: › Improve the operational security and efficiency of high-voltage and EHV grids › Enable optimal grid configurations to reduce current flows and lower costs, especially in ancillary service markets › Optimise the voltage profile to decrease the need for system redispatching, enhancing overall system performance › Provide operators with actionable insights on leveraging AI solutions › Reduce reliance on manual expertise › Support proactive decision-making to effectively address critical conditions
Milestones	Projects based on this concept will contribute to reaching the following milestones: › Mission 4: AI-based reporting and analysis of system operation › Mission 4: AI-based decision support system for system operation › Mission 3: Near-real-time platforms for dynamic system simulations (e.g. for DSA)

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 7	**AI-BASED DECISION SUPPORT SYSTEM SOLUTIONS FOR FUTURE SYSTEM OPERATIONS**
Barriers	› The primary challenge lies in managing the confidence level (trustworthiness) of AI-proposed solutions and the consequent interpretation and reaction of the operators. › Uncertainty regarding the allocation of responsibilities in ambiguous situations is a critical concern, highlighting the need for clearly defined roles, responsibilities, and protocols to manage such scenarios effectively. › Ensuring the system's acceptance will require early engagement (also in the design stage) of future users in the control room, as well as comprehensive training and continuous support to facilitate a smooth and sustainable transition. › Managing scheduled maintenance outages also presents a challenge, as AI suggestions might block or alter planned activities, leading to potential operational conflicts. Striking a balance between maintenance priorities and system recommendations will be essential. › Another significant barrier is integrating the system into existing operational processes and the related actions needed to guarantee overall cybersecurity. › Creating databases for AI training could be critical, first to define the most suitable data format, and then for cybersecurity, integrity, and data-quality reasons. Instead, generating and validating synthetic data to reflect current and future grid configurations will require dedicated resources and specialised expertise.
Policy context	The project must align with European regulations promoting technological innovation in grid management, such as EU Regulation 2019/943 on electricity. Furthermore, the use of AI and synthetic data must comply with European guidelines on data governance (ensuring transparency, security, and GDPR compliance) and with the AI Act, including quality and risk assessments, technical requirements, training for deployed systems, governance, and registration in the regulatory AI system database.
State of the art	Current solutions for managing power flows rely primarily on operator expertise and historical data analysis. The application of AI-based algorithms in operational grid management is still in its early stages, limited to conceptual studies or small-scale pilot projects. Existing databases are insufficient to represent the rapidly evolving dynamics of the grid, making the development and use of synthetic data essential. Currently, there are many questions about how to effectively integrate AI solutions into decision-making processes, ensuring a balance between automated suggestions and human judgment.
TRL current/target	**The current TRL for similar AI-based systems in grid management is estimated at 4–5**, reflecting the conceptual phase of development. **The project aims to advance these solutions to a TRL of 7–8**, through pilot implementations in a real-world environment, where the integration of synthetic data and AI algorithms will be validated in operational conditions.
Timeline	2026–2030
Expected collaboration with	› Software developers/ICT service providers › Universities and RTOs

PROJECT CONCEPT 8: Resilient and integrated grid operations for extreme events

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 8	**RESILIENT AND INTEGRATED GRID OPERATIONS FOR EXTREME EVENTS**
Needs addressed	The escalating frequency and intensity of extreme weather events (such as heat waves, storms, wildfires, floods, etc.) due to rising global temperatures and security events (including those arising from military risks), coupled with the complex interdependencies within an integrated energy system, demand a profound enhancement in grid resilience, real-time risk management capabilities, and robust cybersecurity measures. In fact, secure power system operation requires limiting the extent, severity, and duration of system degradation following an extreme event. Enhanced power system resilience can be attained by implementing measures focused on anticipation and preparedness. This includes advanced forecasting, comprehensive modelling, and the identification of preventative strategies using scenario-based and probabilistic techniques. These initiatives, when integrated with real-time adaptive actions, facilitate effective disturbance absorption and rapid systemic recovery.
Scope	Projects that implement solutions to increase the resilience of grid operations in response to extreme events address several key topics, including: › Preventing energy supply disruptions and ensuring rapid restoration after extreme natural and man-made events › Enhancing the interoperability of control systems, data platforms, and communication protocols across the integrated electricity, gas, and heating sectors to ensure coordinated resilience strategies › Adapting cybersecurity protocols for early threat detection, containment, and recovery › Implementing predictive analytics based on AI and machine learning (ML) to investigate system vulnerabilities in extreme weather events and security threats, leveraging multiple data sources, including ground-based sensor networks and satellite Earth Observation data › Developing blackout management coordination procedures, including IBR, and incorporating them into regional system recovery plans › Establishing strategic, decentralised reserves of critical high-voltage equipment (e. g. autotransformers / mobile autotransformers) and developing optimised logistics for their rapid deployment and replacement, ensuring supply continuity in the event of prolonged or severe damage › Strengthening resilience through advanced physical security measures, including structural solutions and electronic systems, to significantly increase infrastructure resilience to direct land and air physical threats (and, where relevant, maritime threats) › Limiting the physical escalation of severe internal faults on high-criticality grid assets (in particular, large power transformers, HVDC converter transformers, generator step-up transformers, and strategic substation transformers) and integrating asset-level consequence indicators (e. g. tank rupture, fire, oil release, collateral substation damage, restoration complexity) into resilience planning and operational scenarios
Expected outcome	The projects developed within this concept will contribute to: › Development of advanced modelling techniques, including methods and tools for analysing extreme events in quasi-real-time › Development of methods and tools for predicting critical operational situations › Preparation of solutions for absorbing threats and reducing the impact of emergency events › Proposing an improved regulatory framework for restoring services after extreme events › Development of cybersecurity protocols adapted to integrated and highly digitised systems › Development of joint test scenarios between TSOs, DSOs, other relevant governmental bodies, and civil protection services for crisis situations › Asset-level consequence models for high-criticality grid assets, enabling TSOs to weigh physical-resilience and restoration-readiness measures alongside electrical security margins

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 8	**RESILIENT AND INTEGRATED GRID OPERATIONS FOR EXTREME EVENTS**
Milestones	Projects based on this concept will contribute to reaching the following milestones: › Mission 3: Development of restoration plans and update of pan-EU system defence plan › Mission 3: Demonstration of system restoration plans › Mission 4: Enhanced toolbox to manage critical extreme weather events in real time › Mission 4: Transition to probabilistic risk management approach › Mission 4: Innovative cybersecurity approach for control centres › Mission 4: Innovative training concepts and backup procedures › Mission 5: Advanced interconnectivity modelling for better system integration between control areas › Mission 6: Network codes for the integrated energy system, including the definition of roles and responsibilities
Barriers	› Lack of experience with integrated systems › Access to high-quality, harmonised, and repeatable data, including wide-area observation data, together with the protocols required for precise predictive analysis › Difficulties resulting from the scalability of test and pilot solutions compared to real-world scenarios › Lack of validated analytical models enabling a coordinated approach to system resilience to natural and anthropogenic threats › Advanced modelling, an innovative approach to cybersecurity, and integrated network management require new employee skills
Policy context	This PC contributes to strengthening Europe's energy security and operational resilience. Key frameworks shaping this approach include the Network Code on Electricity Emergency and Restoration (EU Regulation 2017/2196), which defines procedures for defence and rapid system recovery, and the System Defence and Restoration Plans developed by ENTSO-E and national TSOs under this code. In parallel, Regulation (EU) 2019/941 on risk preparedness in the electricity sector requires Member States to prepare coordinated national crisis plans and conduct stress tests of their power systems. At the broader policy level, the EU Preparedness Union Strategy (2025) introduces a cross-sectoral framework for resilience, combining cybersecurity, emergency response, and critical-infrastructure protection, to ensure that Europe can anticipate, prevent, and swiftly recover from large-scale disruptions. Additionally, the EU Action Plan on Digitalising the Energy System (2022) lays the groundwork for a secure digital energy infrastructure, emphasising cybersecurity, interoperability, and coordinated crisis response across all sectors.
State of the art	ENTSO-E applies probabilistic methods (including Monte Carlo simulations) in the ERAA and Seasonal Outlooks to assess adequacy under climatic variability and forced outages. The Polish operator, together with operators from the Baltic countries, is conducting numerous tests based on simulations of threat scenarios for interconnected power systems. At the practical implementation level, Ukrenergo (the Ukrainian TSO) employs an advanced, multilayered strategy to protect its energy infrastructure. This strategy includes establishing strategic reserves of critical equipment and enhancing emergency response by maintaining repair crews at constant readiness and using live-line work. Physical defences include deploying electronic warfare systems near substations to counter drones, developing an integrated active protection system for critical facilities to ensure timely detection and destruction of aerial targets, exploring underground placement for vital equipment such as relays and automation systems, and using concrete structures (noting that the use of big bags and gabions, given the modernisation of strike capabilities and evolving tactics of their employment, is currently losing its effectiveness). This comprehensive approach integrates physical security with intensified information security monitoring to counter evolving threats. The primary focus is on timely threat monitoring and on adapting planning approaches and implementing countermeasures in response to changing conditions. In parallel, satellite Earth Observation platforms are increasingly used to support wide-area monitoring of transmission corridors and surrounding environments, providing a scalable complement to ground-based and tower-mounted sensing for vegetation, fire-risk, and corridor-condition assessment.
TRL current/target	**Current TRL: 4** **Target TRL: 6**
Timeline	2026–2030
Expected collaboration with	› DSO › Energy service providers/Energy suppliers › Authorities and regulators › Associations and local communities › End users › Remote sensing and Earth Observation data and technology providers

