Power in Transition

R&I ROADMAP 2017–2026

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

European Network of
Transmission System Operators
for Electricity

entsoe

CONTENTS

In a Nutshell

EXECUTIVE SUMMARY

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Research and Innovation is the enabler for moving the energy transition forward. Sound research, development and innovation policies have to bring new technologies to a point at which markets will decide on their uptake.

Grid operators are at the core of the transformative change of the power system that keeps society functioning and our economies operating. They are the integrators of technologies and solutions.

WHY A NEW RESEARCH AND INNOVATION ROADMAP?

The proposed Research and Innovation (R&I) activities in this Roadmap aim to support the transmission system operators (TSOs), as key system integrators of different components and technologies, to answer to societal challenges. The TSOs should also be prepared to face game-changing environments, such as new actors entering the electricity market (e.g., storage, ICT, prosumers, active customers).

The R&I activities of this Roadmap are included in "Integrated Roadmap" developed by ENTSO-E, together with DSOs (EDSO for Smart Grids) and the storage community (EASE) through the participation in the EC service contract project Grid+Storage. The Integrated Roadmap addresses both TSO and DSO functional objectives. The TSO functional objectives in the Grid+Storage Integrated Roadmap will be the same as the ones published by ENTSO-E.

Similar to other products developed by ENTSO-E, the Research, Development and Innovation Roadmap (R&I Roadmap) is also a mandated deliverable providing the medium-/long-term vision for R&I activities coordinated by ENTSO-E and performed by TSOs. Owing to fast technological and policy changes, a midway update/revision of the previous edition (spanning the decade 2013–2022) of the Roadmap is needed, now spanning 2017 to 2026. The revision is also supposed to enable alignment with the process of the European Commission's Integrated Roadmap[1], which requires a more holistic vision and expanded cooperation with other actors. This Roadmap was submitted for public consultation to get stakeholders' views on the proposed ENTSO-E R&I activities[2]. The 10-year Roadmap is complemented by Implementation Plans, issued yearly on a rolling three-year horizon, in which the R&I areas identified here are prioritised, and translated into focused topics to be addressed by concrete projects.

1) EC Integrated Roadmap (2015), C(2015)61317 final

2) The details of the consultation process are presented in Appendix 2

EVOLVING IN A CHANGING CONTEXT AND THE ROLE OF TSOs IN THE PARADIGM SHIFT

The European Union climate/energy policies in 2015 marked a tipping point with the Energy Union Communication, placing the EU citizens at the centre. Energy Union identified Research & Innovation as one of the five pillars where the EU should focus its energy policy.

The Communication "Towards an Integrated Strategic Energy Technology Plan: Accelerating the European Energy System Transformation", set up the new frameworks for R&I activities: the European Technology and Innovation Platforms (ETIPs). These structures merge the former SET Plan European Industrial Initiatives (EIIs) and the European Technology Platforms. At the same time, funding tools – through the Horizon 2020 program – have shifted from a technology-driven approach to a challenge-driven approach. New stakeholders and market players (in generation, storage and market services) are on board with new opportunities for consumers. This puts network operators in a pivotal role and implies a higher responsibility towards society. The transmission grid, as the backbone of the power system, is the key enabler to facilitate the transition to a low-carbon energy system.

TSOs have a key role as system integrators of different components based on technologies (e.g., ICT, materials, storage, and power electronics). The TSO community should also be prepared to face game-changing modifications such as new actors entering the power system. Moreover, TSOs should ensure that the three dimensions of innovation – technology, process and business model – are addressed.

TSOs' role is crucial in this context and the Roadmaps support their engagement in Research and Innovation activities. To this purpose ENTSO-E intends to promote vertical and horizontal cooperation.

» **Vertical cooperation along the electricity value chain:** no single TSO will be able to succeed alone. Thus, TSOs must work together and collaborate with universities, research institutes, industrial manufacturers, DSOs, generation companies, market actors and consumers.

» **Horizontal cooperation:** aims to enhance synergies among TSOs to avoid overlaps, and work on common goals, which can be reached only with a strong, uniform and possibly joint approach to R&I activities.

ENTSO-E APPROACH TO RESEARCH AND INNOVATION

The Energy Union Strategy aims at increasing the use of variable RES in the energy mix, empowering customers and putting households and businesses consumers at the heart of the European energy market. New technologies are developed, and the aim of R&I activities proposed in this Roadmap are an answer to these challenges by making use of new technologies and solutions.

The active consumer (and prosumer) will need smart grids integrating smart meters, highly developed home automation systems and appliances that enable demand response, portfolio management and load optimisation. Big Data management, the Internet of Things, post-processing and security of data are required not only for inter-TSO cooperation but also for the empowerment of consumers.

At the same time, the power system must be secure and safe through better controllability, which requires more observability. Therefore, system operation must take into account the volatility of demand, and the risks to system security due to this. On the other hand, the customer will be involved in demand response. This will require innovative solutions such as automation of the system operation, sub-station digitalisation, and the use of optical or nanotechnologies etc.

Furthermore, a stronger interface between the distribution and transmission, between wholesale and retail markets needs to be enhanced.

Electricity grids must also be prepared to create synergies with other energy networks (gas, heat) and to adopt the transition towards sustainable transport through the deployment of electric vehicles, which requires the evolution of the battery sector and creation of efficient charging station networks.

All these elements suggest adopting a top-down approach to R&I activities. This approach has to be harmonised, as the present TSO initiatives are more oriented to short-term objectives (a bottom-up approach).

The priorities for R&I are driven both by energy/climate policies and power system overall trends on one side, and by shorter-term TSOs' needs, which fit with national R&I programs on the other side. Therefore, a balanced integration of top-down and bottom-up approaches is utilised for the prioritisation process.

STRUCTURE OF R&I PLANNED ACTIVITIES

In line with the overarching R&I framework set by the European Commission[1)], a challenge-based approach rather than the previous task-based one has been adopted for structuring the envisaged activities.

The format of clusters and functional objectives (FO) has been maintained, and the details are presented in Section "Structure of activities in clusters and functional objectives", p. 37; each FO is described in Appendix 1, p. 64. A brief description of each cluster is given in the table below, while the overview of the functional objectives is presented in Figure 1.

Clusters	Description
C1 **Power System Modernisation**	This cluster aims at developing an optimal grid design, based on the use of the most cost-effective technologies/solution, which should enable more flexibility (through the use of demand response, storage, or interface with other energy networks). It also looks at smart asset management models and methodologies, and the improvement of public awareness and acceptance.
C2 **Security and System Stability**	This cluster addresses the improvement of the observability and controllability of the transmission system. This will be carried out through the development of methods, technologies and tools able to handle, process and interchange measured and forecasted data in real time across TSOs but also with DSOs. Network modelling and dynamic security tools are part of this cluster. It aims at improving defence and restoration plans for the pan-European grid. The operation of the power system will be based on the development of new procedures, strategies and models for ancillary services coming from different sources: RES, DSOs, energy storage, etc.
C3 **Power System Flexibility**	This cluster supports the deployment of existing and new system flexibility options such as: » Storage solutions for fast-responding power (time dimension) and energy (less capacity needed) as well as for novel solutions for system services. Technical requirements, economic, market and environmental aspects must be evaluated. » Demand response encompassing the development of tools and specifications for the control of such resources. It will also address the integration of electric vehicles and the modelling of customer behaviour and quantify the degree of flexibility provided by the distribution networks. » ICT and enhanced RES forecast techniques would support the optimal capacity operation of the power system while maintaining the quality and security of the supply. » The enhanced use of the transmission assets.
C4 **Power System Economics & Efficiency**	This cluster aims to propose ways and means to facilitate interactions between the European electricity markets and the pan-European transmission system. The objective is to achieve a more efficient market with an optimised energy mix and security of supply through integration of market and grid operations. All time horizons are treated in this cluster. On the one hand, tools and methods will be proposed to enhance the optimisation of the energy flows at short-term horizons in the pan-European system, considering the intermittency generated by RES. On the other hand, the cluster aims to make proposals to coordinate investments in a context where the quality of the market prices to generate the correct signals for investment is regularly questioned.
C5 **ICT & Digitalisation of Power System**	This cluster aims at considering Big Data management through data-mining tools and the development of interfaces with neutral and transparent data access. The cluster will also consider recommendations for standardisation activities and protocols for communications and data exchanges, the use of new technologies such as the Internet of Things and cyber security issues. ICT is an enabling technology for managing the flexible energy system described in C3.

1) in Horizon 2020 Programme

Clusters	Functional Objectives	FO Comments
C1 Power System Modernisation	T 1 Optimal grid design	Optimal grid design: planning, adequacy, tools
	T 2 Smart Asset Management	Smart Asset Management; predictive and on-condition maintenance; capex optimisation
	T 3 New materials & technologies	Use of new materials and power technologies; new construction and maintenance methods
	T 4 Environmental challenges & stakeholders	Environmental impact, public acceptance, stakeholders participation
C2 Security and System Stability	T 5 Grid observability	Observability of the grid: PMUs, WAM, Sensors, DSO information exchange
	T 6 Grid controllability	Controllability of the grid: frequency and voltage stability, power quality, synthetic inertia
	T 7 Expert systems and tools	Decision support tools, automatic control and expert systems
	T 8 Reliability and resilience	Reliability and resilience: defense and restauration plans, probabilistic approach, risk assessment, self healing
	T 9 Enhanced ancillary services	Enhanced ancillary services for network operation; cross-border supply of services
C3 Power System Flexibility	T 10 Storage integration	Storage integration, definition and use of storage services; system added value from storage
	T 11 Demand Response	Demand Response, tools to use DSR; Load profile, EV impact
	T 12 RES forecast	Improved RES forecast and optimal capacity operation
	T 13 Flexible grid use	Flexible grid use: dynamic rating equipment, power electronic devices; use of interconnectors
	T 14 Interaction with non electrical energy networks	Interaction/coordination with other energy networks (gas, heat, transport)
C4 Power System Economics & Efficiency	T 15 Market – grid integration	Integration of market and grid operation across timeframes (up to real time)
	T 16 Business models	Business models (for storage, grid extension, distributed generation) for optimal investments in the network
	T 17 Flexible market design	Market design for adequacy, flexibility use, cross border exchanges, rationale use of RES, demand management
C5 ICT & Digitalisation of Power System	T 18 Big data	Big data, data mining, data management
	T 19 Standardisation & data exchange	Standardisation, protocols for communications and data exchange with DSOs and other grid operators
	T 20 Internet of Things	New communication technologies, Internet of Things
	T 21 Cybersecurity	Cybersecurity

Fig. 1: Description of Functional Objectives of ENTSO-E R&I Roadmap

WHERE WE ARE TODAY – ASSESSING RESULTS

This Roadmap includes also the monitoring and assessment of R&I efforts, (see Section "Where we are today", p. 44 and Appendix 3, p. 94) which covers the following perspectives:

- Monitoring Roadmap advancement i.e., if and how the clusters and FOs of the original Roadmap have been addressed by on-going projects (ENTSO-E Monitoring Report 2015);
- Assessing the results of recently completed projects and their application into TSO business (ENTSO-E Application Report 2014, including relevant national projects outside the EC funding perimeter);
- Impact analysis of a comprehensive set of significant projects, identifying their main achievements and recommended follow-ups (ad hoc ENTSO-E study performed by consultants with experience in research and innovation activities in power system);
- Overview of key performance indicators and indirect benefits for society at large.

FUNDING, RESOURCES AND REGULATORY FRAMEWORK

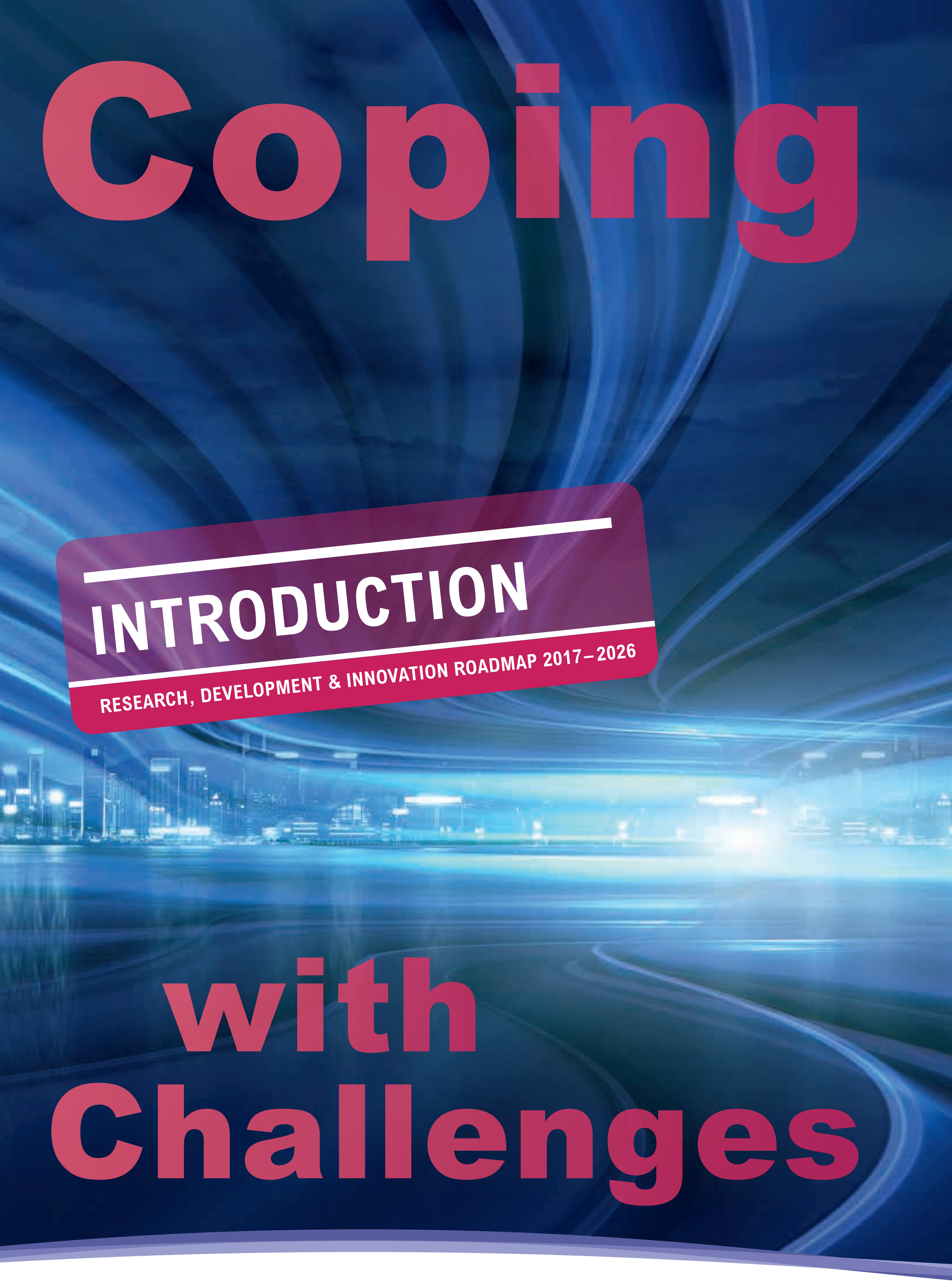
The investment costs for carrying out the objectives of this Roadmap are estimated to be approximately € 1 billion. While EC funding could cover part of the cost, strong support is required by self-financing or other funding instruments to implement the projects.

It is therefore important to strengthen European coordination on R&I management and knowledge sharing to maximise synergies and avoid redundancies. Moreover, EU funding programs are not addressing the multiplicity of short-term, lower-profile challenges and innovation needs that TSOs experience in daily operation of the system. A set of inter-TSO projects and more knowledge-sharing activities are envisaged, outside EC funding schemes, to maximise synergies, best-practice adoption and, ultimately, customer satisfaction.

Only a few EU countries currently account for R&I expenses explicitly in their allowed costs. The R&I costs are considered as operational expenses, and therefore recovered through an ordinary tariff structure subject to efficiency mechanisms; hence the incentive to reduce them. However, EC legislation stipulates that national regulatory authorities are responsible for ensuring that TSOs and DSOs are incentivised to support R&I expenditures. This gap must be properly addressed at European-wide legislative and regulatory levels.

Another opinion claims that research institutes and universities are more suited to perform R&I in all fields including power systems, and TSOs should instead focus only on integrating third-party solutions into the grid. This approach neglects the natural TSO independence and non-competitive core mission, which allows them to act for the system's best interest. Furthermore, TSOs are better equipped to setting R&I directions based on the needs stemming from their daily experience and early spotting of system macro-trends.

A proposal for a more enhanced and harmonised regulatory framework for R&I is presented in Appendix 4.



Coping with Challenges

INTRODUCTION

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

The ENTSO-E Research, Development and Innovation Roadmap (R&I Roadmap), targeted to decision-makers, policy experts and other stakeholders, defines the main research fields for power transmission in the coming decade. It strives to achieve all technical, economical and socially acceptable solutions needed to cope with the challenges facing the pan-European transmission system.

The basic processes used to govern this Roadmap are performed by ENTSO-E in close cooperation with relevant stakeholders. These processes are as follows:

» Designing and approving the ENTSO-E R&I Roadmap;

» Providing support to the EC when defining priorities and R&I programs;

» Fostering TSOs to pool efforts and resources to perform R&I projects, either with self-funding or under EC funding programs;

» Monitoring the achievements of R&I performed throughout the Roadmap;

» Disseminating the results throughout the stakeholder community and facilitating scale-up, replication and implementation of results by the entire ENTSO-E community.

R&I SCOPE AND DELIVERABLES IN ENTSO-E

ENTSO-E is bound by Regulation (EC) 714/2009, part of the third legislative energy package for the internal energy market, and by Directive EC/72/09 to adopt a document that provides a vision on R&I performed by the association and its member TSOs.

ENTSO-E is responsible for implementing the Integrated Strategic Energy Technology Plan (SET Plan)[1)] with the cooperation of European TSOs. This is in full compliance with Regulation (EC) 714/2009 wherein Article 8 §3 states "[…] the ENTSO for Electricity shall adopt: common network operation tools to ensure coordination of network operation in normal and emergency conditions, including a common incidents classification scale, and research plans." ENTSO-E is a key member of the SET Plan structures for R&I efforts for electricity grids and therefore contributes to achieving the objectives of the Integrated SET Plan.