PROJECT CONCEPT 9:
Grid Digital Twin for enhanced real-time observability

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 9	**GRID DIGITAL TWIN FOR ENHANCED REAL-TIME OBSERVABILITY**
Needs addressed	Managing the modern power system is becoming increasingly complex due to the growing penetration of IBR, the variability of renewable generation, and the evolution of energy power markets. Lower system inertia and fluctuating power flows make it harder to predict and control grid behaviour. Extreme weather events are also becoming more frequent and severe, increasing the risk of extended service disruptions and putting additional pressure on real-time operations. As these challenges grow, the conventional approaches used to model and simulate the network, often based on simplified single-line diagram representations, may no longer provide the level of detail required to fully capture system dynamics. To address these issues, digital twins of the electrical grid will play a key role in providing a more accurate grid representation (i.e. three-phase models) and supporting grid control, thanks to advancements in WAMS and protection systems as well as the diffusion of IoT sensors on the grid, expanding the possibilities for DSA and enhanced grid observability.
Scope	The scope of the projects developed under this concept will focus on integrating traditional grid simulation to improve real-time operations by combining high-fidelity models with real-time data. In particular, the projects aim to: › Develop an appropriate grid digital twin that will provide operators with more precise assessments of system stability and early detection of emerging phenomena, supporting simulations in electromagnetic transient (EMT) time domains and simplifying models (especially of power electronic devices) on both transmission and distribution sides. › Enhance physical and geographical representation of grid components to provide a more comprehensive and realistic representation of the grid, supporting decision-making in other key areas of real-time operation, including: – Improving fault detection and localisation to reduce restoration times – Enhancing situational awareness in case of extreme meteorological and climatic events, integrating weather forecasts and real-time environmental data to anticipate potential risks – Optimising grid reconfiguration strategies – Mitigating cascading failures – Area-based adaptive load-shedding schemes built on WAMS systems › Foster the development of grid field-deployable hardware, well integrated with edge computing, operator interfaces, monitoring systems, and coordination layers, to provide granular operational data that supports dynamic responses to system needs.
Expected outcome	The project will contribute to a more resilient and efficient power system, improving real-time decision-making and operational security while enabling a more integrated approach to: › Implement learnings to improve DSA techniques and operational results, in order to optimise security margins, reducing unnecessary constraints on system operation › Enhance early detection of emerging phenomena, such as areas with poor power quality › Enhance grid planning, control, and maintenance activities, improving outage planning efficiency and optimising intervention time without reducing overall maintenance needs › Enable real-time adjustment of protection settings based on evolving grid conditions, predictive maintenance operations, reduction of renewable energy curtailment, and greater interoperability with market models and simulations. › Increase mutual observability at the transmission-distribution interface and at lower voltage levels to better support the flexibility exploitation of distributed energy resources
Milestones	Projects based on this concept will contribute to reaching the following milestones: › Mission 1: Adoption of real-time data sensors and IoT devices for more efficient, cost-effective, and safer remote monitoring › Mission 4: Advanced visualisation options for control rooms › Mission 4: Digital twins for monitoring and enhanced dynamic grid representation › Mission 4: Integration of PMU (WAMS) in DSA processes

MISSION 4 – ENHANCE CONTROL AND INTEROPERABILITY THROUGH DIGITALISATION	
PROJECT CONCEPT 9	**GRID DIGITAL TWIN FOR ENHANCED REAL-TIME OBSERVABILITY**
Barriers	› Implementing a high-fidelity digital representation of the power system involves several challenges. A key issue is integration into existing operational frameworks and adaptation of legacy systems, as well as attention to cybersecurity issues, given the involvement of different integrated and linked physical assets and the huge amount of data exchanged and stored. › The computational burden of real-time three-phase meshed grid models is another constraint. While improving accuracy, their complexity may limit usability for rapid decision-making, making model optimisation essential. › A significant challenge is the deployment and maintenance of a large-scale sensor network, requiring more effort from existing grid maintenance operators. › Data availability, interoperability, and consistency remain a concern, particularly when integrating multiple TSO and DSO sources with differing formats, granularity, and sharing policies.
Policy context	The project aligns with key European regulations promoting grid digitalisation and operational security. Regulation (EU) 2019/943 emphasises the need for advanced monitoring and control tools to enhance system flexibility and renewable integration. Regulation (EU) 2022/869 (TEN-E) supports innovative solutions for grid security and cross-border interoperability. Additionally, the project is in line with ENTSO-E Operational Security Standards, which stress the importance of real-time observability and DSA to maintain grid stability.
State of the art	Ongoing projects (such as TwinEU; **https://twineu.net/**) explore digital twin applications, but no existing initiative fully integrates real-time, high-fidelity modelling with advanced measurement technologies for operational decision-making.
TRL current/target	**Current TRL: 4–5** **Target TRL: 7**
Timeline	2026–2030
Expected collaboration with	› Manufacturers › Software developers/ICT service providers

PROJECT CONCEPT 10: Integrated framework for automated DER flexibility services

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 10	**INTEGRATED FRAMEWORK FOR AUTOMATED DER FLEXIBILITY SERVICES**
Needs addressed	The widespread digitalisation and increasing penetration of DERs are transforming European power systems. This shift, while introducing operational complexities, also creates significant opportunities for novel grid balancing strategies. One of these is to leverage the provision of flexibility services from DERs. To date, the potential of DERs (aggregated or not) in contributing to the safety margins required for stable grid operation remains largely untapped, particularly in TSO markets, such as reserve power and possible markets for congestion management. Key challenges include: › Testing in a real-world environment and validating baselining methods for each product, as well as allocated-volume / settlement processes that account for compensation and rebound › Developing and validating configurable aggregation models (including multiple-BRP scenarios) › Validating TSO–DSO coordination models at the national and / or regional level, with agreed operational procedures and performance objectives › Validating Flexibility Information System (FIS)-ready interoperability specifications and adapters
Scope	In the context of addressed needs, and beyond the Demand Response Network Code (DR NC) and amended Electricity Balancing Regulation (EBGL) requirements, this PC intends to promote the delivery of the implementation layer to leverage DER's potential in providing system flexibility. The scope of this PC includes the following objectives: › Design, test in a real-world environment, and validate precise, accurate, and unbiased product-specific baselining methods, tailored to system-user data where applicable, on field datasets, with selection / validation guidance for national T&Cs › Implement end-to-end measurement and calculation of allocated volumes and settlement processes that account for compensation and rebound effects and provide transparent auditability at the connection point › Provide a configurable aggregation-model framework, including multiple-BRP scenarios and product-specific corrections › Map and assess existing TSO–DSO coordination schemes; subsequently develop, test, and benchmark TSO–DSO coordination schemes at the national and / or regional level (activation sequencing, prioritisation, conflict handling) with agreed operational procedures and performance objectives › Develop FIS-aligned modular interoperability specifications and reference adapters to serve as technical enablers for secure data exchange between TSOs, DSOs, and financial service providers (FSPs), fostering interoperability while allowing flexibility for specific national implementations

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 10	**INTEGRATED FRAMEWORK FOR AUTOMATED DER FLEXIBILITY SERVICES**
Expected outcome	The implementation of this PC is expected to contribute to: › Creation of vendor-agnostic, open, interoperable solutions for DER participation in ancillary services › Demonstration of practical TSO–DSO–aggregator coordination schemes and communication interfaces to coordinate real-time flexibility activation › Demonstration of improved allocated-volume calculation and settlement mechanisms, ensuring more accurate and equitable payments that explicitly account for compensation and rebound effects › Development of adaptable aggregation models and products for DERs (including multiple-BRP scenarios and product-specific corrections), promoting the participation of independent aggregators and accommodating national methodologies › Empowerment of small-scale actors through participation in balancing and other system services markets (and, where applicable, congestion management mechanisms), promoting economic efficiency and grid resilience
Milestones	Projects based on this concept will contribute to reaching the following Mission 5 milestones: › Efficient utilisation of demand-side response › Integration of peer-to-peer, local, wholesale, and ancillary service markets in daily operations › Incentives, tariffs, and business models for flexibility, including operator interactions with aggregators, communities, and customers › Validation of market mechanisms for system security and system adequacy
Barriers	› Fragmented data interfaces and legacy systems can block FIS-ready interoperability and slow conformance testing. › Insufficient data granularity / quality (e.g. missing or non-validated dedicated measurements) jeopardises product-specific baselining, allocated-volume calculation, and transparent settlement. › At the distribution level, the deployment of advanced SCADA and DER Monitoring Systems (DERMS), as well as ICT devices able to control DERs, may be too expensive. › Residual conflicts in the use of DERs for either local flexibility or ancillary services must be managed, even when TSO–DSO coordination procedures are applied. › Some stakeholders might be reluctant to use open interfaces and platforms for data sharing. › Small DSOs or aggregators may lack financial or workforce resources to adopt complex new systems. › Allocated-volume attribution and financial transfer / compensation are complicated by multiple-BRP scenarios and product-specific corrections, increasing the risk of disputes. › Security and privacy requirements can limit data availability and timeliness for validation and real-time operations. › Variations in national T&Cs / methodologies (e.g. baselining rules, settlement practices) create regulatory heterogeneity and slow cross-border cooperation.

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 10	**INTEGRATED FRAMEWORK FOR AUTOMATED DER FLEXIBILITY SERVICES**
Policy context	This PC is aligned with EU Green Deal objectives, the forthcoming DR NC, and the amended EBGL. The draft DR NC and the amended EBGL (as proposed) establish the principles and obligations for demand-side participation and interoperability, including national T&Cs for baselining methods, the FIS as the digital entry point, TSO–DSO coordination and data exchange, and aggregation models and financial transfer/compensation. The Network Code on Cybersecurity, which was also reflected in this PC, provides principle-level requirements for risk management and secure data handling that also apply to flexibility processes. Moreover, the EU Action Plan on Digitalising the Energy System highlights the importance of deploying appropriate data-sharing frameworks to facilitate participation in the wholesale markets of flexible energy resources, which make full use of digital solutions (estimated at over 580 GW of flexibility by 2050). The concept explicitly builds on state-of-the-art pilots and platforms, generalising proven interfaces, datasets, and practices to support national T&Cs and contribute to stepwise EU harmonisation.
State of the art	Italy is testing both a "traffic light" TSO–DSO coordination model and a "local flexibility markets" model for flexibility services for distribution grids, through pilot projects like TSO–DSO Dynamic Traffic Light (Terna and Enel), Enel Edge, Areti RomeFlex, and Unareti MindFlex, under ARERA's regulatory framework. These pilots also involve testing and deployment of ICT technologies at the distribution level, which will be essential to building experience that, in the near future, can enable DER participation in ancillary services markets. A crucial part of these projects is developing ICT and market platforms that enable registration and qualification of distributed resources, real-time or scheduled bidding for flexibility services, and secure communication between aggregators, DSOs, and the TSO. There is also Terna's Energy System Innovation (ESI) program, which focuses on resource aggregation, with a particular emphasis on exploring the technical challenges and system requirements associated with integrating small-scale DER. It is also worth noting cross-border initiatives enabling large-scale DER participation in balancing. For example, the crowd balancing platform Equigy, a non-profit TSO subsidiary, provides harmonised access to TSO markets across Europe, enabling flexibility service providers to maximise revenue by streamlined participation in balancing and redispatch.
TRL current/target	**Current TRL: 6** **Target TRL: 8**
Timeline	2026–2030
Expected collaboration with	› DSO › Energy service providers/Energy suppliers › Authorities and regulators › Associations and local communities › End users

PROJECT CONCEPT 11:
Advanced power system forecasting for enhanced grid stability and market efficiency

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 11	**ADVANCED POWER SYSTEM FORECASTING FOR ENHANCED GRID STABILITY AND MARKET EFFICIENCY**
Needs addressed	The increasing integration of DER into the European power grid introduces significant variability, uncertainty, and new dynamic challenges in power generation and system performance. At the same time, decentralisation tendencies in energy systems redefine grid operators' responsibilities, requiring greater coordination between DSOs, TSOs, and other actors (e.g. aggregators / FSPs, market operators, large consumers / prosumers). A coordinated, holistic approach is essential not only for forecasting both power generation from renewable energy and load but also for comprehensively assessing dynamic system performance, including voltage performance, frequency stability, and the critical issue of system inertia. Understanding how DER contributes to these dynamic aspects is crucial to ensure overall grid stability, resilience, and efficient market operations, as well as to optimise resource allocation. Multi-temporal forecasting tools are needed to minimise forecast errors in DER net injections and improve the visibility of market-driven variations in demand-side response in operations (intraday to week-ahead). In the long term (10 – 20 years), scenario-based forecasting supports system stability and enables anticipatory investments in grid infrastructure and smart technologies, ensuring the long-term reliability and robustness of the European power system in a high-DER future.
Scope	The scope of the projects will be to develop advanced forecasting models that leverage AI and big data analytics and adapt the chosen system to shared usage by TSOs and DSOs and their specific needs. In particular, this PC covers two horizons: (i) short-term / real-time operations and (ii) long-term planning / investments, and focuses on: › Assessing TSOs' and DSOs' everyday needs in terms of the time horizon and quality of the forecast, the user interface and APIs of the forecasting tool, privacy-preserving data-sharing solutions, compatibility with existing IT infrastructure, etc. › Improving DER and demand forecasting across different time frames (reducing long-term errors), integrating real-time data and continuously refining models, and advancing seasonal forecasting, including the dynamic contribution of DER to system performance (e.g. frequency response and voltage support) › Fostering the adaptivity and tailoring of the associated modelling efforts (e.g. ultra-high resolution weather modelling) to energy sector needs › Expanding the methods and formats of applying the latest AI / ML developments for power system forecasting › Developing tool functionality that balances simplicity and practical value with the primary focus on accuracy, while focusing on resilience to data gaps, emergencies, and cyber and physical attacks › Incorporating weather data, market trends, grid conditions, and relevant data from other energy sectors into forecasting models (holistic forecast for system of systems), using advanced techniques to better integrate data from different sources › Fostering industry efforts to standardise forecasting approaches and products › Liaising with bodies responsible for long-term scenario planning (10 – 20 years) to align key assumptions and methods where appropriate › Translating long-term scenario insights into short-term operational forecasting requirements (intraday to week-ahead) and, separately, into anticipatory investment priorities for future system adequacy and resilience