In 2010, ENTSO-E published its first R&D Plan 2010[2)]. In December 2011, an updated version of the first edition of ENTSO-E's R&D Plan was released. The first ENTSO-E R&D Plan initiated a dialogue among European TSOs, European regulatory authorities (ACER), EU Member States and the European Commission. It was also written to serve the needs of TSOs in the first European Electricity Grid Initiative (EEGI) Roadmap, which was approved at the same time as the creation of EEGI in June 2010[3)].

In 2012, the first comprehensive **ENTSO-E R&D Roadmap 2013–2022** was elaborated and issued as the fundamental tool for planning and monitoring the R&I efforts in a coordinated manner among the European TSOs. The first edition of the Roadmap was to cover the decade 2013–2022; its first update was planned to be published in 2017.

However, owing to fast changes and developments of the EC policy framework, and for alignment with the process of the Integrated Roadmap (where ENTSO-E is involved together with other grid operators and stakeholders), the revision has been moved up to 2016.

The ENTSO-E Roadmap is the high-level and long-term planning tool for the necessary R&I activities to secure and maintain an appropriately high level of security of supply in the European electrical power system. The Roadmap builds on opportunities provided by technological trends, the needs of TSOs arising from the operation of the system and market evolution and input from EC and other external stakeholders. Identified gaps serve as a sound base on which to determine the R&I priorities, which, in turn, serve as inputs for the next edition of the Implementation Plan.

The ENTSO-E R&I Implementation Plan is published yearly and aimed at deploying a practical implementation strategy for R&I. With a clear focus on just a few prioritised topics per year, the Implementation Plan represents a crucial step in making innovations happen.

The Implementation Plan builds on the identified priorities and on the inputs received from external stakeholders during consultation phases; it also considers the opinion provided by ACER under its statu-

1) C(2015)61317 final

2) R&D Plan 2010: https://www.entsoe.eu/publications/research-and-development-reports/rd-roadmap/Pages/default.aspx

3) EEGI is one of the EIIs under the SET Plan. EEGI's mission is to create an adequate European grid (both transmission and distribution systems) to achieve the European energy policy goals.

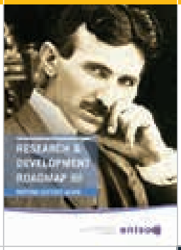
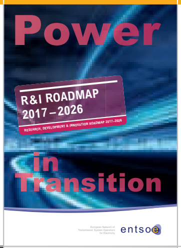
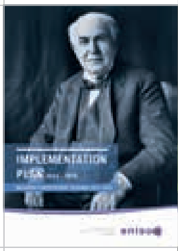
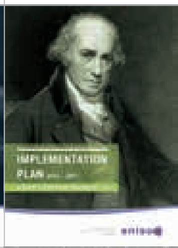
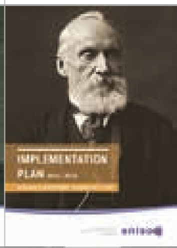
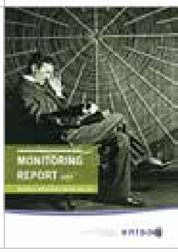
ENTSO-E R&D publications	2012	2013	2014	2015	2016	2017
Roadmap						
Implementation Plan					Upcoming end 2016	
Monitoring/ Application Report						

Fig. 2: ENTSO-E publications on R&I

tory consultation role. The identified R&I priorities are also suggested as inputs to the EC for developing their energy research agenda and funding schemes, such as the Horizon 2020 Energy Challenge. These priorities reflect the vision of TSOs (so-called "bottom-up" approach). The priority list is complemented with topics stemming from EC calls that envisage a wider perspective and reflect an energy system-integrated approach (so called "top-down" approach). In this way, the Implementation Plan is a mean for balancing these two approaches and harmonising the visions of different stakeholders.

Once topics and relevant projects have been defined, they are then articulated in a form of separate projects addressing specific R&I targets. The projects are performed by ad hoc consortia that pool resources from multiple TSOs and other partners. Realisation of R&I projects is then monitored during the lifetime of the projects and shortly after their completion.

In 2013, the first edition of the Implementation Plan according to the Roadmap overall objectives was published, referring to the period 2014–2016; since then, the Implementation Plan has been published annually and summarises R&I activities over a three-year period as stipulated in the Roadmap.

The ENTSO-E R&D Monitoring Report aims to monitor the progress in achieving the goals of the R&I Roadmap as well as to share the acquired knowledge with stakeholders and a wider audience about recent R&I work within ENTSO-E. This, in turn, enables the specifications for the next edition of the Implementation Plan and Roadmap to be designed, establishing an effective iterative procedure.

In 2015, following a suggestion from ACER, ENTSO-E changed the perspective of the Report into an **R&D Application Report** that assesses the results of EU-funded projects carried out by TSOs in terms of potential applications and their relevance for TSOs' daily operation.

An updated edition of the Monitoring Report was published in March 2016. Subsequently, both perspectives (monitoring and application) shall be utilised, in alternative years.

Figure 2 shows ENTSO-E publications issued so far on R&I subject.

PROCESS OVERVIEW

Figure 3 displays a diagram of the R&I framework development within ENTSO-E and elaboration of the relevant publications.

The overall scheme reveals the key link between the ENTSO-E R&I Roadmap and – on the one hand – the path the European transmission system should follow to meet the long-term EU energy policy goals and – on the other hand – the specific R&I projects paving the way for these objectives to be achieved.

The central feature of the overall process is monitoring, which is handled by dedicated processes at all three research levels: framework development, project creation and project realisation.

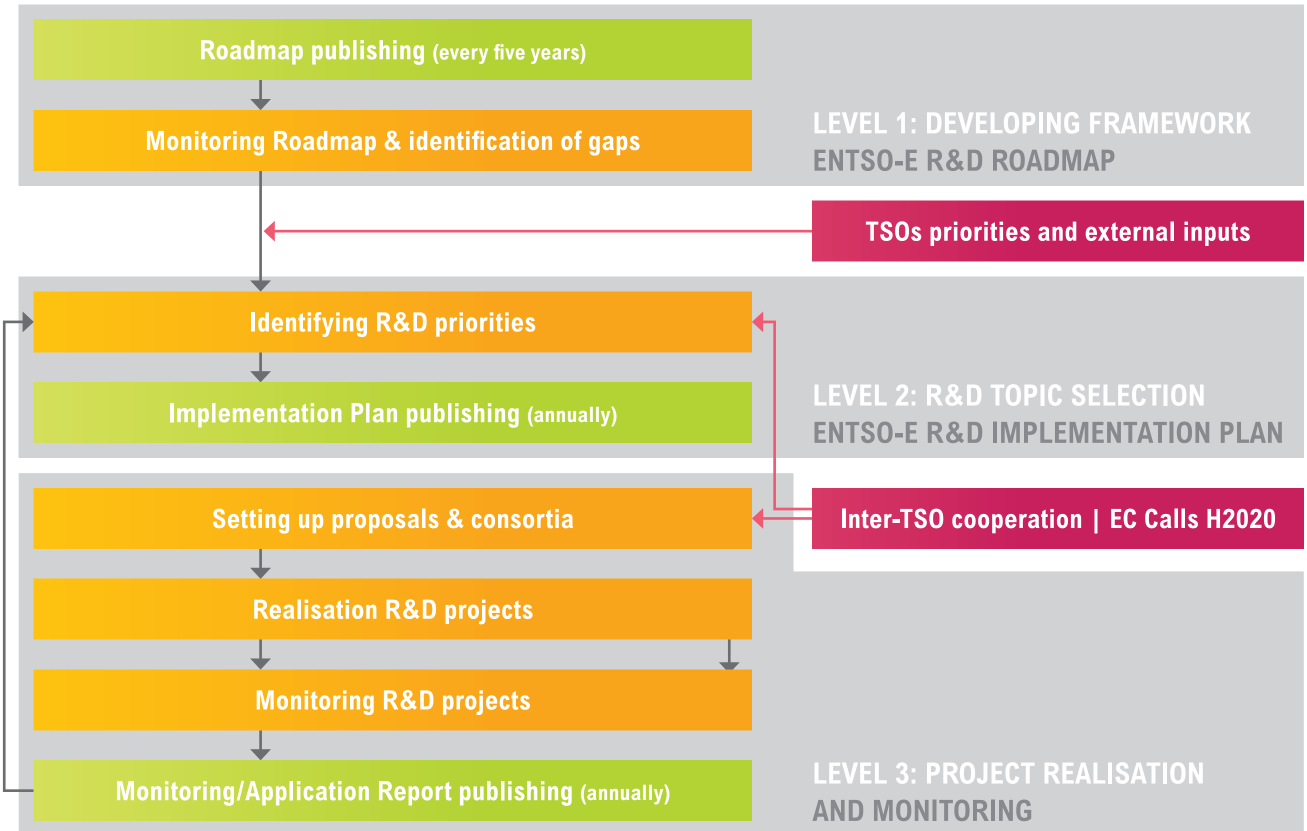


Fig. 3: ENTSO-E publications as the key link among R&I framework development, topic selection and project creation

INTERACTION WITH OTHER EUROPEAN MANDATES

This Roadmap complements the set of mandated deliverables of ENTSO-E: European network codes and the Ten-Year Network Development Plan (TYNDP), as shown in Figure 4.

Whereas TYNDPs concentrate on hardware issues (technologies and system solutions) and network codes on "software" (rule adaptations), this Roadmap encompasses hardware as well as "software" issues over a 10-year window. TYNDPs discuss technology that is mature and currently available. The network codes foster harmonisation and adoption of best practices in a pan-European perspective. Each of these mandates makes an important contribution on the way to achieving Europe's energy policy goals.

Regarding the role of ENTSO-E bodies, the Research, Development and Innovation Committee of ENTSO-E (RDIC) provides the central platform for R&I issues and interacts closely with the other committees (System Development Committee (SDC), System Operations Committee (SOC), Market Committee [MC]), and with the Board and the Assembly of ENTSO-E. All consultation and approval procedures are followed as described in the Articles of Association and Internal Regulations of ENTSO-E.

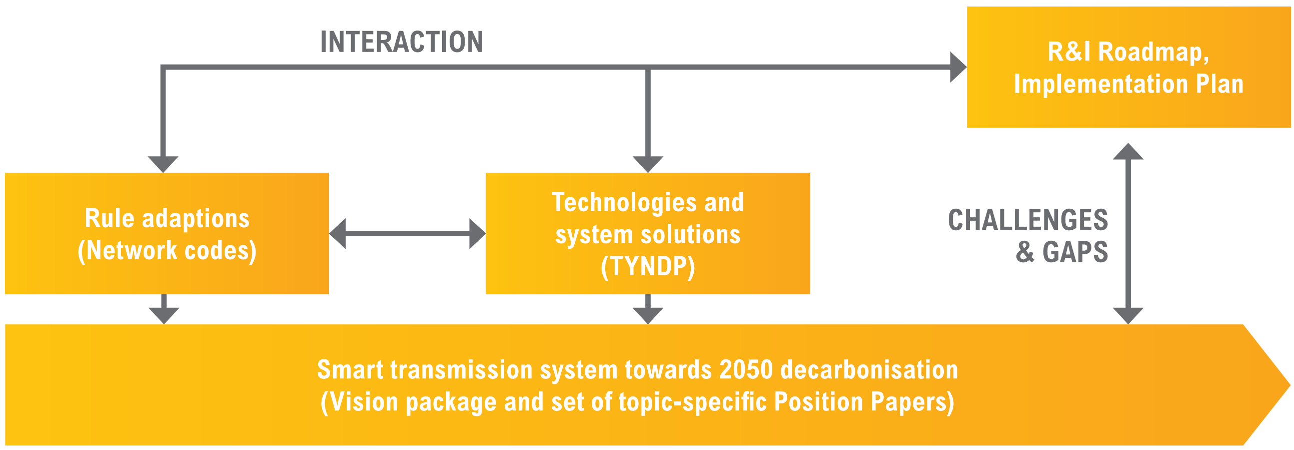


Fig. 4: Interaction between R&I Roadmap and other ENTSO-E mandates

ROADMAP UPDATE / REVISION

The process for updating and refining the ENTSO-E R&I Roadmap and Implementation Plan is presented in Figure 5.

Step 1 involves two parallel streams. In loop 1A (L1A), TSO R&I needs are first assessed and collected, involving all sectors of activities through the ENTSO-E dedicated committees. At the same time, loop 1B demonstrates how the various R&I projects are monitored so that they can determine whether there are any gaps in the topic coverage (gap analysis).

In step 2, represented by loop L2 in Figure 5, external stakeholders (e.g., associations, policy and regulatory authorities, other research and innovation platforms) are consulted to retrieve feedback and additional input on the ENTSO-E update proposals. External consultations for the ENTSO-E Roadmap and Implementation Plan have also been introduced to increase benchmarking, coordination and cross-fertilisation with the R&I planning instruments of other stakeholders. Finally, loop L3 is the formal internal approval process of the deliverables to be published for the general public.

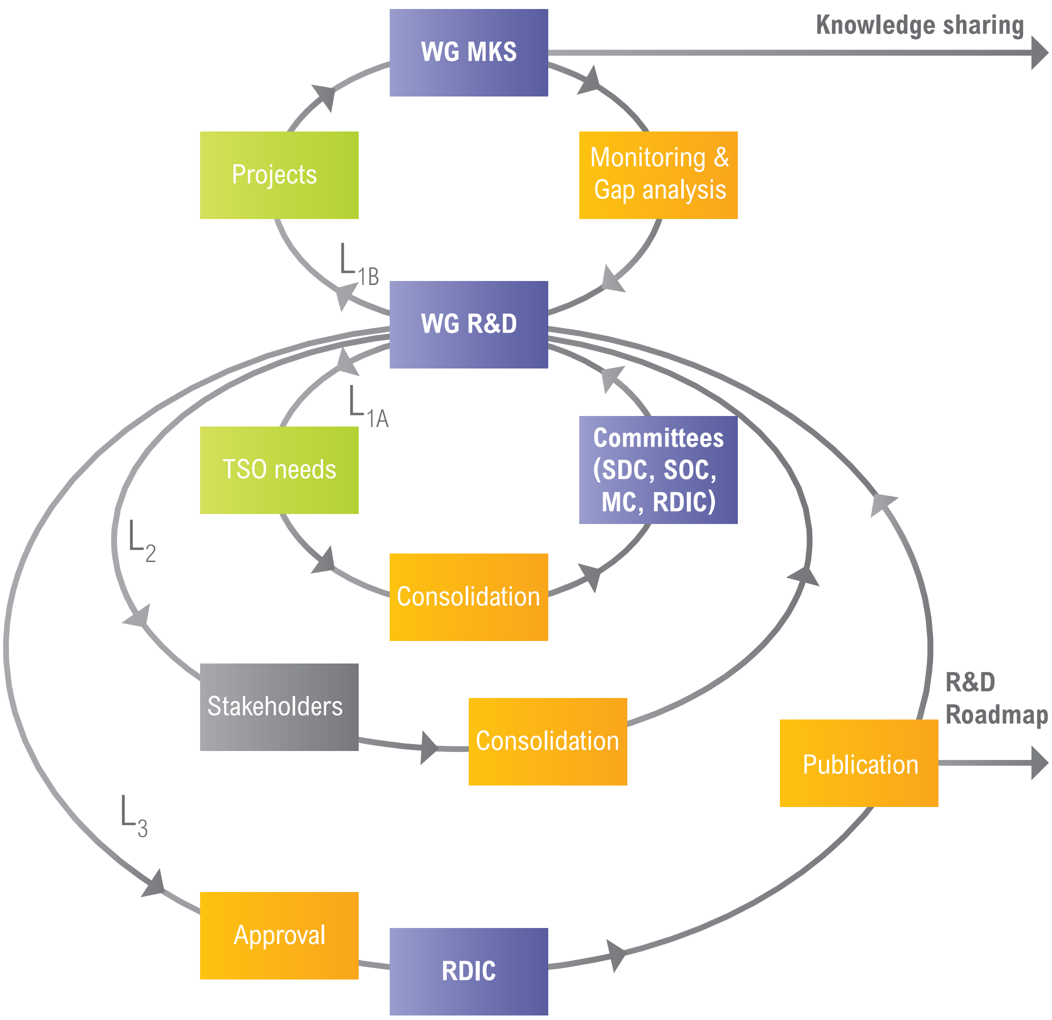


Fig. 5: ENTSO-E process for updating R&I Roadmap

CONSULTATION PROCESS OUTCOMES

Public consultations, both on this Roadmap and on all Implementation Plans issued since the first version of the R&D Roadmap, have resulted in valuable and detailed comments, which have been published, together with relevant replies, on the ENTSO-E website; most of the suggestions have been implemented or elaborated upon.

Some of the issues have also been extensively discussed and further inputs were received within the Grid+Storage support action – i.e., from its partner associations: EDSO for Smart Grids (DSOs), EASE (storage operators), plus some leading European research organisations and consultants.

As mandated by the EC set of rules, ACER provides its opinion on the ENTSO-E deliverables, addressing both the methodologies and the contents. Owing to ACER's broader picture of EU energy sectors, its opinion carries unique weight in shaping future editions of the deliverables. In this way, ACER underpins ENTSO-E in framing the R&I efforts from identification of needs to deployment of results, having a positive spill-over effect over all energy sectors.

ACER commends ENTSO-E's endeavour in establishing a non-discriminatory and efficient platform for R&I activities through the processes of public consultation, engagement of research community and addressing the broad spectrum of research areas, conveniently grouped in clusters, which is a solid ground for future R&I work.

Having drawn attention to the discrepancies between the EC Integrated Roadmap and the ENTSO-E R&I Roadmap, ACER expects ENTSO-E to identify and explain the main gaps and propose solutions to align these documents as much as possible.

ACER has solicited ENTSO-E to shed more light not only on the individual project execution and results publication but also on the level of deployment of the results of the recently finished projects as well as on their effect in achieving EU energy policy targets.

The details of consultation outcomes on the latest publications are reported in Appendix 2.