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 11	**ADVANCED POWER SYSTEM FORECASTING FOR ENHANCED GRID STABILITY AND MARKET EFFICIENCY**
Expected outcome	The implementation of projects on advanced power system forecasting are expected to: › Significantly improve grid stability and resilience through better anticipation of supply–demand imbalances and a deeper understanding of dynamic system performance (e. g. inertia, frequency, voltage stability) under various operating conditions › Enhance market efficiency by improving the availability of high-quality system data and forecasting products, shared via established transparency and market information channels with relevant stakeholders (e. g. BRPs, aggregators), enabling better self-balancing and bidding decisions, improved resource allocation, and fostering new flexibility services. This expected outcome is without prejudice to the rules applicable to market integrity and transparency. › Reduce reliance on costly reserves by lowering forecast uncertainty, enabling more efficient reserve dimensioning and scheduling and reducing the need to commit additional conventional units for security margins, delivering system-wide cost savings › Increase integration of intermittent renewables by proactively mitigating variability through precise forecasting and coordinated operational planning and balancing / congestion management actions (including redispatch where applicable), thereby accelerating decarbonisation goals › Improve coordination in planning and real-time operations between TSOs and DSOs, optimising the utilisation of diverse flexibility sources at the distribution level to support the entire grid › Enable anticipatory investments in grid infrastructure and smart technologies, ensuring the long-term robustness and reliability of the European power system in a high-DER future. › Drive industry standardisation in forecasting methodologies and products, facilitating interoperability and accelerating the adoption of advanced grid management practices across Europe
Milestones	Projects based on this concept will contribute to reaching the following Mission 5 milestones: › Increasing the flexibility of renewable power plants › Enhanced TSO–DSO coordination on system planning, security, and optimal power flow › AI and ML solutions to boost horizontal and vertical system integration › Define ICT requirements and standards to collect data for flexibility markets
Barriers	Potential barriers to implementation may include: › Data availability and quality: sensitivity of forecasting models to the input data; ensuring access to high-quality, real-time data from diverse sources; harmonising data structure; ensuring data privacy while not compromising the value of forecasting › Model viability despite complexity: developing models that can handle the complexity and variability of power systems, including the dynamic behaviour of DER and the challenges of forecasting over extended time horizons for anticipatory investments › Integration challenges: seamlessly incorporating forecasting tools into the existing grid management and market operation systems of both TSOs and DSOs, ensuring compatibility with evolving operational paradigms › Stakeholder acceptance: achieving buy-in from TSOs, DSOs, and market participants for new forecasting methodologies.

MISSION 5 – ENHANCE FLEXIBILITY ASSESSMENT AND MARKET MECHANISMS	
PROJECT CONCEPT 11	**ADVANCED POWER SYSTEM FORECASTING FOR ENHANCED GRID STABILITY AND MARKET EFFICIENCY**
Policy context	This PC aligns with the EU goals outlined in the Green Deal, aiming for carbon neutrality by 2050. It supports the integration of RES and contributes to the objectives of the Clean Energy Package by enhancing system flexibility and supply security. The EU regulatory framework promotes accurate forecasting, data sharing, and cooperation among grid operators to facilitate the integration of renewable energy. The Network Code on Electricity Balancing, the Network Code on Capacity Allocation and Congestion Management, and the Network Code on Operational Security encourage the use of advanced forecasting techniques and tools and cooperation with DSOs in sharing relevant information.
State of the art	Despite the abundance of existing projects engaged in power system forecasting, current forecasting methods primarily rely on statistical models and historical data analysis. While these methods provide baseline capabilities, they often lack the adaptability to handle the dynamic nature of modern power systems with high renewables penetration. The power system forecasting landscape is shifting to more advanced AI- and ML-based methods, which require additional development and refinement for reliable, large-scale implementation in real-world power system operations. Furthermore, it will be crucial to leverage insights and outcomes from relevant industry task forces, such as the work on coordinated TSO–DSO security analysis (e. g. DESAP initiatives), to ensure alignment and build on existing collaborative efforts in developing and deploying such advanced forecasting solutions.
TRL current / target	Commercial forecasting solutions are mature (often TRL 8 – 9); however, AI / ML-based approaches may be less mature (often TRL 6 – 8), depending on the use case and data readiness. **The goal is to achieve TRL 9** for AI-based systems, indicating full system maturity, deployment in operational environments, and scalability.
Timeline	2026 – 2030
Expected collaboration with	Software developers / ICT service providers

PROJECT CONCEPT 12:
Hydrogen Hub: Enhancing grid resilience and flexibility through sector coupling

MISSION 6 – TOOLS AND STRATEGIES FOR OPTIMAL CROSS-SECTOR INTEGRATION	
PROJECT CONCEPT 12	**HYDROGEN HUB: ENHANCING GRID RESILIENCE AND FLEXIBILITY THROUGH SECTOR COUPLING**
Needs addressed	The EC foresees that deploying hydrogen alongside other technologies can contribute to decarbonising energy sectors, provide long-term, large-scale energy storage to address long-term system flexibility challenges, enhance energy security by covering gaps in RES generation, and potentially stimulate economic growth through the market opportunities created.
Scope	Projects will develop a cross-sector framework to integrate hydrogen technologies into the energy system, enhancing grid flexibility, enabling long-duration storage, and providing system services. › This will be achieved by: › Using hydrogen for ancillary services (e. g. frequency regulation) and congestion management to balance intermittent RES › Demonstrating and comparing the cost-effectiveness of long-duration hydrogen storage with other technologies, such as pumped hydro and batteries › Integrating hydrogen into existing electricity and gas grids (power-to-gas) and exploring its use in industrial processes › Developing and validating integrated holistic energy system models to optimise the interaction between electricity, hydrogen, and gas networks › Quantifying the economic and environmental benefits (reduced emissions, improved grid stability) and designing market mechanisms to encourage cross-sector hydrogen integration › Analysing possible frequency ancillary or balancing services provided by hydrogen technologies, including frequency containment reserves (FCR), frequency restoration reserves (FRR), automatic frequency restoration reserves (aFRR), manual frequency restoration reserves (mFRR), reserve restoration (RR), voltage control, or reactive power control and congestion management products
Expected outcome	The projects' activities will: › Significantly enhance grid resilience and flexibility through sector coupling › Lower CO_2 emissions and advance decarbonisation goals by replacing fossil fuels with hydrogen › Develop new business models to support system security and adequacy › Enable stakeholders to capitalise on opportunities within the energy sector › Evaluate long-duration hydrogen storage potential and its associated benefits, reinforcing the role of hydrogen alongside other technologies in developing the grid › Implement cross-sector planning covering storage, hydrogen, heating and cooling, and transportation, to ensure a coordinated approach to energy resilience › Deliver progress in energy storage, system integration, and sustainable infrastructure development
Milestones	Projects based on this concept will contribute to reaching the following Mission 6 milestones: › Assessment of energy storage and cross-sector integration potential for system services restoration › Quantification of the flexibility potential unlocked by sector coupling › New business models for system security and adequacy › Assessment of long-duration storage potential of hydrogen and the associated benefits on electrical grids › Integration of a solution for flexibility from hydrogen in system operation › Cross-sector planning, including storage, hydrogen, heating and cooling, and transport

MISSION 6 – TOOLS AND STRATEGIES FOR OPTIMAL CROSS-SECTOR INTEGRATION	
PROJECT CONCEPT 12	**HYDROGEN HUB: ENHANCING GRID RESILIENCE AND FLEXIBILITY THROUGH SECTOR COUPLING**
Barriers	› Limited maturity of hydrogen technologies for large-scale deployment › High costs of hydrogen infrastructure › Lack of mature market mechanisms and clear regulations regarding the profitability of hydrogen solutions compared to existing alternatives › The need for incentives › Insufficient infrastructure for hydrogen production, storage, and distribution › Challenges in retrofitting existing natural gas grids to handle hydrogen › Complexity in aligning stakeholders from electricity, gas, and other industry sectors to implement the same approach › Geographical requirements › Constraints for the produced hydrogen to be green
Policy context	› European Green Deal: Aligns with the EU's overarching goal to achieve climate neutrality by 2050, emphasising the decarbonisation of energy systems and increased use of renewable hydrogen › Fit for 55 Package: Supports the EU's interim target to reduce greenhouse gas emissions by 55% by 2030, with hydrogen as a key enabler for reducing emissions in hard-to-abate sectors › EU Hydrogen Strategy (2020): Encourages the deployment of renewable hydrogen technologies, aiming for 40 GW of electrolyser capacity by 2030 and the creation of a hydrogen ecosystem › TEN-E Regulation (Revised 2022): Promotes cross-border energy infrastructure development, including hydrogen networks, and prioritises projects of common interest (PCI) for funding and support › REPowerEU Plan (2022): Highlights the role of hydrogen in enhancing energy security and reducing dependence on fossil fuel imports, particularly in light of geopolitical challenges
State of the art	The current state of the project reflects the growing integration of hydrogen technologies into energy systems. Projects will now try to demonstrate the feasibility of blending hydrogen into existing gas grids, while exploring its role in grid flexibility and ancillary services.
TRL current/target	› Specific applications like electrolysers are currently at TRL 7–8, since they are already deployed in pilots and demos in various European projects. › Hydrogen storage technology is currently around TRL 6–7. › Hydrogen fuel cells, currently around TRL 6–7, are being tested for their potential to provide ancillary services, but their large-scale integration into the grid remains in the early stages. › Given the current pace of research, policy support, and funding, the target TRL in the next 5 years for these technologies would likely be 8–9 for electrolysers and 7–8 for the other parts of the technology chain mentioned above.
Timeline	2026–2030
Expected collaboration with	› Manufacturers › Standardisation bodies › Authorities and regulators › Utilities

PROJECT CONCEPT 13: Analysis of cross-sector integration potential and role model definition

MISSION 6 – TOOLS AND STRATEGIES FOR OPTIMAL CROSS-SECTOR INTEGRATION	
PROJECT CONCEPT 13	**ANALYSIS OF CROSS-SECTOR INTEGRATION POTENTIAL AND ROLE MODEL DEFINITION**
Needs addressed	Achieving decarbonisation goals while maintaining secure and resilient power systems represents a significant challenge that cannot be solved by the power sector in isolation. A holistic approach is essential, and this is where sector coupling offers huge benefits. In fact, by integrating and leveraging technologies and strategies from other sectors, such as heating and cooling (buildings and industry), transportations, gas and hydrogen, energy-intensive industrial processes, agriculture, and waste management for bioenergy, etc., the power sector can unlock crucial flexibility.
Scope	Projects are expected to explore where and to what extent cross-sector integration is possible and to define a successful role model that clarifies responsibilities and accountabilities for each involved actor. In particular, the scope of this PC is to: › Develop an analytical tool to compute the potential contribution of different sectors when integrated with the power system › Define a framework to assess cross-sector potential, opportunities, and possible impactful collaborations › Define actor roles, responsibilities, and expected commitments › Develop interoperable repositories for data sharing between actors from different sectors to feed simulation tools › Establish indicators to track how the different roles and their impact on the system evolve over time
Expected outcome	Projects will contribute to: › Increasing power system flexibility › Increasing variable renewable power system hosting capacity › Increasing resilience to extreme events › Enhancing coordination between stakeholders and operators from different sectors › Quantifying the potential contribution of the different sectors in guaranteeing and improving the security, reliability, and restoration of the power sector, enabled by the development of an integrated energy system
Milestones	Projects based on this concept will contribute to reaching the following Mission 6 milestones: › Assessment of electrification potential in residential, services, industry, heating and cooling, and transport › Scenarios for progressive cross-sector integration › Development of a harmonised cross-sector role model › Feasibility studies for the operation of integrated systems › Standards for cross-sector interoperability and data exchange › Network codes for the integrated energy system, including the definition of roles and responsibilities
Barriers	› Each sector operates with its own primary objectives and agendas. Reconciling them can be challenging, leading to misaligned priorities. › Different organisational cultures, work styles, and objectives can create friction and misunderstanding, hindering effective collaboration. › The process of reviewing operational standards for energy infrastructure proceeds slowly. › Some sector coupling technologies are not yet competitive in terms of cost and performance.

MISSION 6 – TOOLS AND STRATEGIES FOR OPTIMAL CROSS-SECTOR INTEGRATION	
PROJECT CONCEPT 13	**ANALYSIS OF CROSS-SECTOR INTEGRATION POTENTIAL AND ROLE MODEL DEFINITION**
Policy context	This PC aligns with EU objectives outlined in its strategic documents. It supports the integration of RES, aiming for carbon neutrality by 2050 as outlined in the Green Deal, and contributes to the objectives of the Clean Energy Package by enhancing system flexibility, supply security, and governance regulation. The EU regulatory framework promotes data sharing and cooperation among operators to facilitate the integration of renewable energy. Recent EC policies for the energy sector increasingly emphasise structured cross-sector integration and clear role definition, particularly through data governance and digitalisation strategies. The EU Action Plan for digitalising energy laid the foundation for a common European energy data space, aiming to foster interoperable infrastructures, shared standards, and coordinated data access among actors from the energy, mobility, and building sectors. Moreover, according to the Clean Industrial Deal, sectoral transition will enable informed investment decisions, facilitate the mobilisation of more capital, and ultimately accelerate progress towards a cleaner and more competitive industrial future.
State of the art	Demonstrators implementing multi-energy solutions that provide flexibility to the power system have been developed within the European framework. The EU projects Magnitude and SENERGY NETS demonstrate the use of cross-energy carrier systems for new grid services, particularly through the aggregation of heating and cooling devices. Several projects focusing on electric vehicle (EV) integration into power systems are ongoing; for example, the EU project FLOW implements technological solutions to enable EV smart charging (and V2G), delivering benefits to system operators.
TRL current/target	**Current TRL: 5–6** **Target TRL: 8–9**
Timeline	2026–2030
Expected collaboration with	Authorities and regulators

Conclusion

The RDI Implementation Plan 2026 – 2030 consolidates ENTSO-E's commitment to driving Europe's energy transition through coordinated and forward-looking innovation. By translating the RDI Roadmap 2024 – 2034 into PCs, the Implementation Plan provides a coherent framework to guide TSOs in addressing emerging challenges and preparing the grid for a decarbonised, digital, and resilient future.

The 13 PCs outlined in the Implementation Plan are designed to be a strategic bridge between research and real-world application, ensuring that innovation directly supports operational needs and policy priorities. Through their focused, modular, and complementary design, they foster technology maturation, interoperability, and cross-sector integration while accelerating the implementation of advanced solutions for grid modernisation, HVDC expansion, digitalisation, distributed resource management, system resilience, etc.

Each PC is described in detail in Chapter 4 using a uniform structure that presents information on the needs addressed, scope, expected outcome, links to RDI Roadmap milestones, barriers to deployment, policy context, current state of the art, TRL, timeline, and partners with whom collaboration is deemed necessary.

This Implementation Plan not only looks to the future but also analyses current and recent RDI efforts to assess how existing RDI initiatives can be leveraged to develop a strong foundation for future innovative projects. By mapping ongoing and recently completed TSO and EU projects, ENTSO-E aims to inform and strengthen PCs through structured and transparent knowledge sharing.