In

EVOLVING IN A CHANGING CONTEXT

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Motion

ENTSO-Es R&D Roadmap 2013–2022 was drafted considering the SET Plan, specifically in view of the EIIs. These initiatives were based on the three pillars of the EU Climate and Energy objectives: environmental sustainability, security of the energy supply and competitiveness, and on the three targets defined in the Climate and Energy Package[1]:

- 20 % cut in greenhouse gas (GHG) emissions (from 1990 levels)
- 20 % of EU energy from renewables
- 20 % improvement in energy efficiency.

1) http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

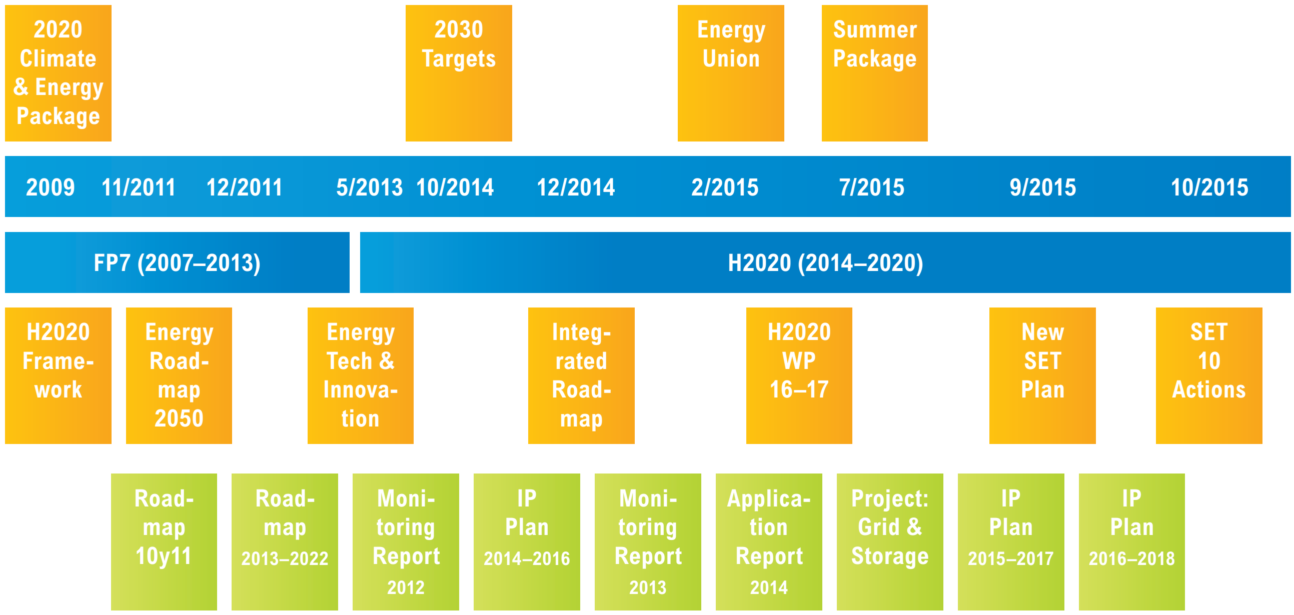


Fig. 6: Evolving Context and ENTSO-E Reaction

ENTSO-E and its member TSOs are at the core of these developments. The present R&I Roadmap is part of the process where ENTSO-E position itself in the changing context (Figure 6). This positioning is strategically determined by the expected evolution brought by the Energy Union in 2015 in the SET plan-related activities and by the framework conditions of the funding program Horizon 2020.

POLICY-RELATED ISSUES

2030 climate and energy policy targets [2)]

The concern about the climate and environment determines the need to establish demanding objectives for 2030 (Figure 7):

- » At least 40 % cuts in GHG emissions (from 1990 levels)
- » At least 27 % share for renewable energy
- » At least 27 % improvement in energy efficiency

Strengthened by the COP21 outcome, this framework helps drive progress towards a low-carbon economy and thus entails a huge effort from TSOs in R&I and in network reinforcement to cope with them.

2020	2030	2050
-20% GHG	≤ -40% GHG	≤ -85% GHG
20% RES	≥ 27% RES	≥ ?% RES
20% Energy Efficiency	≥ 27% Energy Efficiency	≥ ?% Energy Efficiency
10% Interconnections	15% Interconnections	?% Interconnections

Fig. 7: EU climate/energy targets

2) http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

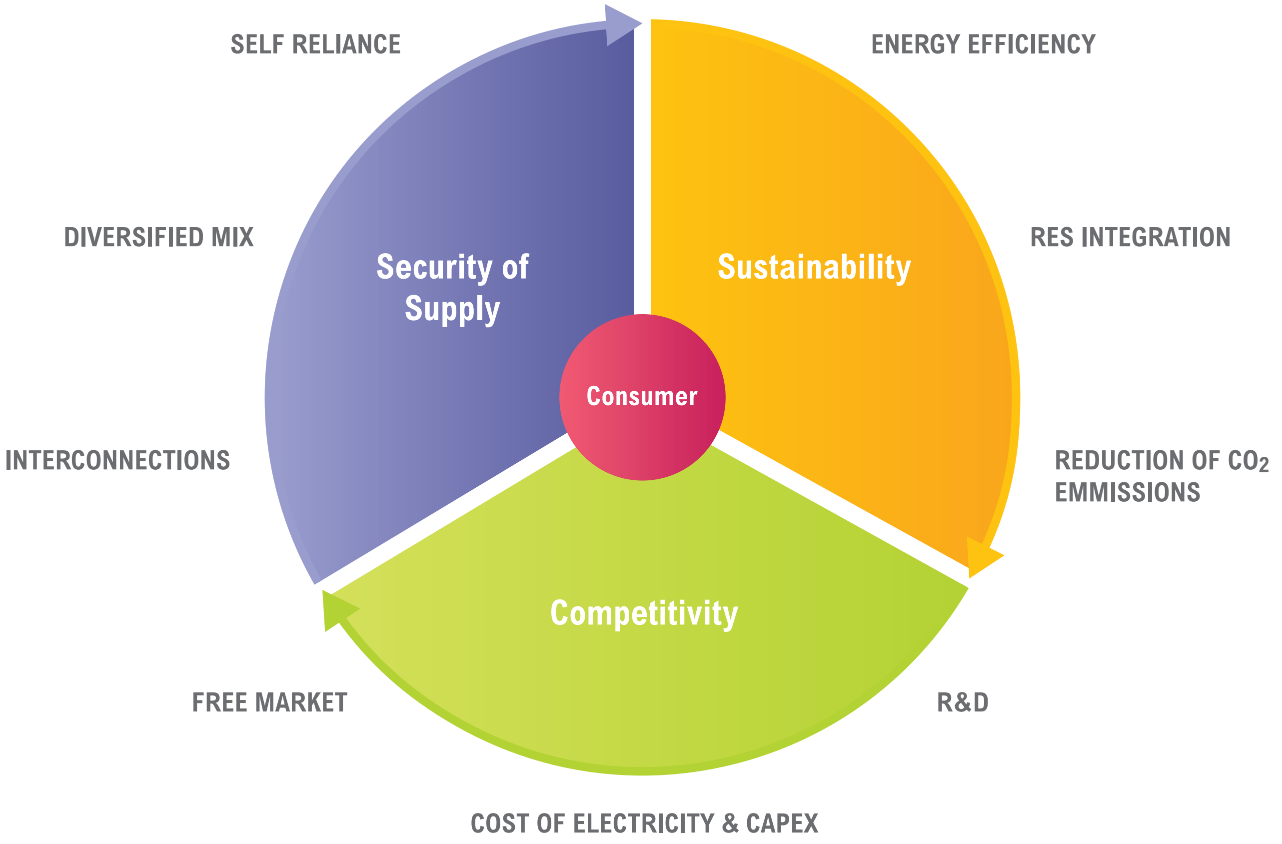


Fig. 8: Energy Union Focus

ENERGY UNION

In February 2015, the European Commission released the Communication on the Energy Union [3], which addresses the challenges and opportunities that the European Union encounters towards an energy system without GHG emissions. The five essential dimensions of the strategy to achieve these objectives are as follows:

» Energy security, solidarity and trust;
» A fully integrated European energy market;
» Energy efficiency contributing to moderation of demand;
» Decarbonising the economy, and
» Research, innovation and competitiveness.

Innovation and technology development become a cornerstone of the pathway to reduce fossil primary energy, diversify the energy sources and develop a flexible and integrated system, from generation to networks and demand, but also to transform the changes of the energy sector in an economical and industrial opportunity for Europe in the medium term.

3) COM(2015) 80 final

SUMMER PACKAGE

Five months after the adoption of the Energy Union Strategy, the Summer Package has been adopted with the aim of empowering the consumer to transform Europe's energy system. This proposal gives prominence to the "energy efficiency first" principle and put households and businesses consumers at the heart of the European energy market.

Figure 8 represents the holistic view of the approach of the European Commission to decarbonise the energy system, considering the main pillars circling the consumer at the centre of the holistic view.

SET PLAN-RELATED ISSUES

The challenges and R&I needs of the EU energy system are defined in the Integrated Roadmap[4] derived from the SET Plan. It is also in line with the longer-term perspective set out in the Roadmap for moving to a competitive low-carbon economy in 2050, the Energy Roadmap 2050.

Five key challenges have been defined:

1) The consideration of the consumer as an active participant of the system (which is at the centre)
2) The need to increase energy efficiency
3) The security of the system and its optimisation
4) The competitiveness
5) The integration of renewable energies

In this context, networks play a vital role in the challenge oriented to system optimisation, because they are the hardware that enables the integration of the generation and the demand resources, and in revealing that these are no longer two separate worlds; they are merging.

Key aspects affecting this roadmap are the following:

» The necessary modernisation of the network (to adapt to the rapidly changing environment and to establish synergies among different energy operators)
» The take-off of the storage and the conversion of the energy into different vectors
» The increasing necessity of system flexibility, also enabled by the demand response
» The security of supply and the affordability of the electricity services, the optimisation of the energy system at a local/urban level.[4]

PARADIGM SHIFT

It is now irrefutable that the European power system is in the middle of a deep transition period in which it will be radically transformed. Electricity is essential to our economy and way of life, and new stakeholders and market players are developing a wide range of opportunities for consumers.

The interaction and collaboration of TSOs and DSOs will be essential. This will imply strong coordination and the exchange of huge quantities of data.

The power of tomorrow is one of flexibility, hardware and software, neighbouring regions, and coexistence of centralised and decentralised power generation solutions. All of these trends will be accentuated further on, particularly with a huge amount of RES projected by 2030 and beyond.

The current policy scenarios set several megatrends in the electricity sector:

» Market integration
» Interconnections and electricity corridors
» Renewable integration
» Energy efficiency
» Consumer at the centre (active participation, self-consumption, electric vehicles, aggregation, etc.).

4) https://setis.ec.europa.eu/system/files/Towards%20an%20Integrated%20Roadmap_0.pdf
5) "Smart Cities and Communities"

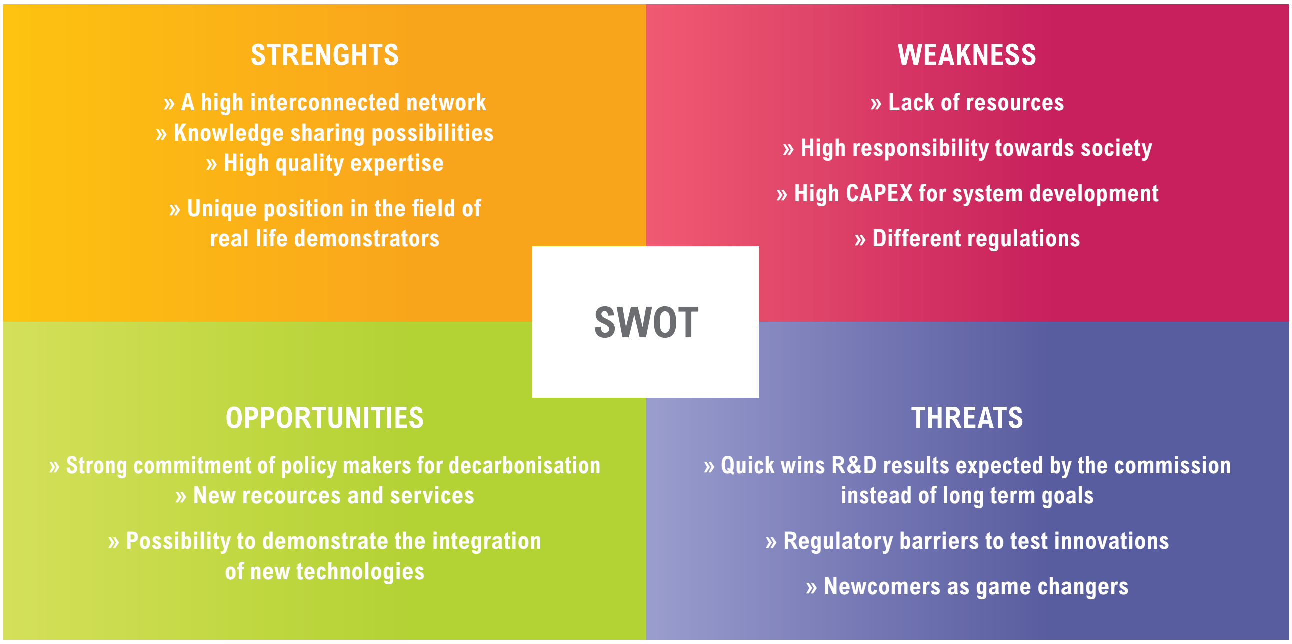


Fig. 9: SWOT analysis in a nutshell

SWOT ANALYSIS

To better frame the needs and leverage on existing strongholds, a SWOT (strengths, weaknesses, opportunities and threats) analysis has been performed on the R&I stance and contributions by the TSO community. The results are summarised in Figure 9.

ENTSO-E VISION AND POSITION PAPERS

ENTSO-E's 'Vision Package' is its response to the Energy Union Communication[6)]; it includes four Position Papers on an enhanced market design and innovation, on regional cooperation to complete the internal energy market, on better regulation for energy in the EU and on the interaction of security of supply and European markets

New stakeholders and market players get on board and develop a wide range of opportunities for consumers, who must be present in all markets. All of this puts network operators in a unique position while placing a high responsibility towards society on them because the energy transition requires their strong support. The members of ENTSO-E consider that strong European cooperation, with an important role for regions, is the basis for addressing the opportunities and challenges related to Europe's energy transition, which must be built upon innovation. The power system of tomorrow is one of flexibility, of the co-existence of centralised and decentralised power generation, of hardware and software, and of emerging regions. This Roadmap, together with the other ENTSO-E deliverables, is therefore one of the fundamental building blocks for effective fostering and management of the required innovation in the grids.

6) https://www.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/entsoe_vision01_web.pdf

Our Drivers

EUROPEAN R&I FRAMEWORK AND NEW ENTSO-E STRATEGY FOR R&I

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

EVOLUTION OF EUROPEAN R&I FRAMEWORK

The SET Plan evolved towards more integrated actions in which the development of individual technologies must be complemented and integrated into a wider system view, which becomes the new focus of the plan. Among the 10 actions identified by the Integrated SET Plan, Action 4, "Increase the resilience, security and smartness of energy system", should ensure that integration aspects are considered. Targets regarding the capacity of the power system to integrate considerable amounts of RES are set up. Priority actions on how to achieve a flexible system that will enable the integration of variable RES are identified.

Fig. 10: Drivers for updating the ENTSO-E R&I Roadmap

Horizon 2020 focuses its activities on the integration of the consumer and flexible means to allow more renewables into the power system. Data exchanges, synergies with other networks and with the different actors involved in the development of the power system, are relevant. A streamline of various research and innovation (R&I) roadmaps is being sought.

The Integrated SET Plan intends to streamline the process for addressing challenges and plans for R&I considering the integrated approach: The former SET Plan EIIs (EEGI for the electricity grid) and the European Technology Platforms have been replaced by the European Technology and Innovation Platform (ETIP). The main role of the new ETIP is to provide strategic advice to the EC and the SET Plan Steering Group based on consensus and to pool together different actors in the energy system.

At the same time, ENTSO-E, through its participation in a service contract project Grid+Storage, is already working with DSOs (represented by EDSO for Smart Grids) and the storage community (represented by EASE) towards more integrated solutions.

Figure 10 shows the R&I policy drivers and the internal changes in the R&I strategy, which are at the base of the revision of the Roadmap.

THE NEED FOR COORDINATED RESEARCH AND INNOVATION

The coordination of R&I efforts is of paramount added value to the Roadmap. Even in an increasingly enforced TSO cooperation within the ENTSO-E framework (as has already occurred for system operation, grid codes, electricity market rules, planning TYNDP), each TSO/regulator/country still has its own approach to R&I, and some TSOs do not carry out R&I at all. Therefore, cooperation, synergies, overlap avoidance, and common goals can be reached only with a strong, uniform and possibly joint approach to R&I activities.

The Roadmap is the main instrument for coordinating/harmonising R&I programs carried on by different actors and with different motivations; i. e.:

- public research, performed by public institutes/regulated actors and paid for by tariffs or financed by the governments,
- private industry research, which is concentrated in a few large manufacturing companies driven by commercial targets for selling equipment to electric utilities;
- utility research (generation, trading, marketing, consumer behaviour, demand responsiveness), focused on the demonstration/market uptake phase and often driven by short-term operational issues.

In particular, the public research needs coordination/governance both horizontally (among different TSOs) and vertically (among TSOs, DSOs and other actors).

REASONS FOR ENTRUSTING R&I TO ENTSO-E AND TO TSOs

TSOs are serving the society with security of supply, supporting the market and integrating sustainable energy sources. R&D enable TSOs to reduce their internal costs and optimise processes in a cost-effective way. In this light, TSOs are performing R&I for the benefit of their customers and stakeholders. The main reasons for strong involvement of the transmission operators' community in the R&I activities are as follows:

European energy system transforms fast

- There is an enhanced role for electricity network operators as integrators of different technologies (ICT, materials, power electronic).
- There is a growing need to coordinate all of these efforts to avoid overlaps and have a targeted approach to reach objectives with high priorities – i.e., to receive more value for the same cost of investment.