The screening conducted among TSOs to identify relevant ongoing RDI projects represents a first step, which can be reinforced through future efforts to ensure that all successful outcomes are effectively leveraged in subsequent projects and ultimately reach the market.

Access to national and European funding remains a crucial step for success, enabling the scaling up of innovation and bridging the gap between demonstration and deployment. Equally, sustained political and financial commitment will be required to de-risk grid investments and ensure stable frameworks for long-term modernisation.

In conclusion, the ENTSO-E RDI Implementation Plan 2026 – 2030 outlines a shared pathway to accelerate the transition towards a secure, smart, and sustainable European power system. By defining a comprehensive set of PCs aligned with the most pressing RDI priorities, the plan provides a strategic framework to translate long-term system needs into concrete innovation actions, support cross-border collaboration, and drive the development of technologies essential for Europe's energy transition.

The Implementation Plan ultimately aims to lay the foundations for the energy system transformation needed to meet Europe's decarbonisation goals and to ensure a secure, affordable, and cost-effective energy system for all consumers, in alignment with the EU energy policy landscape and objectives.

List of acronyms

Acronym	Description
AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
AI	Artificial Intelligence
ARERA	Italian Regulatory Authority
BESS	Battery Energy Storage System
CBCA	Cross-Border Cost Allocation
CEF	Connecting Europe Facility
DC	Direct Current
DER	Distributed Energy Resources
DR NC	Demand Response Network Code
DSA	Dynamic Security Assessment
DSO	Distribution System Operator
EC	European Commission
EBGL	Electricity Balancing Regulation
ENTSO-E	European Network of Transmission System Operators for Electricity
EHV	Extra-High Voltage
EU	European Union
FIS	Flexibility Information System
FSP	Financial Service Provider
GFM	Grid Forming
EMT	Electromagnetic Transient
HVDC	High-Voltage Direct Current
IBR	Inverter-Based Resources
ICT	Information and Communication Technology
IoT	Internet of Things
NRA	National Regulatory Authority
PC	Project Concept
PEID	Power Electronic Interface Devices
RDI	Research, Development, and Innovation
RES	Renewable Energy Sources
RTO	Research and Technology Organisations
STATCOM	STATic synchronous COMpensator
TRL	Technology Readiness Level
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
WAMS	Wide Area Monitoring Systems

Glossary

Term	Definition
Aggregator / Flexibility Service Provider (FSP)	A market entity or specialised company that pools the flexibility potential of multiple distributed energy resources – spanning households, commercial premises, and industrial sites – and offers their combined capacity (to system operators) into dedicated markets as a single, manageable resource.
AI Decision Support System	An AI-based software tool that continuously processes heterogeneous grid data and generates actionable recommendations for human operators. By simultaneously considering multiple risks, constraints, and optimisation opportunities at a speed and scale beyond manual capability, the system supports operational functions such as congestion management, fault localisation, optimal redispatch, and DER coordination. A defining characteristic is that final decision authority remains with the human operator: the system augments situational awareness and accelerates analysis without autonomously executing control actions.
Ancillary Services	Services that specific energy generators and / or consumption units sell and can be activated by grid operators to keep the grid balanced and stable. These can include frequency regulation (FCR, aFRR, mFRR, RR), voltage control, reserve capacity, reactive power control, and congestion management. System operators pay for these services in dedicated markets. Commission Regulation (EU) 2017 / 1485 of 2 August 2017 establishing a guideline on electricity transmission system operation: › FCR (frequency containment reserves) means the active power reserves available to contain system frequency after the occurrence of an imbalance. › FRR (frequency restoration reserves) means the active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value. › RR (replacement reserves) means the active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including generation reserve.
Asset Management	Asset management encompasses the planning, operation, maintenance, and disposal of physical power infrastructure across its entire life cycle, with the primary objective of optimising the balance between cost, risk, and performance by integrating asset condition data into investment and operational decisions.
Baselining	The process of estimating the amount of electricity a flexible resource would have exchanged in the absence of a dispatch signal or flexibility request issued by a system operator. An accurate and robust baseline estimation is a prerequisite for objectively verifying whether a DER or aggregator has delivered the contracted flexibility volume, and for determining the magnitude of the actual demand reduction or shift achieved.

Term	Definition
Battery Energy Storage System (BESS)	An electrochemical energy storage that captures electrical energy and delivers it back to the grid or end users on demand. A BESS consists of batteries arranged in modules and paired with a power conversion and management system. By decoupling the timing of energy production from consumption, a BESS can play a key role in grid balancing.
Distributed Energy Resources (DER)	Small-scale electricity generation and consumption assets, either controllable or not – including rooftop PV, battery storage systems, EVs, and heat pumps – connected at the distribution voltage level. When coordinated through an aggregation mechanism, these resources can be dispatched collectively to deliver grid services.
Dynamic Rating (DLR)	A set of methods for continuously calculating the real-time ampacity of overhead lines based on actual operating and environmental conditions rather than fixed conservative limits derived from worst-case seasonal assumptions. DLR can unlock substantial additional transfer capacity on existing infrastructure by combining real-time meteorological data, conductor temperature measurements, and thermal models of the conductor to compute the maximum allowable current at each moment without exceeding safe mechanical and thermal thresholds.
Dynamic Security Assessment (DSA)	The process of evaluating whether a power system can withstand a defined set of disturbances, such as faults, line trips, or sudden generation loss, and return to an acceptable steady-state operating condition without violating operational limits. Unlike static security assessment, which checks pre- and post-disturbance snapshots, DSA explicitly accounts for the system's time-domain behaviour, capturing transient phenomena that unfold in the seconds following a disturbance.
Electromagnetic Transient Simulation (EMT)	EMT models and analyses rapid and short-duration events in electrical power systems, known as electromagnetic transients, such as those generated by the switching of converters or faults. EMT simulations are computationally intensive but necessary for understanding the complex interactions between modern power electronic devices.
Grid Digital Twin	A high-fidelity dynamic model of a physical electricity network continuously synchronised with its real-world counterpart through live data streams from sensors, smart meters, phasor measurement units (PMUs), and SCADA systems. It is a virtual replica of the real electricity grid, able to simulate in real-time the network's electrical state, topology, and asset conditions, enabling operators and planners to monitor system behaviour as it evolves.
Grid Forming (GFM)	The capability of power electronic converters to support voltage and frequency regulation in electrical grids, thereby improving stability in systems dominated by RES. A GFM converter can actively control its output frequency and voltage and operate autonomously.
High-Voltage Direct Current (HVDC)	A system that uses direct current to transmit electric power over very long distances. In HVDC systems, current flows in one direction without fluctuations, making it more efficient for undersea cables and long-distance land connections.

Term	Definition
HVDC Circuit Breaker	A switching device that interrupts the flow of normal and abnormal DC. The challenge in breaking DC is the absence of a natural zero current crossing. To break the DC, either additional oscillatory circuits for the generation of zero-crossings or additional power electronics are needed.
Internet of Things (IoT)	A network of everyday objects connected to communication networks to provide a range of services or applications in energy areas such as smart grids, home automation, or intelligent transportation.
Inverter-Based Resources (IBR)	Devices such as solar panels, wind turbines, and batteries that connect to the electricity grid through an electronic converter rather than through a conventional electric generator.
Multi-Terminal (MT) HVDC Grid	An HVDC in which three or more converter stations are interconnected, allowing power to be exchanged between multiple AC systems through a shared DC infrastructure. Unlike point-to-point HVDC links, MT HVDC systems enable more flexible power routing and can integrate geographically dispersed resources into the AC grid through a common DC backbone.
Network Code	A set of rules drafted by ENTSO-E, with guidance from ACER, to facilitate the harmonisation, integration, and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market and achieving the EU's energy objectives. ENTSO-E also cooperates with EU DSO Entity on the drafting of Network Codes and Guidelines, notably on cybersecurity and demand-side flexibility.
Power-to-Gas	An energy conversion process in which surplus or curtailed electricity, typically from variable renewable sources, is used to produce gaseous energy carriers through electrochemical or thermochemical reactions. The resulting gases can be injected into existing gas infrastructure, stored at scale, used as industrial feedstock in hard-to-abate sectors such as steel or chemicals, or converted back to electricity through fuel cells or conventional generators when demand requires.
Sector Coupling	The systemic integration of historically separate energy-consuming and energy-carrying sectors (including electricity, heating and cooling, transport, industry, and gas) through technologies and infrastructure that enable the conversion, exchange, and coordinated management of energy flows across sector boundaries. Sector coupling allows surplus renewable electricity to be converted and utilised in other sectors, thereby reducing renewable curtailment and fossil fuel use and unlocking new sources of flexibility for the power system.
STATic synchronous COMpensator (STATCOM)	A fast-acting device capable of providing or absorbing reactive current and thereby regulating the voltage at the point of connection to a power grid. It is categorised under flexible alternating current transmission system (FACTS) devices. The technology is based on voltage source converters (VSCs) with semiconductor valves in a modular multilevel configuration.

Term	Definition
Synthetic Data	Artificially generated datasets that reproduce the statistical properties, correlations, and distributional characteristics of real-world data without containing any actual sensitive records. In the energy sector, synthetic data addresses two critical constraints: the confidentiality of operational data held by grid operators and utilities, and the scarcity of records for rare but high-impact events such as cascading failures, extreme weather contingencies, or large-scale cyberattacks. A key requirement is that synthetic datasets preserve the statistical fidelity of the original data.
System Inertia	Refers to the energy stored in large rotating synchronous generators. When generation and load become imbalanced, the spinning mass naturally resists sudden changes in rotational frequency, automatically and instantaneously releasing (or absorbing) stored kinetic energy to slow down the rate of frequency change, buying time for frequency regulation mechanisms to respond.
Technology Readiness Level (TRL)	A scale from 1 to 9 for assessing the maturity level of a technology, as defined by the European Commission for the Horizon Europe program: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2026-2027/wp-15-general-annexes_horizon-2026-2027_en.pdf
Ten-Year Network Development Plan (TYNDP)	A Union-wide 10-year network development plan, developed by ENTSO-E every two years, that plays a central role in the development of electricity transmission infrastructure across the EU. The main objectives of the TYNDP are to: › Identify investment gaps, including cross-border capacities › Assess the benefits of proposed infrastructure projects › Support adequate cross-border interconnection, non-discrimination, fair competition, and a well-functioning electricity market › Ensure the transparency of the European electricity transmission network
Wide Area Monitoring System (WAMS)	A monitoring infrastructure that provides real-time synchronised measurements across geographically dispersed nodes of a power system, enabling operators to detect dynamic phenomena. Its core is the PMU, which captures voltage and current phasors at high sampling rates using GPS-based time-stamping to synchronise data across the network with microsecond precision.

Annex: Summaries of the Project Concepts (fiches)

TRL 1 2 3 4 **5** 6 **7** 8 9

PROJECT CONCEPT 1

MISSION 1
Enhance grid use and sustainability

Improve supply chain resilience

PC 01

Needs addressed

- Grid upgrades face EHV equipment shortages and long delays
- Coordinated asset management boosts efficiency and security
- Align specs and maintenance to cut delays and share resources

Expected outcomes

- Assessment and an actionable roadmap for standards development
- Expanded pool of suppliers supported by common methodologies and tools for maintenance, monitoring, and risk management
- Aligned maintenance and spares strategies to optimise outage planning and emergency response

RDI Milestones

MISSION 1

- **Standardisation of asset management approaches**
- **Development of methods to mitigate risks (e.g. in the supply chain) for European TSOs**
- **SF6-free solutions operating in high voltage and extra high voltage grids**
- **Circular economy and environmentally friendly components included in planning and asset management**

TRL 1 2 3 4 **5** 6 7 **8** 9

PROJECT CONCEPT 2

MISSION 1
Enhance grid use and sustainability

Streamline network investments

PC 02

Needs addressed

- Develop methods to identify and prioritise key grid investments
- Optimise funding and use innovative financing to speed projects
- Work with TSOs and regulators to integrate renewables and boost security

Expected outcomes

- Increase cross-border capacity and strengthen market integration
- Improve planning methods and create a targeted investment plan for bottlenecks
- Apply a balanced, cost-effective approach to fund traditional and innovative grid solutions

RDI Milestones

MISSION 1

- **Harmonised methods for coordinated planning of highly loaded networks**
- **Integration of dynamic ratings and AI-based renewable power forecasts**
- **Advanced reconfiguration and control of network and assets**
- **Demonstration of innovative technologies for power flow control and increasing grid efficiency**

TRL 1 2 3 4 5 **6** **7** 8 9

PROJECT CONCEPT 3

MISSION 2

Onshore and offshore grid development and integration

Streamline HVDC converter concepts

PC 03

Needs addressed

- Large scale meshed multi-vendor HVDC grids
- Alignment of requirements for HVDC converters, cables and monitoring
- Synthetic inertia by grid forming HVDC converters

Expected outcomes

- Align TSO requirements to accelerate HVDC component production.
- Develop 525 kV breakers and grid-forming converters with storage
- Build simulation tools to identify interaction among converters and development of fault identification techniques (e.g. by travelling waves)

RDI Milestones

MISSION 2

- **Alignment of requirements for HVDC, cable and monitoring systems**
- **Alignment of reliability and maintenance concepts**
- **Alignment of offshore platform types**
- **Development and test of critical MT HVDC components**
- **Simulation tools, compliance tests and test facilities for HVDC converters**

TRL 1 2 3 4 5 **6** **7** 8 9

PROJECT CONCEPT 4

MISSION 2

Onshore and offshore grid development and integration

Development of tools and procedures to optimise the operation of HVDC onshore and offshore cables

PC 04

Needs addressed

- Operational challenges when using same service providers
- Standardisation of procedures for faster completion and simpler processes
- Testing solutions for optimised HVDC systems

Expected outcomes

- Optimised repair, maintenance, and monitoring of HVDC cables
- Enhanced legal protection, security measures, sustainable materials use, flexible offshore platform designs and reduced environmental impact
- Easier interconnections, increased interoperability with simplified systems and better availability of components and skilled personnel.

RDI Milestones

MISSION 2

- **Alignment of reliability and maintenance concepts**
- **Alignment of offshore platform types**
- **Alignment of HVDC, cable and monitoring systems**
- **HVDC system planning criteria and identification of possible new interconnectors**

TRL 1 2 3 4 5 6 **7** **8** 9

PROJECT CONCEPT 5

MISSION 3

Ensure secure and stable operation of the hybrid AC/DC grid

Development of near-real-time tools and demonstrators for dynamic hybrid AC/DC system simulations

PC 05

Needs addressed

- Rising use of IBR creates new stability challenges that must be managed
- Advanced tools are urgently needed for real-time system management
- Analytical platforms for assessing and controlling AC/DC system dynamics

Expected outcomes

- Improve efficiency through hybrid AC/DC networks without compromising security, quality, and continuity of supply
- Enhance real-time monitoring and control capabilities to prevent loss of system stability and manage unexpected events
- Updated methodologies, standards, and tools to support TSO operations

RDI Milestones

MISSION 3

- **Standardisation of the simulation tools interfaces**
- **Develop near-real time platforms for dynamic system simulations in relevant frequency ranges**
- **Develop tools and models for large scale pan-EU dynamic analysis**

TRL 1 2 3 4 **5** 6 **7** 8 9

PROJECT CONCEPT 6

MISSION 3

Ensure secure and stable operation of the hybrid AC/DC grid

Roadmap for GFM capability as a solution for a power electronics-dominated system

PC 06

Needs addressed

- New Grid Forming (GF) requirements and capabilities
- Technological needs for managing PEID stability through collaborations
- Grid Forming models for various devices demonstrating interoperability