Strong pressure from stakeholders to consider innovative solutions in ENTSO-E products

- There is growing expectations from other sectors (generation, storage, distribution) but also developers of systemic approaches and models for additional involvement of TSOs in R&I projects, especially as providers of functionalities of the power system.
- All TSOs' activities and all ENTSO-E's deliverables require innovation as a continuous process: system operation and the implementation of network codes will need short-term innovation; planning paradigms, reflected in the periodic TYNDPs, must be more open to innovative solutions; the evolution of market design at the national and European level will also need to consider innovative solutions introduced by new players.

Potential new players – "game changers"

- The TSO community must be prepared to face game-changing modifications, such as new actors entering the power electricity market, and to define cooperation in activities with the ICT sector, to smarten the grids.

ENTSO-E establishes a strong presence in the European R&I landscape and is a focal point for knowledge sharing, coordination of innovation across TSOs' business domains and a voice in the European innovation structures, affecting the outcome of the activities carried out by the TSO community. The ENTSO-E vision is that the transmission grid, as the backbone of the power system, is the pivotal enabler to facilitate the transition to a low-carbon energy system. It is necessary that the grid be the natural area for field demonstrations to facilitate third parties' successful collaboration to innovate and bring benefits for the society at large.

NEW ENTSO-E STRATEGY FOR R&I

Horizon 2020 – the EU Framework Program for Research and Innovation 2014–2020 is focused on challenges to be faced, rather than on individual topics or sectors; this also opens up participation of numerous actors, thus increasing the level of competition and uncertainty over call outcomes. The consequence is a potential gap between TSOs' R&I priorities and EC funding policy, which could raise a risk that topics of interest for TSOs would not be properly covered in the calls.

For these reasons, a strategic repositioning of R&I policy within ENTSO-E has been decided and enacted.

On the one hand, ENTSO-E is involved in **EC-driven research projects**. This is the first pillar giving ENTSO-E a central aggregation and coordination role, as statutorily mandated. Under this pattern, ENTSO-E has intensified the interactions and formal collaborations with associations of DSOs, of storage operators and of research institutes (such as EDSO4SG, EASE, EERA) in the spirit of the integrated approach advocated by EC. Thus, this first pillar will continue to abide by the following principles:

» Contribute to shape the European energy policy: identifying, fostering and leveraging on the European added value of the projects;
» Define and adopt criteria for topic prioritisation and develop projects with a cross-cutting character (system and market operation, grid planning, system development, network code enactment);
» Establish an ENTSO-E policy to support projects proposed by other stakeholders.

On the other hand, there are also projects that are large enough to overcome the national level and that can be more quickly started and efficiently managed by the TSO community. This self-initiated inter-TSO cooperation will optimise the use of available resources through better coordination among national, regional and European structures as a second pillar, which will also focus on the following elements:

» Build an R&I knowledge and experience sharing platform to spread best R&I practices among the TSOs
» Disseminate national project result outside the framework provided by EC
» Establishing a database on projects and their state of completion.

The primary aim of the second pillar is therefore to create more value for TSOs by building projects in a lighter framework than that provided by EC and on topics not addressed (or not timely enough) by EC calls.

The ENTSO-E R&I strategy scope is to accomplish the following:

» Ensure system view: develop and move towards a system view in which services such as flexibility or data handling structures will emerge, requiring very close cooperation across TSOs and across TSOs and DSOs. R&I is a key component for the operation and development of the pan-European energy system aiming at integrating new technologies, innovative solutions and new actors in the short term (e. g., facilitate the implementation of the network codes) and long term (e. g., planning, new grid architectures that maximise social welfare at the European level).
» Ensure that the three dimensions of innovation (technology, process and business model innovation) are all addressed. Ensure that R&I activities lead to implementation of the Smart Systems concept. Consider technology readiness levels (TRL) when defining project and system requirements.

The setup of commonly agreed-upon interfaces between the new actors and network operators as well as the development of new business models would facilitate tapping into the unused potential to ensure the present and future energy system needs cost-effectively.

» Cooperate with regulators and DSOs, and advocate for a fit-for-purpose regulatory scheme supportive of innovation in networks, which sends the right signals to underpin innovation activities at the TSO level and to free the necessary level of expertise and resources of the system operators.

COOPERATION ASPECTS

No single TSO will be able to conquer the many challenges facing the electricity industry. To succeed, TSOs must work together and collaborate with universities, research institutes, DSOs, generation companies, consumers and industrial manufacturers. Through close cooperation and cost-sharing, Europe's TSOs can achieve their R&I goals and maximise results, as illustrated in Figure 11. Knowledge can be quickly disseminated and shared among stakeholders and interested parties.

Full-scale demonstrations of R&I projects must be coordinated across Europe. This drastically reduces demonstration costs and stimulates further R&I. The proposed ENTSO-E R&I strategy encompasses the following cooperation aspects:

» Facilitation of **inter-TSO cooperation** and promotion of TSO R&I activities by giving advice (e.g., projects using a lean approach are easier to handle). The introduction of inter-TSO cooperation will contribute to address TSOs' challenges not covered by EU funding schemes. The inter-TSO cooperation will be oriented to deliver short-term results and maximise the added value. If needed, it would also enable building consortia with third parties and securing funding for issues close to the TSO core business (e.g., topics pertaining to network code implementation, assets, SCADA, control).

» **Driving role regarding interactions with other players and actors** (universities, research institutes, DSOs, storage, equipment manufacturers) from the early stage to ensure that the system perspective, integration aspects, and interfaces are effectively considered

» Ensuring appropriate **input to standardisation** organisations aiming at adequate and interoperable standards.

» **Efficiently accessing international R&I organisations** such as IEA, IEEE, JRC or CIGRÉ for mutual learning from R&I results.

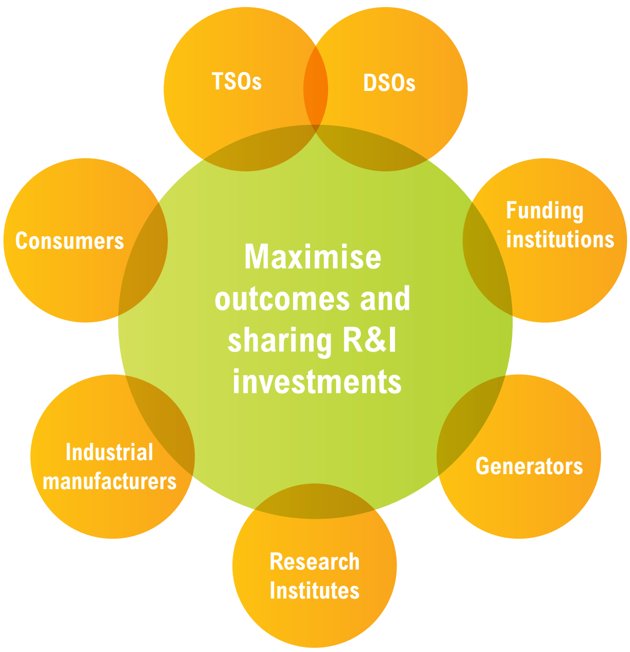


Fig. 11: Maximisation of benefits, sharing of investments and duplication avoidance as a result of collaborative R&I activities

At the Core

IDENTIFICATION AND STRUCTURE OF R&I ACTIVITIES

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

The priority for R&I activities is driven by the transformation of the power system as well as by evolving policy goals. At the same time, TSOs express their needs, which encompass a variety of issues and challenges in the shorter or long term depending on their R&I strategy and cooperation with other stakeholders.

The R&I activities proposed in this Roadmap had to take into account policy developments, ENTSO-E's R&I strategy, and the needs of TSOs.

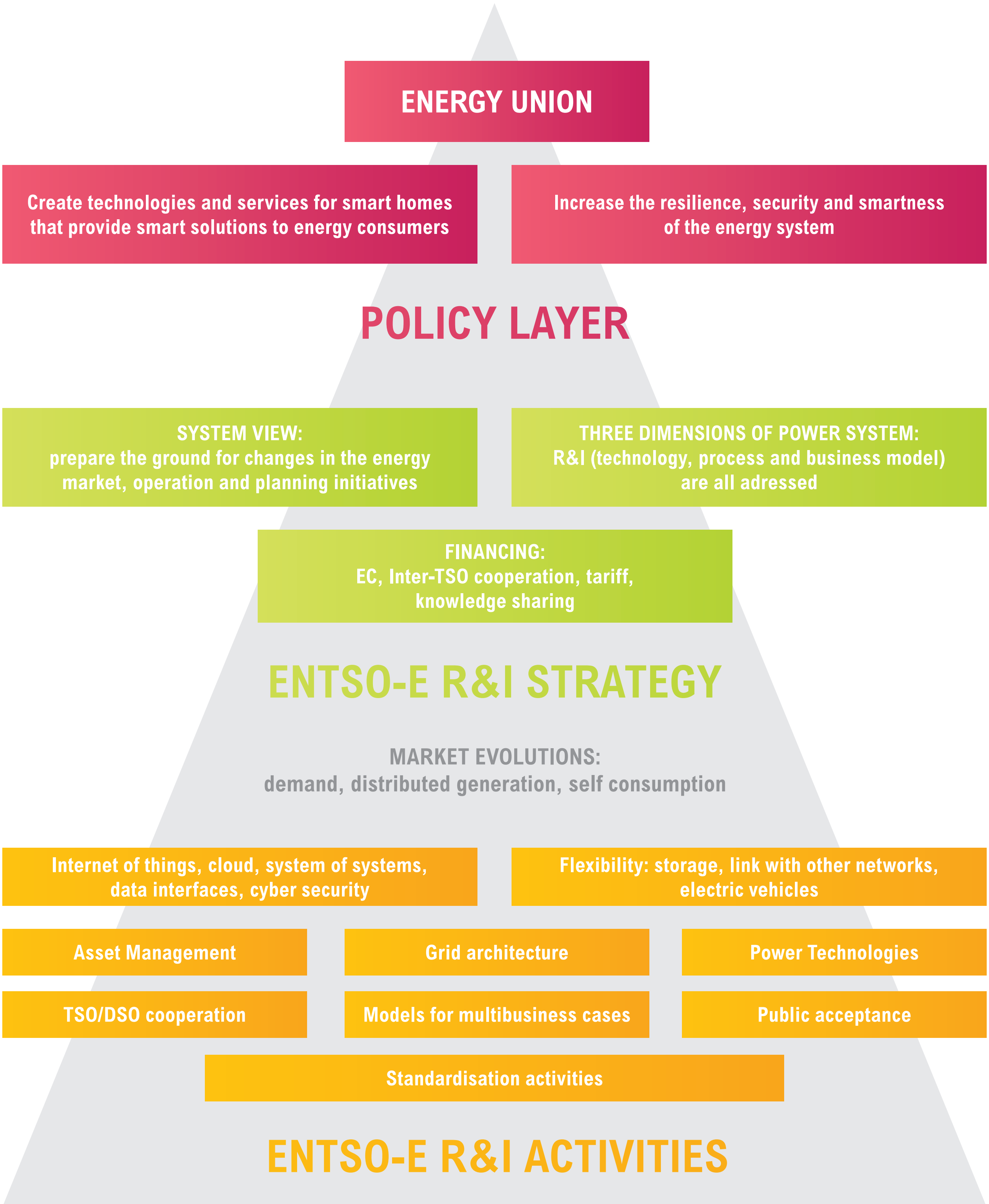


Fig. 12: Changed conditions and ENTSO-E reactions

CHANGED FRAMEWORK: REACTION FROM TSO COMMUNITY

In reaction to the evolving context, ENTSO-E has adopted the approach to consider its R&I activities by using a framework through which it will not only answer the TSOs' needs but also address both stakeholder's requirements and policy challenges.

The increased use of variable RES, the digitalisation of the power system and the cyber security issues related to these developments, the more active participation of the customer in the energy market are new challenges to which the power system answers by investing in R&I activities clustered around:

- **Flexibility:** The sources of flexibility are multiple and sometimes competing. Some of them were considered in the previous Roadmap including demand side response and electricity networks themselves. The evolutions in other sectors such as batteries brought new solutions/challenges into the power system and the necessity to enlarge the spectrum of options contributing to system services. The interactions with other energy carriers might also become an option in itself.
- **Digitalisation of the power system:** The developments brought by the ICT sector to the whole society and economy will impact the power system as well. The move from a "copper-based power system" to a system that integrates more extensively the ICT, data management and data hubs and considers cyber-security issues is paramount. These new developments should be considered and even integrated completely into research activities of the power systems – hence the need for defining complete new activities that were not considered in Roadmap 2013–2022 regarding the digitalisation of the power system.
- **Maintaining security and system stability:** Many achievements and advancements were registered in Roadmap 2013–2022, such as in the cluster related to planning: Grid architecture, through the projects carried out. On the other hand, new issues and new technologies must be considered, so the aspects related to, for example, the grid architecture could be seen from the perspective of solving a challenge such as the flexibility or modernisation of the grid. Important achievements have been made in power technologies or network operation clusters according to Roadmap 2013–2022. However, there is a need to continue to work on the use of new materials or tools and algorithms that will process increasingly more information to to address security and system stability.
- **Economic efficiency of the power system:** Regarding the market issues faced by TSOs, half the activities proposed in Roadmap 2013–2020 were carried out, but new issues such as Web-based applications, new business models for distributed flexibility, storage, etc., bring new options for acquiring various services in a more cost-effective manner and therefore result in.

IDENTIFICATION OF AREAS OF ACTIVITIES

In the Roadmap 2013–2022, ENTSO-E clarified the priority criteria governing the choice of projects and topics. These criteria were developed from the perspective of the integration of different technologies in the European electrical system. Indeed, the mission of the TSO does not consist in evaluating one single technology but rather in ensuring that the deployment of various technologies in the electricity system is accomplished in the most effective and beneficial way.

In the past two years (2014–2015), the primary objective of ENTSO-E and TSOs was the modernisation of the European electricity grid fostering R&I in areas such as integration of power technologies, demand side response, and operations.

The main objective for the period 2016–2017 is to begin to address the issues regarding the transformation of the European energy system into an integrated one. Strong emphasis will be put on the integration of storage, on the use of ICT to integrate different technologies and on market services. At the same time, links among electricity, gas and heat networks must be identified, modelled and used. These links will increase flexibility, solidarity and sustainability of supply and will also allow further penetration of RES.

The idea of active participation of the consumer in this energy transition translates into building smart grids – more specifically, building smart cities integrating smart meters, highly sophisticated home automation systems and home appliances achieving demand-response. The end user will be able to control through smart appliances his/her own consumption via cell phone or tablet or through aggregators and, as such, shape electricity prices (portfolio management and optimisation).

To address consumers' active participation, new challenges must be considered. One challenge is the integration of ICT technologies into energy power systems. Big Data, post-processing and security of data are required not only for inter-TSO cooperation but also for the creation of knowledge sharing platforms. Collection, storage and backup of data are of crucial importance for knowledge management.

The road towards Energy Union requires smart grids with advanced flexibility and storage capabilities. The challenge is the implementation of innovative solutions – for example, substation digitisation, thus eliminating copper hardwiring for control, efficient management of inter-substation automation, etc.

To accomplish energy efficiency, the advent and implementation of new advanced materials and technologies is a prerequisite. Fault analysis and location, dynamic line rating, power cable investigation, advanced monitoring techniques for power transformers, the use of optical or nanotechnologies instead of conventional CTs, low-power VTs, and digital breakers are just some of the examples that challenge power systems.

At the same time, the power system must be secure and safe through better controllability (faster, more accurate response, reactive power control).

Electricity grids must be also prepared to embed the transition to sustainable transport. This is twofold; the first regards the deployment of electric vehicles, which in turn requires the evolution of the battery sector and the creation of efficient charging station networks.

STRUCTURE OF ACTIVITIES IN CLUSTERS AND FUNCTIONAL OBJECTIVES

ENTSO-E's R&D Roadmap 2013–2022 and the previous editions of the Implementation Plans were, in essence, built via the bottom-up approach, based on TSOs' spontaneous indications of research topics. This approach shaped a sectorial structure of the Roadmap, which is manifested in clusters of different R&I areas and subdivided in FOs.

As shown in the previous section, the changes in policy and the developments in other sectors are drivers for the developments and the proposal for ENTSO-E's R&I activities.

Moreover, ambitious scenarios for RES development by 2030 and 2050 for R&I activities are at the basis of the development of new clusters/FOs. These developments will require more flexibility and more dynamic operation of TSO businesses.

The key drivers for the structural changes in the R&I Roadmap are thus directed to addressing the challenges to an integrative approach and to system needs, as shown in Figure 13.

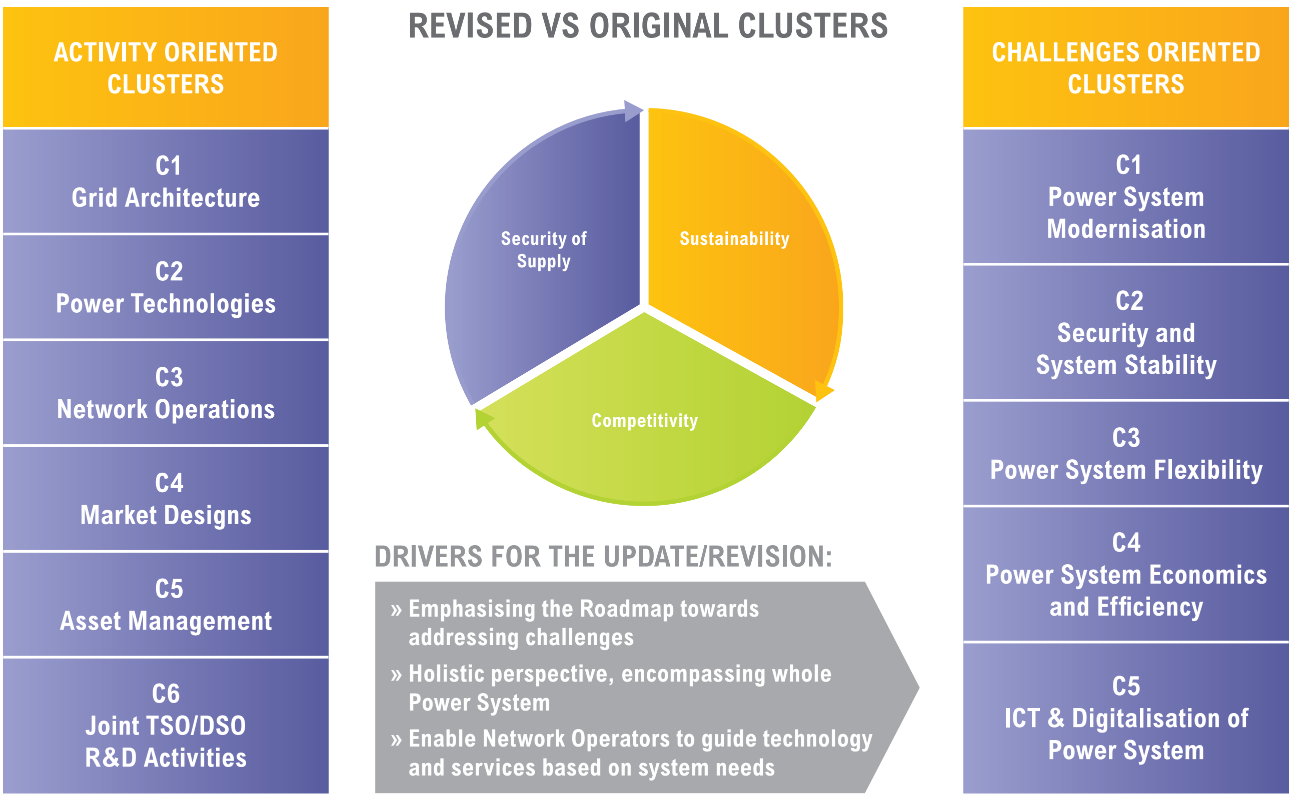


Fig. 13: Main drivers for the revision of ENTSO-E R&I Roadmap structure

The correspondence between the clusters of the previous Roadmap and the clusters of the new ENTSO-E R&I Roadmap (2017–2026) is presented in Figure 14:

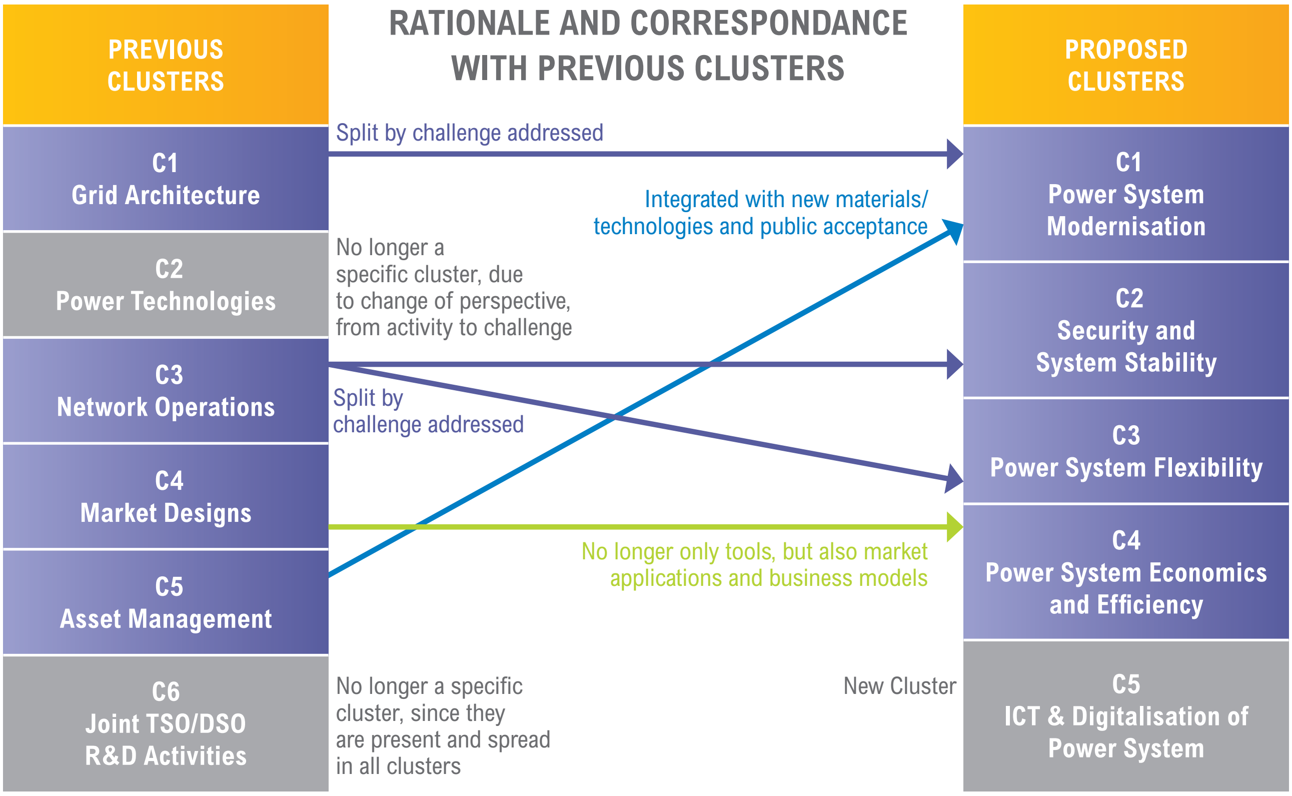


Fig. 14: Correspondence between the previous and the new Roadmap clusters

» CLUSTERS/CHALLENGES

The proposed clusters are expected to deliver the following outcomes:

Clusters	Expected Outcomes
C1 **Power System Modernisation**	This cluster aims at developing an **optimal grid design** based on the use of the most cost effective technologies/ solutions that should enable more flexibility (through the use of demand response, storage, interface with other energy networks). It should also aim at maintaining a **robust and cost-effective infrastructure** by making use of new technologies and tools. These include the use of **new power technologies** such as superconductors but also identifying requirements for the **development of new materials**. It also looks at **smart asset management models** and methodologies and the improvement of **public awareness and acceptance**.
C2 **Security and System Stability**	This cluster addresses the improvement of the **observability** of the transmission system. This will be carried out through the development of methods, technologies and tools able to handle, process and interchange measured and forecasted data in real time across TSOs but also with DSOs. It also addresses issues regarding the **controllability** of the power system through the development of dynamic system security models and tools enabling the TSOs to operate the system near stability margin but without jeopardising its security. This is accomplished by developing expert system and decision-making support tools that anticipate potential critical situations and provide TSOs with solutions with estimated probability of success rate in real time. It aims at improving **defence and restoration plans** for the pan-European grid by using a system approach. This will include the use of various sources including DER for system restoration, the investigation of the impact of micro-grids and the use of tools based on a probabilistic approach to enable the economic operation of the system. The operation of the power system should also be based on the development of new procedures, strategies and models for **ancillary services** coming from different sources: RES, DSR, energy storage etc.
C3 **Power System Flexibility**	This cluster supports the deployment of existing and new system flexibility options such as for example: » **Storage solutions** are an option for fast-responding power (time dimension) and energy (less capacity needed) as well as for novel solutions for ancillary services. Availability and distribution of energy storage will become important for development of a resilient transmission system. Energy storage comprises development of mature technology such as hydropower but also novel solutions (e. g., batteries, fly wheels, power to gas etc.) Storage availability in terms of functionalities/requirements for operation as well as for planning purposes should be considered. Technical requirement, economic, market and environmental aspects must be evaluated. » **Demand response** encompasses the development of tools and specifications for post- and direct feedback (real-time) consumption to achieve a significant reduction in peak demand. It will also address the integration of electric vehicles and the modelling of customer behaviour and quantify the degree of flexibility provided by the distribution networks. » ICT and **enhanced RES forecast** techniques will support the optimal capacity operation of the power system while maintaining the quality and security of the supply. » The **electricity grid** itself can become **a source of flexibility** though the increased use off cross-border exchanges or power flow control devices for the use of new methodologies that increase the use of transmission capacity in a cost-effective manner.
C4 **Power System Economics & Efficiency**	This cluster aims to propose ways and means to facilitate interactions between the European electricity markets and the pan-European transmission system. The objective is to achieve a more efficient market with an optimised energy mix and security of supply **through integration of market and grid operations**. All time horizons are treated in this cluster. On the one hand, tools and methods will be proposed to enhance the **optimisation of the energy flows** at short-term horizons in the pan-European system, considering the intermittency generated by RES. On the other hand, the cluster aims to make proposals to **coordinate investments** in a context where the quality of the market prices to generate the correct signals for investment is regularly questioned.
C5 **ICT & Digitalisation of Power System**	This cluster aims at considering **Big Data** management through data-mining tools and development of interfaces with neutral and transparent data access. The cluster will also consider recommendations for standardisation activities and protocols for communications and data exchanges, the use of new technologies such as the Internet of Things and cyber security issues. ICT is an enabling technology for managing the flexible energy system described in C3.

The exhaustive list of FOs is given in Figure 15, which offers more details regarding the types of activities to be carried out in each cluster.

Clusters	Functional Objectives	FO Comments
C1 Power System Modernisation	T 1 Optimal grid design	Optimal grid design: planning, adequacy, tools
	T 2 Smart Asset Management	Smart Asset Management; predictive and on-condition maintenance; capex optmisation
	T 3 New materials & technologies	Use of new materials and power technologies; new construction and maintenenance methods
	T 4 Environmental challenges & stakeholders	Environmental impact, public acceptance, stakeholders participation
C2 Security and System Stability	T 5 Grid observability	Observability of the grid: PMUs, WAM, Sensors, DSO information exchange
	T 6 Grid controllability	Controllability of the grid: frequency and voltage stability, power quality, synthetic inertia
	T 7 Expert systems and tools	Decision support tools, automatic control and expert systems
	T 8 Reliability and resilience	Reliability and resilience: defense and restauration plans, probabilistic approach, risk assessment, self healing
	T 9 Enhanced ancillary services	Enhanced ancillary services for network operation; cross-border supply of services
C3 Power System Flexibility	T 10 Storage integration	Storage integration, definition and use of storage services; system added value from storage
	T 11 Demand Response	Demand Response, tools to use DSR; Load profile, EV impact
	T 12 RES forecast	Improved RES forecast and optimal capacity operation
	T 13 Flexible grid use	Flexible grid use: dynamic rating equipment, power electronic devices; use of interconnectors
	T 14 Interaction with non electrical energy networks	Interaction/coordination with other energy networks (gas, heat, transport)
C4 Power System Economics & Efficiency	T 15 Market – grid integration	Integration of market and grid operation across timeframes (up to real time)
	T 16 Business models	Business models (for storage, grid extension, distributed generation) for optimal investments in the network
	T 17 Flexible market design	Market design for adequacy, flexibility use, cross border exchanges, rationale use of RES, demand management
C5 ICT & Digitalisation of Power System	T 18 Big data	Big data, data mining, data management
	T 19 Standardisation & data exchange	Standardisation, protocols for communications and data exchange with DSOs and other grid operators
	T 20 Internet of Things	New communication technologies, Internet of Things
	T 21 Cybersecurity	Cybersecurity

Fig. 15: ENTSO-E R&I Roadmap clusters and FOs

The clusters and FOs are greatly interdependent, so each cluster/FO addresses at least one task or duty that is immanent to all TSOs: **Network Operation, Asset Management, Network Planning, Market**, or duties stemming from **Societal & Stakeholder** needs. Likewise, each task or duty of a TSO will be addressed by more than one cluster.

This cross-correlation can suitably be represented in the form of a two-dimensional mapping matrix, as shown in Figure 16.

TSO mission & duties	CHALLENGES – macro trends external driven				
	C1 Modernisation	C2 Security	C3 Flexibility	C4 Economics	C5 ICT
OPERATION		T5 T6 T7 T8 T9	T10 T11		T18
ASSET MANAGEMENT	T2 T3		T13		T21
PLANNING	T1		T12		
MARKET ENACTING				T15 T17	T20
SOCIETAL & GRID STAKEHOLDERS DUTIES	T4		T14	T16	T19

Fig. 16: Two-dimensional matrix mapping the cluster topics and TSO duties

The customer is specifically considered into R&I activities of this Roadmap. As such, some functional objectives are oriented towards the customers as presented in Figure 17.

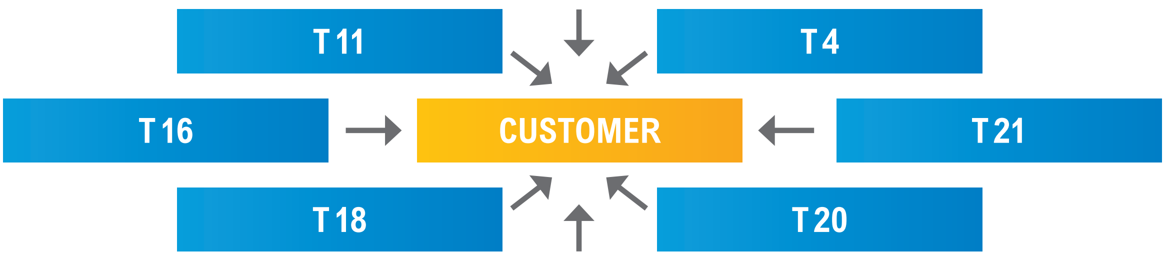


Fig. 17: Customer in the Functional Objectives of the Roadmap

A global estimation of time-scale to address the various FOs is given in Figure 18; however, it must be clear that this timing, as well as the order in the list of clusters and in the list of the FOs, does not imply a prioritisation among them. The prioritisation process shall indeed be deployed in the yearly Implementation Plans where more detailed topics and concrete projects are identified, merging this top-down process with a bottom-up approach taking into account also resources allocation options, both in terms of TSOs needs and innovation programs, and in terms of EU funding policies (Horizon2020 and subsequent programs).

The prioritisation process and the Roadmap actual deployment will therefore consider all the following criteria:

» TSO needs and own R&I projects

» Resources allocation priorities (EU and national calls on specific topics)

» Gap analysis vs. Roadmap advancements

» Innovation level and feasibility

» Technology Readiness Levels

» Economic value added

» European value added.

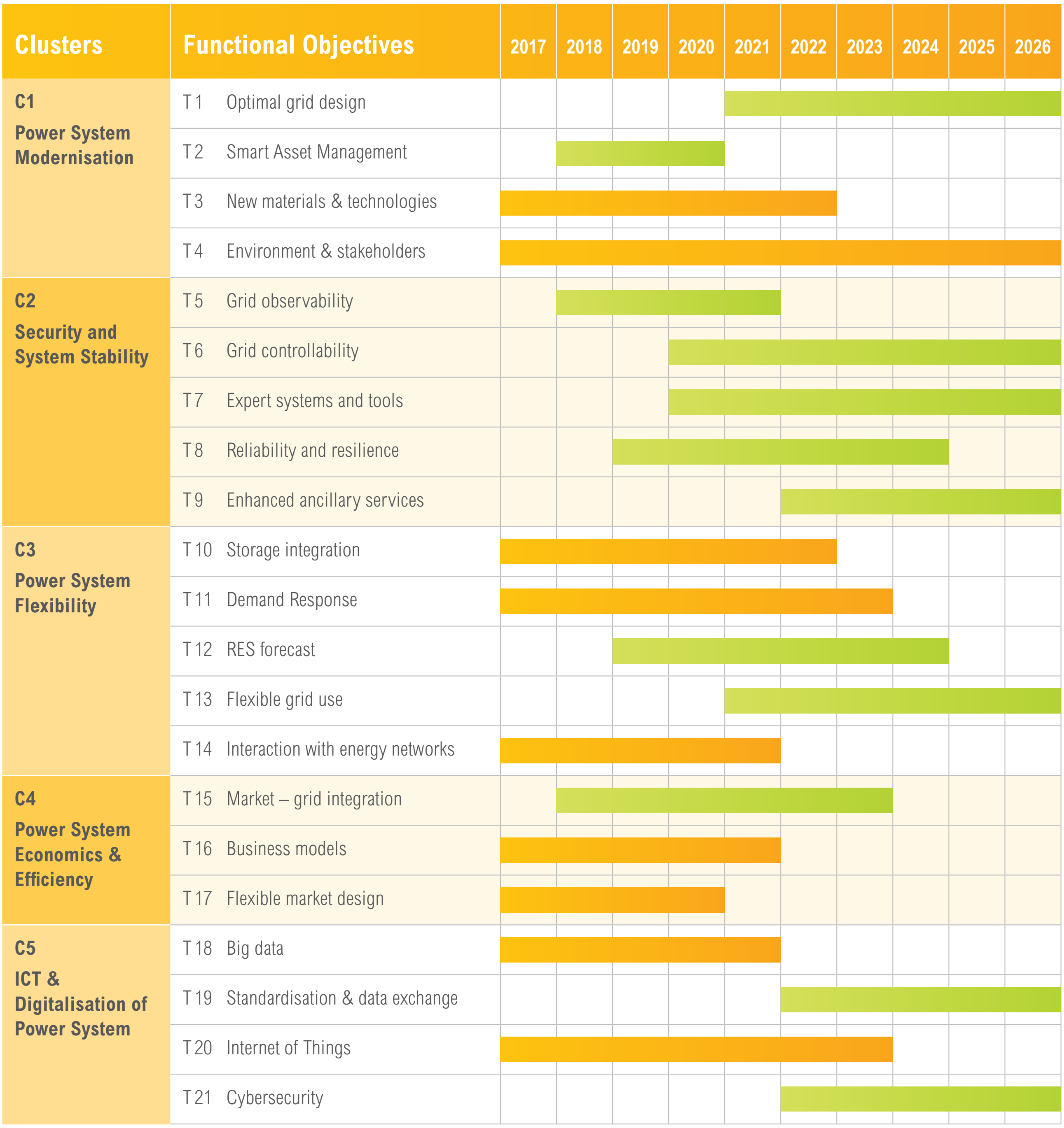


Fig. 18: Overview of timetable of clusters and FOs (brown blocks refer to Horizon 2020 already known indications)

State of Affairs

WHERE WE ARE TODAY

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Figure 19 shows the structure of the previous ENTSO-E R&D Roadmap 2013–2022. It comprises the following clusters and FOs:

Clusters	Functional Objectives	
C1 Grid Architecture	T 1	Definition of scenarios for pan-European network expansion
	T2	Planning methodology for future pan-European system
	T 14	Towards increasing public acceptance of transmission infrastructure
C2 Power Technologies	T 3	Demonstration of power technology to increase network flexibility and operation means
	T 4	Demonstration of novel network architectures
	T 5	Interfaces for large-scale demonstration of renewable integration
C3 Network Operation	T 6	Innovative tools and methods to observe and control the pan-European network
	T 7	Innovative tools and methods for coordinated operation with stability margin evaluation
	T 8	Improved training tools and methods to ensure better coordination at the regional and pan-European levels
	T 9	Innovative tools and approaches for pan-European network reliability assessment
C4 Market Designs	T 10	Advanced pan-European market tools for ancillary services and balancing, including active demand management
	T 11	Advanced tools for capacity allocation and congestion management
	T 12	Tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation
C5 Asset Management	T 15	Developing approaches to determine and maximise the lifetime of critical power components for existing and future networks
	T 16	Development and validation of tools that optimise asset maintenance at the system level, based on quantitative cost/benefit analysis
	T 17	Demonstrations of new asset management approaches at the EU level
C6 Joint TSO/DSO R&D Activities	TD 1	Increased observability of the distribution system for transmission network management and control
	TD 2	The integration of demand side management at DSO level into TSO operations
	TD 3	Ancillary services provided through DSOs
	TD 4	Improved defence and restoration plan
	TD 5	Methodologies for scaling-up and replicating

Fig. 19: ENTSO-E R&D Roadmap 2013–2022 structure

MONITORING OF THE R&I ROADMAP

In March 2016, ENTSO-E published the R&I Monitoring Report 2015[1]. A total of 71 R&I projects were considered, 33 European and 38 national; 41 projects were completed, and 30 are still ongoing, as shown in Figure 20. Only the projects deemed to be relevant to TSOs and that had been performed within Europe were monitored; all projects under consideration were funded either through the EU, Member States or directly from TSOs.