Expected outcomes

- Development of flexible yet robust requirements and standards for manufacturers and suppliers of Grid Forming Converter devices
- Reduce development costs and enhance system capabilities
- Demonstrate interoperability of different GF devices in equivalent environment (e.g. hardware in the loop)

RDI Milestones

MISSION 3

- **Stability margins measure and assessment for PEID dominated systems**
- **Grid forming demonstrators' development for medium amount of PEID penetration**
- **Grid forming demonstrators' development for large amount of PEID penetration**

TRL 1 2 3 **4** 5 6 7 **8** 9

PROJECT CONCEPT 7

MISSION 4
Enhance control and interoperability through digitalisation

AI-Based Decision Support System solutions for future system operations

PC 07

Needs addressed

- Direct support to real-time system operation using AI
- AI tools to manage grid overload, current flows and voltage security
- Synergies of an AI-based decision support system with current tools

Expected outcomes

- Develop AI-driven simulation/optimisation tools for complex scenarios
- Create independent EU-level database combining historical and synthetic grid data to train and validate AI algorithms
- Establish AI training programs, operational guidelines, and protocols for system operators

RDI Milestones

MISSION 3
MISSION 4

- **Development of near-real time platforms for dynamic system simulations (e.g. for DSA)**
- **AI based reporting and analysis of system operation**
- **AI based decision support system for system operation**

TRL 1 2 3 **4** 5 **6** 7 8 9

PROJECT CONCEPT 8

MISSION 4
Enhance control and interoperability through digitalisation

Resilient and integrated grid operations for extreme events

PC 08

Needs addressed

- Enhanced resilience and real-time risk management for extreme events
- Preparedness through advanced forecasting and scenario-based strategies
- Real-time adaptive actions to enable rapid recovery after disturbances

Expected outcomes

- Develop advanced modeling and prediction tools for real-time analysis and management of extreme and critical operational events
- Prepare solutions for emergency impact reduction and service restoration
- Enhance cybersecurity protocols and coordinate joint crisis test scenarios among TSOs, DSOs, and civil protection services

RDI Milestones

MISSION 3
MISSION 4
MISSION 5
MISSION 6

- **Development of restoration plans and update of pan-EU system defence plan**
- **Demonstration of system restoration plans**
- **Enhanced toolbox to manage critical extreme weather events in real time**
- **Transition to probabilistic risk management approach**
- **Innovative cyber security approach for control centres**
- **Innovative training concepts and backup procedures**
- **Advanced interconnectivity modelling for better system integration between the control areas**
- **Network codes for the integrated energy system, including the definition of roles and responsibilities**

TRL 1 2 3 **4** 5 6 **7** 8 9

PROJECT CONCEPT 9

MISSION 4
Enhance control and interoperability through digitalisation

Grid Digital Twin for enhanced real time observability

PC 09

Needs addressed

- Improve system stability assessment and early phenomena detection
- Simplify PEID models across transmission and distribution networks
- Better fault detection and situational awareness during extreme events

Expected outcomes

- Dynamic Security Assessment to optimise security margins
- Improve early detection of power quality issues and enhance grid planning, control, and amaintenance.
- Support predictive maintenance, reduce renewable energy curtailment, and increase interoperability with market models and simulations.

RDI Milestones

MISSION 1
MISSION 4

- **Adoption of real-time data sensors and IoT devices for a more efficient, cost-effective and safer remote monitoring**
- **Advanced visualisation options for control rooms**
- **Digital twin for monitoring and enhanced dynamic grid representation**
- **Integration of PMU (WAMS) in dynamic security assessment**

TRL 1 2 3 4 5 **6** 7 **8** 9

PROJECT CONCEPT 10

MISSION 5
Enhance flexibility assessment and market mechanism

Integrated framework for automated DER flexibility services

PC 10

Needs addressed

- Manage operational complexities introduced by increased DER penetration
- Calculate DER baselines and improve TSO-DSO coordination
- ICT platforms, standardised data exchange, and vendor-agnostic control

Expected outcomes

- Develop vendor-neutral, open solutions and scalable business models to enable DER participation in ancillary services and energy markets
- TSO-DSO-aggregator schemes for real-time flexibility activation
- Implement improved settlement mechanisms, promoting independent aggregators market participation and cross-border market uniformity

RDI Milestones

MISSION 2
MISSION 4
MISSION 5

- Update of network codes for ancillary services (RfG 3.0)
- EU standardised data exchange protocols and ICT platforms
- ICT platforms for mass deployment of ancillary services from distributed resources
- Efficient utilisation of demand side response
- Integration of peer-to-peer, local, wholesale and ancillary services markets in daily operations
- Incentives, tariffs and business models for flexibility, including operator interactions with aggregators, communities and customers
- Validation of market mechanisms for system security and system adequacy

TRL 1 2 3 4 5 **6** 7 8 **9**

PROJECT CONCEPT 11

MISSION 5
Enhance flexibility assessment and market mechanism

Advanced power system forecasting for enhanced grid stability and market efficiency

PC 11

Needs addressed

- DER impacts on dynamic system performance (voltage, frequency, inertia)
- Enhanced coordination among actors to maintain grid stability
- Optimise DER dispatch and support long-term infrastructure investments

Expected outcomes

- Forecast supply-demand imbalances and improving coordination between TSOs and DSOs using dynamic system conditions insights
- Optimissed resource allocation, and reduced reliance on costly reserves
- Support anticipatory grid investments and drive standardisation in forecasting to ensure long-term system reliability

RDI Milestones

MISSION 2
MISSION 4
MISSION 5

- **Increasing the flexibility of renewable power plants**
- **Enhanced TSO–DSO coordination on system planning, security and optimal power flow**
- **AI and ML solutions to boost horizontal and vertical system integration**
- **Definition of ICT requirements and standards to collect data for flexibility markets**

TRL 1 2 3 4 5 6 7 8 9

PROJECT CONCEPT 12

MISSION 6

Tools and strategies for optimal cross-sector integration

Hydrogen Hub: Enhancing grid resilience and flexibility through sector coupling

PC 12

Needs addressed

- Hydrogen to solve the issue of the system's long-term flexibility
- Large-scale hydrogen to support decarbonisation and economic growth
- Power sector coupling with hydrogen to create new market opportunities

Expected outcomes

- Strengthening grid resilience and flexibility through sector coupling
- Promotion of system security with new business models and greater renewable electricity use
- Reinforcing the role of hydrogen through long-duration storage, cross-sector planning, and integrated energy solutions

RDI Milestones

MISSION 6

- **Assessment of energy storage and cross-sector integration potential for system services restoration**
- **Quantification of the flexibility potential unlocked by sector coupling**
- **New business models for system security and adequacy**
- **Assessment of long-duration storage potential of hydrogen and associated benefits on electrical grids**
- **Integration of solution for flexibility from hydrogen in system operation**
- **Cross-sector planning including storage, hydrogen, heating & cooling and transports**

TRL 1 2 3 4 5 6 7 8 9

PROJECT CONCEPT 13

MISSION 6
Tools and strategies for optimal cross-sector integration

Analysis of cross-sector integration potential and role model definition

PC 13

Needs addressed

- Holistic approach involving multiple sectors to achieve decarbonization
- Flexibility from heating, cooling, transportation, gas, hydrogen, etc.
- integrating and leveraging technologies from different sectors

Expected outcomes

- Increase power system flexibility, renewable hosting capacity, and resilience to extreme events
- Enhance stakeholders/operators' coordination across different sectors
- Quantify sector contributions to security, reliability, and restoration through integrated energy system development

RDI Milestones

MISSION 6

- **Assessment of electrification potential in residential, services, industry, heating & cooling and transports**
- **Scenarios for the progressive cross sectors integration**
- **Development of a harmonized cross-sector role model**
- **Feasibility studies for the operation of integrated systems**
- **Standards for cross-sector interoperability and data exchange**
- **Network codes for the integrated energy system, including the definition of roles and responsibilities**

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