The completion status of each FO, of each cluster and of the whole Roadmap were determined by assigning percentages to the following progress indicators:

» **Completed** – percentage of objectives that have been successfully finished
» **Ongoing** – percentage of objectives that are currently being worked on
» **Proposed** – percentage of objectives that have been proposed but are awaiting approval
» **Not started** – percentage of objectives on which no work has commenced or been proposed

Some remarks are given as follows:

1. The number of monitored projects in this report is 71, compared to the 38 projects monitored in the R&I Monitoring Report 2013.
a. Many important European projects have been successfully completed since 2013 or have been newly incorporated into this report, and their results have become available (AFTER, BestGrid, eBadge, EcoGrid EU, e-Highway2050, GridTech, ICOEUR, iTesla, LIFE, Merge, Real-Smart, SEETSOC, Umbrella, and Wind-Grid) in addition to many national projects.
b. New European projects were funded and have started since the R&D Monitoring Report 2013 was published (BEST PATHS, e-Storage, evolvDSO, Future-Flow, INCREASE, Migrate, Promotion, and Smartnet).

2. There have been major achievements to facilitate the massive integration of renewable energy sources into the system (e.g., by the improvement of wind forecasts, the use of probabilistic approaches, better assessment of required reserves, and the implementation of innovative tools to support the decision-making process for system operators).

3. A new set of management and control concepts to facilitate the safe integration of electric vehicles into the European electricity system has been developed, using as much renewable generation as possible, including a suite of simulation tools capable of analysing the effect and adequacy of different integration scenarios.

4. New tools support the long-term planning of the European electricity system, providing options for a pan-European grid architecture under different scenarios, including a combination of distributed generation, demand management, storage, and innovative transmission technologies (FACTS, HVDC, UHVAC, etc.), paying specific attention to the integration of large quantities of renewable energy sources.

5. There have been studies on the feasibility and effect of the development of an offshore grid system in the North Sea and on the integration of wind energy into the European system.

6. New tools support the simulation of cross-border interaction, including power flow exchange, frequency regulation, reserve sharing, wide-area monitoring, and data exchange definition and procedures.

7. Several initiatives aim at reducing the environmental and social effect of power infrastructures as well as increasing public perception and acceptance.

1) https://www.entsoe.eu/publications/research-and-development-reports/rd-monitoring-report/Pages/default.aspx

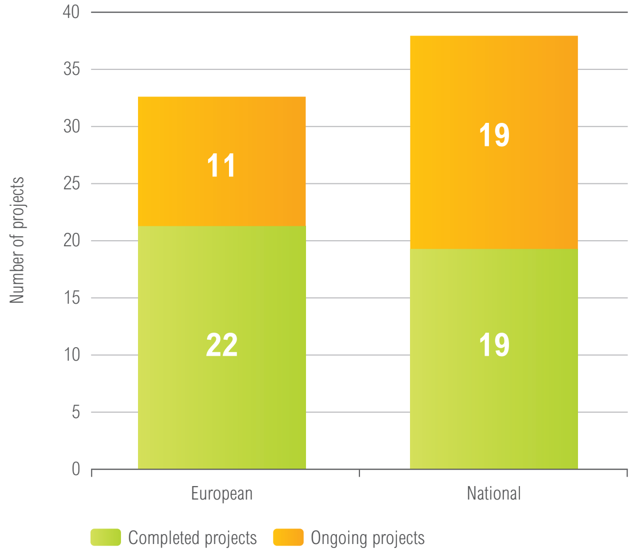


Fig. 20: European and national projects monitored in R&I Monitoring Report 2016

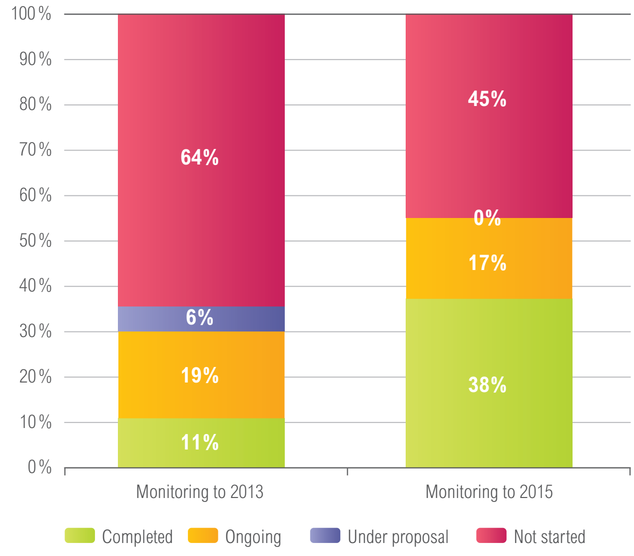


Fig. 21: Cluster progress of R&D Roadmap 2013–2022 in December 2013

CLUSTER PROGRESS

Roadmap 2013–2022 has experienced a great advance since 2013, from an estimated 11 % of completion to an actual 38 %, whereas an additional 17 % is already underway; see Figure 21 and Figure 22. Nevertheless, this means that less than half of the technical objectives are covered yet, so it is essential to continue the progress by focussing on the remaining areas that have yet to be started.

As shown in Figure 22, Clusters 1, 2 and 3 have achieved a high degree of completion, especially Cluster 1.

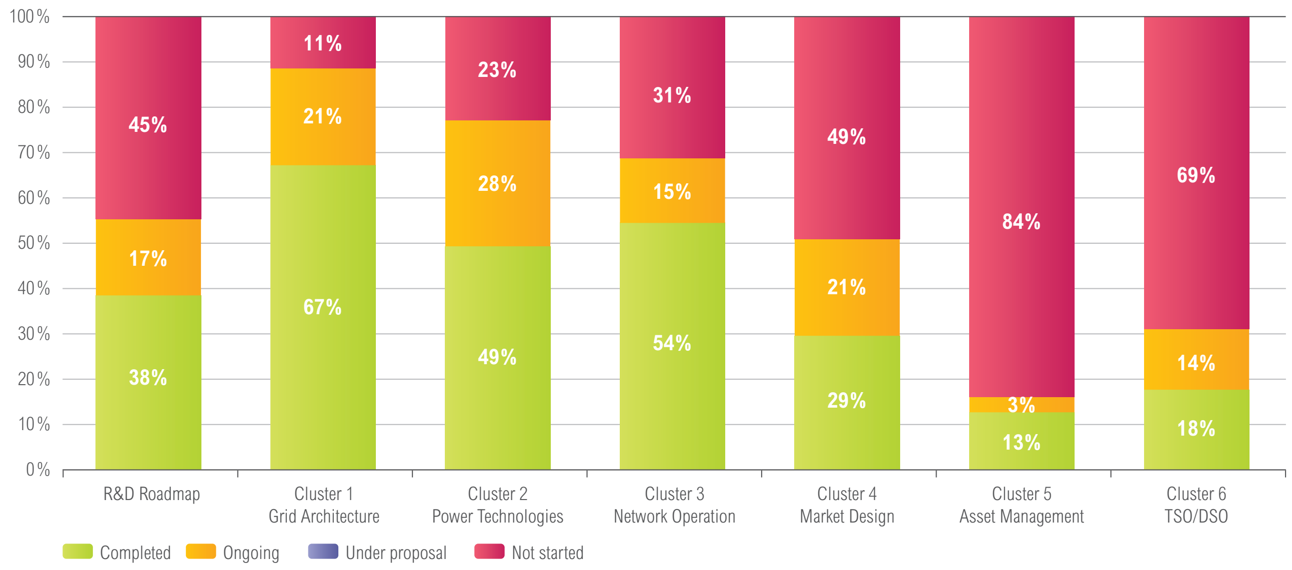


Fig. 22: Cluster progress of R&D Roadmap 2013–2022 in December 2015

GAPS AND RECOMMENDATIONS

The gap analyses have shown that although there are many ongoing projects, significant effort is still required in some areas. The replacement of existing grid infrastructure is forcing TSOs to search for the best possible balance between investing in new power technologies while optimising and prolonging the performance of existing ones.

The TSO/DSO interface should also receive significant attention to increase system observability and deploy new services that ensure overall system security. In addition, considerable effort is still needed to design and implement the internal electricity market and incentivise new system services with respect to the allocation methods for the capacity and reserves to cope with uncertainties from renewable energy sources, load, and system disturbances.

Areas with high R&I priorities:

1. Asset management aims to validate the benefit of individual lifetime condition and life expectation assessment compared to an average assessment of several similar components based on generic parameters (age of equipment, switching steps, etc.) and to establish evaluation/estimation protocols for component statuses that are comparable across TSOs. In addition, maintenance activities with the network 'live', and implementation of devices and robotics for problem detection deserve to be addressed.

2. Joint TSO/DSO activities and improved coordination between boundary grids aim to develop simulation tools and methods that detect weaknesses in the system with respect to the reconnection of DER and storage systems and the risk of breakdowns caused by reconnection. Emerging ancillary services from aggregated small-energy sources and demand response and management at the DSO level provide extra means and system services for TSO operation. New modelling methods and tools for steady-state and dynamic analyses should also be developed.

3. Market design aims to investigate interactions among system operations, dynamic capacity, reserve allocation methods, and design grid tariff mechanisms for active demand-side management and to correlate the load curve and integration of renewable energy sources at the regional and pan-European levels.

ASSESSING RESULTS OF R&I PROJECTS

APPLICATION REPORT

The R&I Application Report, published by ENTSO-E in March 2015[1)], has addressed the aspect regarding the use of R&I project results (with a main focus on EC-funded projects) into the TSOs' daily business. The report addresses nine relevant EU-funded projects (ANEMOS Plus, EWIS, ICOEUR, MERGE, OPTIMATE, PEGASE, REALISEGRID, TWENTIES and WINDGRID) that were finalised between 2009 and 2013 and involved one or more TSO members of ENTSO-E.

As concrete examples extracted from the full report, the following can be mentioned: The use of the TWENTIES Project results in the development of the interconnector project between Spain and France (HVDC technology, dynamic rating) or the use of new tools for wind generation forecast (WINDGRID

1) https://www.entsoe.eu/Documents/Publications/RDC%20publications/150305_RD_application_report_2014.pdf

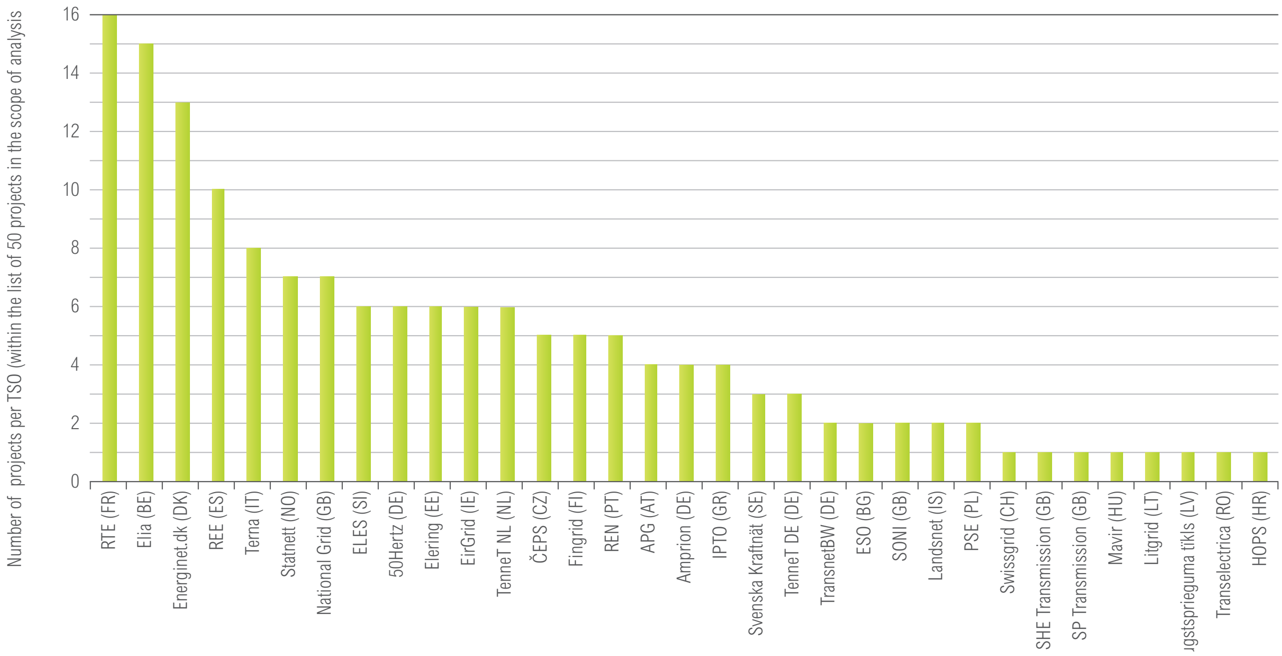


Fig. 23: Participation of ENTSO-E members in selected R&I projects

and ANEMOS Projects) and load simulation tools (MERGE Project). Through inter-TSO cooperation, support from the EC, clearly defined goals in the ENTSO-E R&I Roadmap and relevant implementations plans, the projects carried out have achieved significant results. Approximately 20 projects with a beneficial outcome and strong involvement of TSOs have been financed or co-funded by the EC in the last six years. On top of that, there are plenty of started and completed projects implemented at a national level whose results can be used through knowledge-sharing activities. A set of significant projects are summarised and presented, grouped by the ENTSO-E Roadmap's clusters.

Selection of these projects is made by measuring whether the task with which it contributes to this topic is completed beyond 75 %; this selection is reported in Appendix 3.1

IMPACT ASSESSMENT

ENTSO-E has carried out an impact assessment of the main recent European projects, as a further step beyond the mere monitoring of Roadmap fulfilment, which is the scope of the periodic monitoring reports.

The projects analysed, totalling approximately 50, are the following: i) finished in 2013 or before; ii) recently finished or finishing (end date between 2014 and June 2016); iii) ongoing (end date after 2016); iv) just started (start date in 2015–2016).

Project representatives have been asked to identify the main achievements (reached or expected) of their projects, with many project results being considered as intermediate steps towards these main achievements. In this way, 176 main achievements were identified, to which input and output TRL were associated, as well as FO(s) based on the ENTSO-E R&I Roadmap.

The type of achievement and their relevant next steps have been categorised as follows:

1. **Methodology** (includes methodology for designing new rules, scenarios, …)

2. **Software** (includes development and demonstration of simulation tools, decision-making support tools, …)

3. **Hardware** (includes development or demonstration of pieces of hardware)

4. **Database** (includes quantified scenarios, results of cost-benefit analyses, …)

5. **Policy, regulation, market** (includes business models, policy recommendations, …)

6. **Other**

Type of next steps:

» Further research
» Further development
» Demonstration
» Deployment

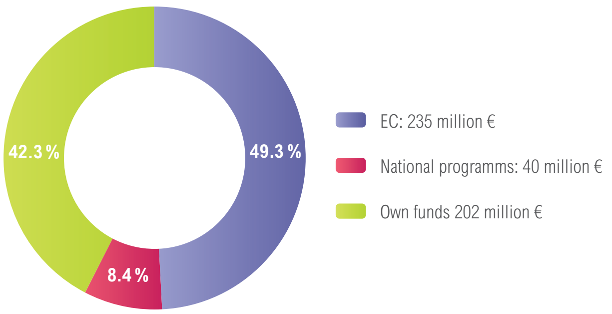


Fig. 24: Distribution of budget for R&I projects involving TSOs

Amongst the 16 most promising R&I achievements (reported in Appendix 3.2), with a high potential of implementation before 2020, 12 come from European projects, and four are from national projects. Sharing the knowledge gained and promoting the outcomes reached by national projects with a high potential of replicability or scalability should be pursued to make the most of R&I investments in Europe. Numerous analyses can be performed based on the information gathered in the questionnaires. In this report, it has been chosen to highlight the most promising R&I achievements, identified by cross-checking four pieces of information included in the questionnaires:

1. **Output Technology Readiness Level (TRL): achievements with output TRL higher than or equal to seven (system prototype demonstration in operational environment) have been selected;**

2. **Achievements expected to be followed by deployment as the next step, with a target year no later than 2020;**

3. **Analysis of the explanations given by project coordinators about the importance and urgency for the TSOs to implement the project achievements;**

4. **The budget of the project.**

Thirty-two ENTSO-E members have been or are involved in these projects, from a minimum of one project for seven TSOs to more than ten projects for four TSOs. (Figure 23).

In total, the overall budget of the 50 projects studied is 477 M€, of which 275 M€ come from public funds (approximately 235 M€ from European programs and 40 M€ from national programs, see Figure 24).

ACHIEVEMENTS

The projects' main achievements are distributed within each cluster of ENTSO-E R&D Roadmap 2013–2022 as presented in Figure 25 A). Amongst the 176 achievements inventoried, only 49 are related to one single cluster; the other 127 achievements are related to two, three or four clusters, which explains why the figures displayed in the graph sum up to more than 100 %. The different types of achievements are distributed as presented in Figure 25 B).

Significant results have been obtained for improving the planning activities and the operations of the TSOs, although these results must be followed by further research and development. The assessed projects' results have brought to light the growing importance of the software layer, thus calling for more R&I work to fully understand the new dynamics of the system and the needs in terms of IT (high-performance computing, Internet of Things, Big Data management) not only for operations but also for planning and asset management. National projects in which real-life experiments are conducted should show the benefits of digitalised substations.

A closer look at this figure reveals that the majority of executed and published literature focuses on the development of methodologies and their corresponding simulation/integration tools within the scope of network operation (mainly grid compliance and provision of ancillary services by RES) and power (i. e., energy resources) technologies.

Regarding new technologies, running projects will give answers in the near future on the optimal solutions for the revamping of the existing HVAC network and the integration of HVDC links, connected to HVDC grids bringing the production of large off-shore wind farms to densely populated areas.

The analysis also highlights the effort of TSOs to better appraise market designs and develop cross-border collaborations for system services.

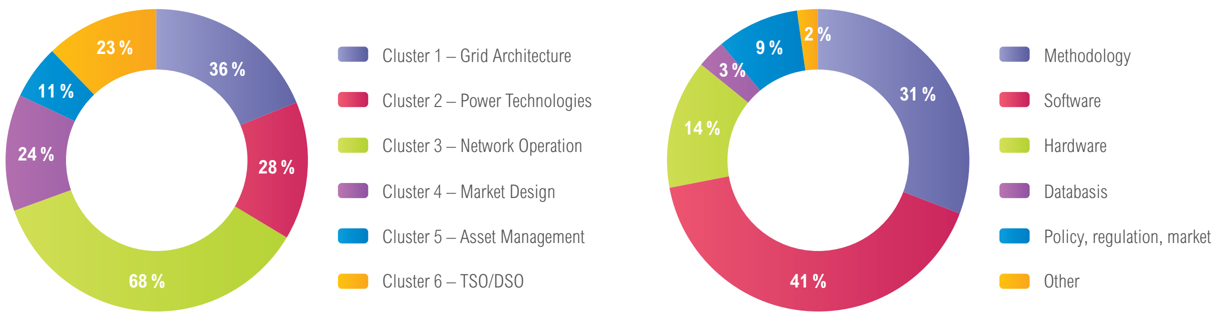


Fig. 25: a) Achievements per Cluster of ENTSO-E Roadmap 2013–2022; b) Achievements per category

What's in for Society

IMPACTS AND BENEFITS

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

SOCIAL WELFARE AND INDIRECT BENEFITS

This R&I Roadmap will have impacts and benefits for TSOs and stakeholders as well as for society at large. The overall impact and benefits of the R&I Roadmap are depicted in Figure 26. By anticipating and preparing for upcoming challenges, this Roadmap brings the European vision of sustainable energy to fruition. The European energy market will build on its strong transmission backbone and continue to maintain security of supply while allowing full deployment of the electricity market. Furthermore, synergistic effects can be exploited in Europe to reduce costs and maximise results. Finally, this Roadmap allows European manufacturers and ICT providers to develop innovative products and bring them to market. Cooperation with research partners will create new opportunities and allow ENTSO-E to further refine this Roadmap in the coming years.

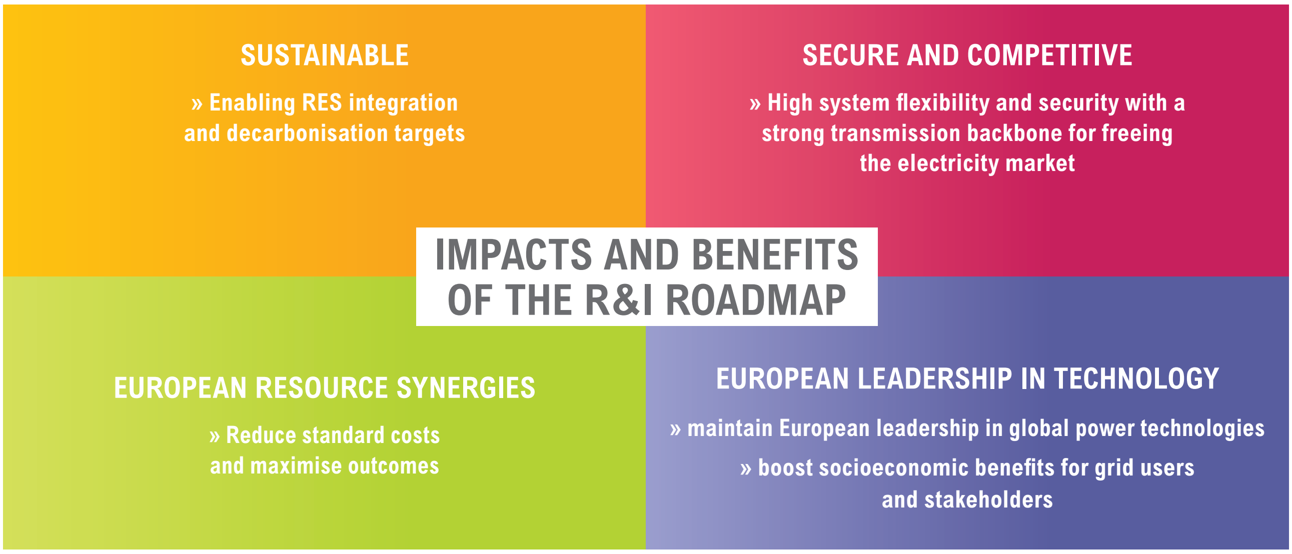


Fig. 26: Overview of R&I benefits and impacts

European R&I also promotes scaling-up and replication of best practices (planning, market, operation) and a more efficient energy market, thus maximising social welfare in Europe.

Without R&I, investments in the transmission system will be unnecessarily expensive or misaligned with existing assets. Furthermore, budget and time pressures would force European TSOs to work independently and inefficiently on small-scale projects that would not likely be compatible with other TSOs. Collaborative R&I leads to smart and innovative solutions that benefit Europe as a whole. As foreseen by this R&I Roadmap, European customers will receive affordable yet secure electricity as well as flexible services through innovative market design and cost-effective implementation of the smart grid.

Manufacturers with proprietary solutions for load and generation equipment will appreciate the feedback from TSOs so that their solutions can be further optimised. A competitive marketplace for solutions also keeps costs of hardware and software solutions in check.

This R&I Roadmap promotes interoperability among manufacturers' solutions. Furthermore, ongoing standardisation activities benefit from the R&I clusters and large-scale demonstrations.

R&I collaborations between European TSOs and other research partners generate enormous synergies. When TSOs are able to speak with 'one voice', research partners are encouraged to explore solutions that are appropriate for all of Europe. Pan-European project coordination also prevents redundant R&I and therefore optimises spending. By cooperating on research, TSOs can pool their resources and hence share investment costs and risks.

Demonstration of new technologies is the key to maintaining and developing the power grid of the future. It promotes pan-European harmonisation and standardisation efforts, which benefit TSOs and manufacturers alike. By reinforcing collaborations with DSOs and generation companies, grid operations and planning can be optimised by developing systematic R&I solutions. Innovative concepts can be rapidly disseminated throughout Europe so that the best technologies and solutions can emerge and gain acceptance. What are the benefits for European society? The synergies generated by pan-European cooperation will lead to lower R&I costs, improved services for electricity supply in all TSO control areas and evened-out disparity. The joint pursuit of common goals serves to strengthen ties between EU Member States.

KEY PERFORMANCE INDICATORS

The **key performance indicators (KPIs)** for electricity networks (including the transmission network) were designed within the framework of the EEGI supported by the Grid+ project financed by the EC with the collaboration of the working group Monitoring and Knowledge Sharing of ENTSO-E.

The EEGI Roadmap (covering transmission and distribution as well as the merging aspects between these two parts of the power system) was designed to allow European electricity networks to continuously deliver effective, flexible capacities to integrate actions of grid users at affordable costs.

The developed set of KPIs looks at two aspects:

» implementation effectiveness KPI

» expected impact KPI

The Implementation Effectiveness KPI measures the percentage of completion of R&I objectives defined in the present R&I Roadmap. The methodology includes the evaluation of activities that are completed, ongoing, under proposal and not started.

The Expected Impact KPIs consist of the following:

» **Overarching KPIs** – a limited set of network and system performance indicators,

» **Specific KPIs** – provide an overview of other specific technical parameters relevant for network operators and related to the different innovation clusters and FOs

» **Project KPIs** – proposed by each R&I project that will stem from this Roadmap and will be listed in the Implementation Plans.

This Roadmap aims to deliver innovative pathways for preparing European electricity networks to enable the ambitious 2050 agenda adopted by European Member States: a low-carbon economy leaning on the three pillars of European energy policy: sustainability, energy market competitiveness, and security of supply.

The completion of the different R&I objectives presented in this document will have several benefits. Such benefits will be fully realised only when the different proposed solutions are in the European transmission system. It is difficult to summarise the different benefits into a single KPI.

Whereas wind, solar, biomass and other industrial initiatives focus on developing generation technologies to produce green electricity and consumers focus on reducing their electricity consumption via energy efficiency programs, the electricity network operators' contribution to these goals must be to have a sufficient network capacity to reliably host such new technologies as well as the existing grid users.

The **enabling capability** of electrical networks refers to their **capacity** to accommodate renewable electricity generation (sustainability), ensuring enough **flexibility** for the system operation and serving customers according to affordable electricity pricing (market competitiveness) while maintaining the system reliability at levels compatible with societal needs (security of supply). The TSOs must indeed be ready to provide solutions for integrating different grid technologies and users, both from existing and new generation (e.g., RES) for existing and new demands (e.g., electric vehicles), while combining with the other industrial initiatives to be in line with the ETIP Plan orientations. They do so not only by ensuring efficient operation and maintenance of the transmission grid but also by playing their role as market facilitators.

It is therefore advantageous to introduce a single overarching KPI:

"Sustainable network with increased network capacity at affordable cost"

It is believed, however, that the single overarching goal of the Roadmap can be met on the basis of the following:

- implementing massively innovative solutions from a set of R&I cluster activities (and deployed individually or in combination);
- meeting investment and operation cost targets set by regulators, once scaling-up and replication studies have been performed;
- meeting societal wishes for network expansion routes that fulfil environmental constraints.

The expected contribution of the future deployed solutions to the abovementioned improvement goal can be further expanded into a set of specific KPIs defined at the cluster level (see Figure 27). All KPIs defined above (overarching and technical) are meant to be comprehensible, meaningful and measurable. They appear to be in line with most of the KPIs proposed by the Smart Grid Task Force for deployment purposes, together with the KPI calculation methodologies. However, scaling-up and replication studies of the R&I results will be needed to properly frame the expected KPI values for deployment, supporting the cost/benefit analysis of the deployed innovations, which must include the industrialisation costs of the validated solutions.

DRIVERS – SELECTION – ACTIVITIES

HIGH LEVEL OBJECTIVES	» Reduce CO_2 emissions	» Interconnections » Diversified mix » Self reliance system	» Minimum 27 % RES energy efficiency	» Internal market » Electricity price Reduce Capex	» Consumer at the centre
KPIs & CHECK POINTS	» Extended asset lifetime » Identify the cost effective technologies	» Reduction of network congestion » Increase quality of service supply	» Increment in RES hosting capacity » Reduction of RES curtailment	» Energy price variation » Capex spending optimisation	» Number of services provided by the consumer side
R&I ACTIVITIES	» Optimal grid planning » Smart Asset Management » Use of new materials and power Technology » Environment	» Observability » Controlability » Decission support tools » Reslience » Ancillary services	» Storage integration » Demand Response » RES forecast » Dynamic grid » Coordination other players » Grid architecture	» Web based markets » Market integration » Business models » Market designs	» Big Data » Standardisation » New communication » Cybersecurity
TSO FINAL GOALS	C1 Power System Modernisation	C2 Security and System Stability	C3 Power System Flexibility	C4 Power System Economics and Efficiency	C5 ICT & Digitalisation of Power System

Fig. 27: Mapping among KPIs, R&I clusters and EU policy goals

Sustain(ed)

INVESTMENTS, FUNDING, RESOURCES

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Effort

The estimated investment cost for implementation of TSOs' objectives is approximately 1 billion euros. This amount has been built with a bottom-up approach: the investment in each cluster results from summing up the estimations of the FOs within each cluster (Figure 28).

Clusters	Functional Objectives	Budget per cluster
C1 Power System Modernisation	T1 Optimal grid design	**220 million €**
	T2 Smart Asset Management	
	T3 New materials & technologies	
	T4 Environmental challenges & stakeholders	
C2 Security and System Stability	T5 Grid observability	**290 million €**
	T6 Grid controllability	
	T7 Expert systems and tools	
	T8 Reliability and resilience	
	T9 Enhanced ancillary services	
C3 Power System Flexibility	T10 Storage integration	**280 million €**
	T11 Demand Response	
	T12 RES forecast	
	T13 Flexible grid use	
	T14 Interaction with non electrical energy networks	
C4 Power System Economics & Efficiency	T15 Market – grid integration	**70 million €**
	T16 Business models	
	T17 Flexible market design	
C5 ICT & Digitalisation of Power System	T18 Big data	**90 million €**
	T19 Standardisation & data exchange	
	T20 Internet of Things	
	T21 Cybersecurity	
	Total:	**950 million €**

Fig. 28: Budget per cluster

The methodology for the investment estimation relies on a gap analysis between the requirements from ENTSO-E Roadmap 2013–2022 and the resources are presented in the assessment study in Section "Where we are today", p.48 and Appendix 3. This gap analysis was performed by cluster and FO, and the result was distributed through the revised FOs accounting for the degree of overlap between the previous and revised FOs. These resources were completed with new activities described in the FOs of the clusters regarding "Flexibility", "Economic Efficiency and " Digitalisation of the power system". The estimations are based on the budgets of the existing projects and on the potential number of projects required.

SOURCES OF FUNDING

Contributions of EC to the first set of calls for R&I on electricity networks (TSOs, DSOs and storage), through Horizon 2020 program, could be evaluated to approximately 100 M€s per year. However, EC funding covers only part of the cost, typically approximately 50 %, so strong support by self-financing or another funding instrument is required to implement the projects.

According to "Smart Grid Projects Outlook 2014" [1] produced by JRC, TSOs take part in 6 % of the projects for the smart grid in the R&I scene, and they invest most of their resources in developing smart network management, integration of large-scale RES, demand response, virtual power plants and electrical vehicles.

Public funding still plays a crucial role in stimulating private investment in smart grid R&I and D&D projects. According to the JRC report, 49 % of projects have received financing from private capital, 22 % of the EC, 18 % of national funding sources and 9 % of regulators. Approximately 90 % of the projects have received some form of public funding.

Figure 29, based on a recent survey among TSOs, shows that the EC is the most prevalent source of funding for conventional investment areas. However, research areas deployed by market integration and the EC 20-20-20 targets, such as market designs, joint TSO–DSO or Demand response, are mostly being funded either by national programs or by TSOs' own funding. Regarding the number and typology of beneficiaries of EU funding, it must be kept in mind that, contrary to previous research framework programmes, Horizon 2020 uses a challenge-based approach. This allows topics to be defined more openly and to establish a competitive culture with respect to financial resources. Indeed, the first set of calls in power transmission (Work Programme 2014–2015) has attracted plenty of proposals:

- » Innovation and technologies for the deployment of meshed off-shore grids (LCE5): one proposal
- » Transmission grid and wholesale market (LCE6): 11 proposals
- » Large-scale energy storage (LCE9): 15 proposals
- » Modelling and analysing the energy system, its transformation and impacts (LCE21): 41 proposals.

Therefore, it will be impossible to achieve all ENTSO-E Roadmap objectives solely through EC-funded projects.

Another source of financing could be found through the Connecting Europe Facility (CEF Energy), a European programme with a budget of € 5.85 billion dedicated to improving the trans-European energy infrastructure spanning through 2014–2020. ENTSO-E's

1) http://ses.jrc.ec.europa.eu/smart-grids-observatory

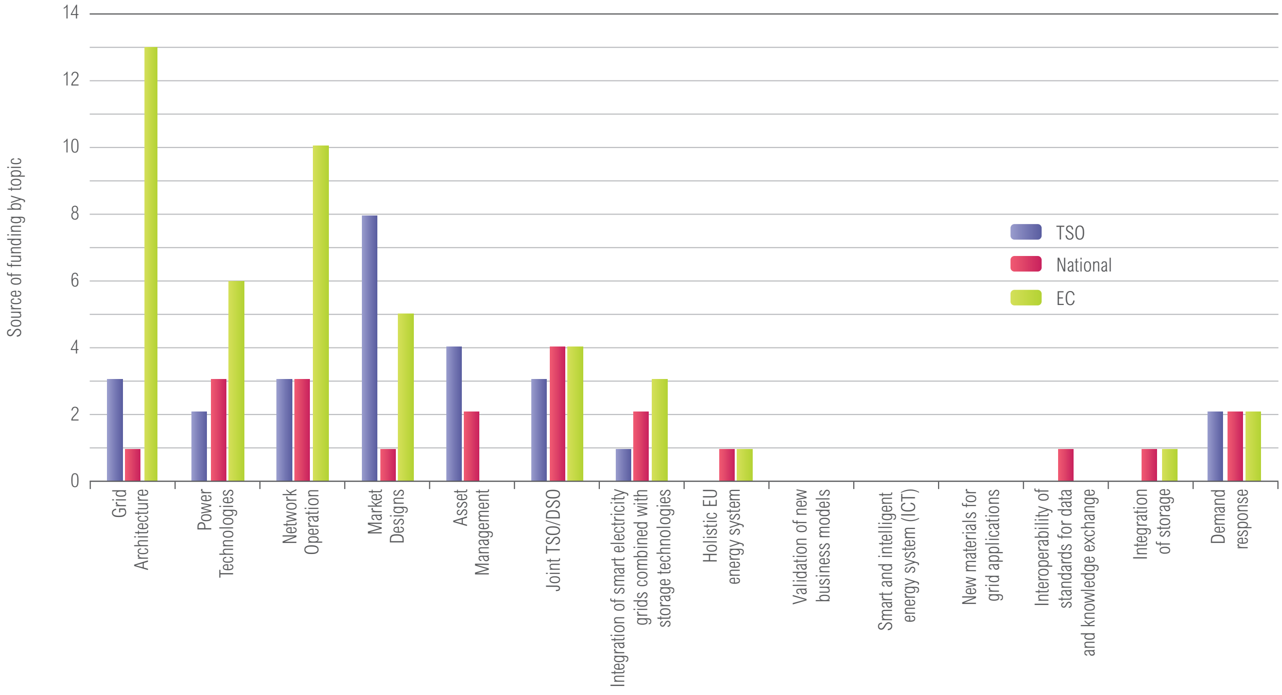


Fig. 29: Source of funding by topic

TYNDP is mandated as the sole instrument for being labelled Projects of Common Interest (PCIs). Based on previous criteria assessments, some of these projects could become candidates for the CEF Energy Program. Some of the PCIs financed through CEF Energy are in an early stage of development. For demonstration and close-to-market projects, CEF Energy could be an option, as it has been the call for a proposal made by Horizon 2020 Work Program 2015.

NATIONAL / TSO PROGRAMMES

According to the latest assessment report (Appendix 3.2), from a total of 477 M€ of R&I investment, 8 % was from national programs, 42 % from TSOs' own investment, and the rest is EC funding.

National R&I programmes and other financing schemes are in place in addition to EC funding. To maximise synergies and avoid redundancies, national and international programmes must be coordinated to, for instance, avoid the duplication of addressed topics.

TSOs are currently spending on average less than 0.5 % of their annual turnover on R&I although in the last year (2015) a certain improvement took place for some TSOs [2]. This is far below Europe's 2020 objective of 3 % (R&I expenditure as a percentage of the GDP; see Figure 30).

2) e. g., Estonia, Finland (expected to increase in 2016), Netherlands, UK, France, Lithuania

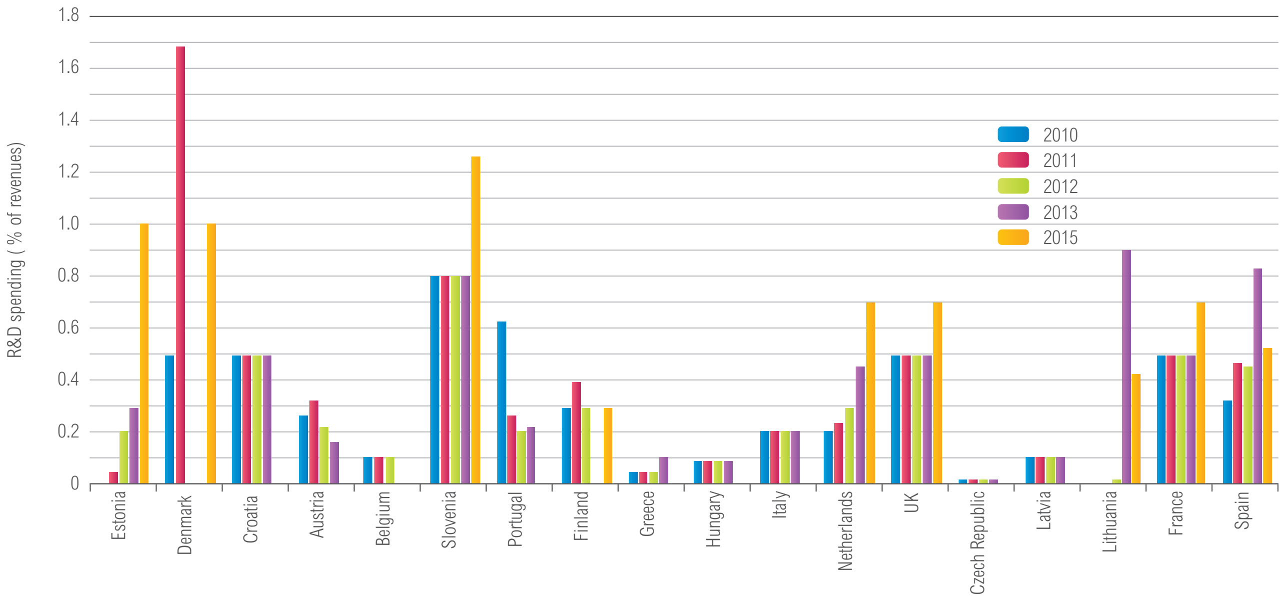


Fig. 30: R&I spending in percent of TSO revenue (For some countries the data has been updated for the year 2015 (yellow bar). For the rest of countries the R&D spending (% of revenues) refers to the year 2013. For Germany due to the existence of 4 TSOs, the country is not listed in the figure.)

REGULATORY APPROACH TOWARDS R&I

The difference between the ultimate cost of a project and its European funding must be covered by TSOs and other stakeholders participating in the project. At the same time, directive 2009/72/EC, part 37.8 stipulates that national regulatory authorities are responsible for ensuring that TSOs and DSOs are incentivised to support R&I expenditures.

When there is no explicit national regulation for R&I expenses, these financial efforts are mostly considered as operational expenses. These costs are, therefore, recovered through normal tariff mechanisms updated accordingly and are in many cases subject to efficiency mechanisms, hence with the incentive for TSOs to reduce them.

This is the main reason why some TSOs have constraints in dedicating more R&I expenses included in their allowed costs, thus making it difficult to step up to the R&I challenges as laid out in the R&I Roadmap and Implementation Plans.

In some countries, the opinion prevails that research institutes and universities are better equipped to perform R&I in all fields, including power systems, while also claiming that TSOs should instead focus only on integrating third-party solutions into the grid. This neglects the natural TSO independence and its role in standing for the system's best interest, which means inspiring the technical solutions so that the system remains independent of any supplier and the consumers can gain the most value from innovations.

Other countries have opted to finance electricity-related R&I through national research programmes and to delegate the responsibility of implementing solutions to national energy agencies or similar organisations. If the organisation is not a TSO[3], this approach disregards the system's knowledge and operation experience built in the TSO structure, which otherwise could be leveraged to achieve effective results in an efficient way.

Some other countries wish to retain accountability through a regulatory framework and are pushing towards utilising European funds, which they perceive as a transparent financing mechanism. However, EU funding work programmes do not address all challenges and innovation needs that TSOs experience in daily operation of the system.

Therefore, official recognition from national regulatory authorities and ACER/CEER of the need for covering R&I expenses would bring benefits by leveraging the TSO natural independence and expertise towards engaging stakeholders, operating and managing research programmes, and disseminating results, thus promoting a smooth, effective and efficient implementation of the EU energy strategy.

Specifically, an expanded R&I budget, not capped by efficiency gain mechanisms, would allow TSOs to launch more projects to meet the targets of ENTSO-E R&I Roadmap or to match the EC Horizon 2020 "Innovation Actions" type of calls requiring TSO involvement.

There are also other potential benefits such as the following:

» Establishing a long-term strategy for TSO R&I activities at both national and European levels;
» Ensuring consistent collaboration between TSOs and other stakeholders in pursuit of a fully integrated energy system;
» Better uptake of projects into the market applications.

3) In Denmark and Ireland, for example, TSOs are responsible for electricity-related research programmes.

The following aspects should be addressed:

» Cost-effective use and access to various financial instruments at national and European levels for R&I activities on transmission systems;
» Recognition of leading role of TSOs and ENTSO-E in determining the actions required to integrate various energy/ICT technologies into European energy system.

Market uptake of grid technologies must be fostered by supporting the development of a regulatory framework for innovation in line with European/regional harmonisations of the whole power system. An overview of a more desirable and harmonised regulatory framework for R&I is reported in Appendix 4, based on the following key points:

» Ensure that TSOs, national regulatory authorities (NRAs) and policy makers recognize and integrate the value of innovation in their strategies and frameworks;
» Provide incentives mechanisms for innovation;
» Take into account the long-term nature of R&I: specific treatment of R&I if TSOs are proactive is to be applied;
» Improve existing regulatory tools and implement safeguard remuneration mechanisms;
» Ensure a better complementarity between regulatory frameworks and R&I support schemes (e.g., EC funding);
» Align objectives to serve energy system needs: TSOs and ENTSO-E to play a central role in the integration process setting up system requirements;
» Require cost effectiveness and interoperability of the developed solutions;
» Apply output regulation: Selection of innovative solutions with the highest value for the society;
» Ensure active participation of the NRAs to R&I coordination when different stakeholders are involved.

All the

APPENDIX 1 FUNCTIONAL OBJECTIVES

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Details

» APPENDIX 1: Description of the Functional Objectives

» CLUSTER C1: POWER SYSTEM MODERNISATION

T1	Optimal grid design
Contents	**Challenges:** New planning methodologies and network infrastructure tools are needed to connect energy generation sites involving variable RES and DER to demand areas, as well as to integrate demand response, storage and the interface with other energy/transport networks. The approaches to grid design at the European level must be developed by taking into account a broad spectrum of novel technologies for generation, transmission, storage, and demand response, as well as the evolution of boundary conditions (single European energy market, new business models, climate change, etc.). Moreover, the pan-European electricity system should make use of ICT powered "System of System" for which dedicated research priorities on planning and development methodologies are addressed (DG Connect Research Program Horizon2020[1]). The pan European electricity system should become a critical case study to test such new planning and architecture approaches[2]. **Objectives:** The objective is to develop planning tools methodologies and simulation software to assess the options for a pan-European power system, in particular for the transmission system infrastructure. It should also facilitate system simulations at the European level to compare several design options based on different technical, economic and environmental criteria, and accounting for emerging technologies and business models. Another objective is to integrate the planning perspectives: how the grid planning phase can best serve the future operational needs during the grid operation phase. **Scope:** T1 Addresses the medium-term adequacy and the long-term planning for system development, particularly accounting for the energy scenarios provided by TYNDP and e-Highway 2050. It also addresses grid planning within uncertainty framework, i. e. probabilistic approaches, no regret options, risk management at planning phase. **Specific tasks:** » To investigate state-of-the-art planning methodologies and software, technology portfolios and different regulatory frameworks. » To develop software tools for cost-benefit assessment of expansion options and for validating the impact on grid planning of coordinated design of architecture, power flow control devices and other expected technologies. » To develop planning software to optimise location, coordination, control and integration of technologies within the existing and future system architecture and operation. » To develop planning methods that combine electricity market analysis, production capacities (all kinds, including DER), demand response capacities and infrastructure, storage, and environmental constraints, both at the transmission and distribution levels, with the aim of strengthening expected weak points on the grid. » To develop probabilistic planning methods that respect the variability of RES, demand response, storage, self-consumption, and their uncertainty. » To propose network investments at the EU level. » To take into account the expected coordination levels at transmission level and develop a top-down network development approach involving regional initiatives to avoid extra investments or lower system reliability. » To account for coupling with other energy networks (especially gas but also heat and cold) in the planning studies (simulations), e. g., dynamic coupling between gas and electricity networks (link with T14). » To account for maintenance operations in the new planning tools (the system must remain operable when maintenance operations are performed). » The flexibility brought by software must be taken into account in the flexibility means (for example, smart substations) » To develop modular infrastructures, both in term of size/capacity and in terms of voltage level.

1) https://ec.europa.eu/digital-single-market/en/system-systems

2) ECSEL (Electronic Components and Systems for European Leadership): the ECSEL Joint Technology Initiative (JTI) is a merger of the ARTEMIS embedded systems JTI and the ENIAC nano-electronics JTI, together with the European Technology Platform EPOSS (Smart Systems Integration). The ECSEL JU started in 2014 and will be fully operational up to 2020, followed by a running down phase till 2024.

T1	Optimal grid design (continued)
Expected outcomes	TSOs will be able to optimise network development and identify the most cost-effective technologies based on recognised optimisation goals, constraints and maximisation of RES integration. Delivery of planning tools for network development, both for cross-border and TSO-DSO system development, accounting for a broad spectrum of novel technologies (generation, transmission, storage, demand side response and management). As such, it will enable better decision making, leading to: » less investments/cost » higher reliability » maximised RES integration
Expected impacts	This long-term planning approach will enable manufacturers, DSOs, energy retailers and other energy companies to create provisional development plans. Investment signals will be sent to energy generators, load centres, TSOs and DSOs, taking into account European network investments.
Contributors	TSOs, DSOs, Research institutes, Technology providers, Regional initiatives
Additional information	Interdependent with T4, T10, T13. Also builds on previous projects: e-Highway2050, Realisegrid
Budget estimated	40 million €
Timeline	2021 – 2026

T2	Smart asset management
Contents	**Challenges:** The power network is continuously challenged with the choice between implementing maintenance procedures to extend lifetime, upgrading equipment to increase lifetime, replacing failing subsystems or partial replacement of infrastructure. These actions must take into consideration worker safety, the quality of service, and OPEX and CAPEX negotiated with the regulator. Therefore, there is a need to revisit the lifetime prediction modelling based on extended parameters, to define new and reliable monitoring systems, to specify and develop new and relevant heuristics and approximations for integrated, realistic and workable frameworks, and to demonstrate how these approaches can be implemented, scaled up and replicated at effective cost so that the expected benefits are realised. **Objectives:** The objective is to maintain robust and cost effective network infrastructures with reliable performance by optimising asset management through: » Validation of new monitoring concepts for components and systems in view of scheduling maintenance that maximises network flexibility; » Elaboration and validation of new selective maintenance methodologies that leverage condition-based, predictive-based and risk-based approaches; » Development of new failure models by improving the understanding of how working conditions impact the aging of critical network components, creating enhanced monitoring systems or performing ex-post analysis of assets that have been removed from the grid. » Implementation of new breakthrough technologies, such as robotics or drones, in order to reduce costs and increase human safety and asset availability. **Scope:** Maximising the value for money through enhanced monitoring of health and improved methodologies to support preventive and selective maintenance decisions; new means for line and substation inspections and monitoring.

T2	Smart asset management (continued)
Contents	**Specific tasks:** » To identify parameters (climate conditions, operating conditions, potential for hardware and software, among others) that impact the lifespan of components. » To establish evaluation/estimation protocols for component conditions that are comparable across TSOs, with in-depth analysis and shared experiences. » To validate the added value of individual lifetime assessments compared to an average assessment of several similar components based on generic parameters (age of equipment, switching steps, etc.). » To develop new ways of detecting component failure based on failure models (probabilistic models, i. e.; link with GARPUR) » To develop software for estimation of component real life time (to be checked vs manufacturer declared lifetime), based on set of historical data of measured operation conditions (voltage, load, frequency) since in operation. » To integrate new sensors and new equipment condition monitoring approaches based on distributed technologies. » To implement robotics for automated condition monitoring or diagnostic systems for incipient problem detection, as well as to intervene in hostile environments and avoid the need for human maintenance. Also includes live line maintenance and working practices and the use of drones for network monitoring. » To propose scaling up and replication rules for new asset management approaches at the pan-European level. » To improve the modelling of rare, severe-impact events through inter-TSO collaboration on related data. » Improve methodologies, methods and software for physical protection of the grid infrastructure and protecting against natural catastrophes, terrorism, cyber-attacks. » To link with standardisation is key in terms of assessing the validity of the diagnostic methodologies investigated, validating the measuring chain, and ensuring the safety of operation (especially for live line work).
Expected outcomes	» New approaches for extending the lifetime of existing power components based on improved monitoring and measurement of their health. » New maintenance approaches for managing critical assets based on risk and optimisation, that are shown to reduce operational costs while increasing network flexibility and ensuring adequate power quality. » New specifications and guidelines for interoperability and standardisation to be used by manufacturers of sensors and IT systems to support health monitoring, selective maintenance and enhanced asset management. » Optimised maintenance approaches for new power technologies should be assessed using adapted CBA methodologies. Consequently, new training methodologies will be developed for workers performing asset management (including live line maintenance). » Best practices and guidelines for scaling-up and replication of coordinated asset management techniques.
Expected impacts	» Increased share of renewables in the supply mix due to greater grid flexibility and availability provided by optimal asset management. » Increased grid capacity while maintaining the same level of quality and security of supply, thus leading to a more efficient electricity market. » Optimised costs for asset maintenance activities while increasing the performance of existing assets. » Integration of new power technologies with optimum asset management methodologies.
Contributors	TSOs, Technology providers and Research institutes
Additional information	Interdependent with T7, T13, and T18. Also builds on a previous project: Realisegrid Linked to IoT and big data: use of the data to estimate lifespan and establish ageing/failure models (probabilistic models, cf. needs for GARPUR, for instance)
Budget estimated	40 million €
Timeline	2018 – 2021

T3	New materials & technologies
Contents	**Challenges:** The increasing integration of variable RES and the advent of the single European electricity market have increased the free flow of energy at the regional level. In addition, assets are reaching the end of their lifetime. There is a need to upgrade existing assets, which are typically performing close to their limits but which are facing public reluctance. Advanced transmission technologies must be tested and existing lines improved. The integration of new technologies into the existing infrastructure presents interoperability issues that must be solved. **Objectives:** Emerging power technologies will be demonstrated and validated to increase the flexibility and capacity of the existing power grid. New materials and technologies, including energy storage, will be tested and validated to increase performance, extend lifetime, improve the maintenance of current assets, find efficiency opportunities, and set standards for the transmission system. **Scope:** New types of conductors (using nanotechnology or superconducting materials), high-temperature conductors, composite core conductors, coatings and superficial treatments, composite supports, energy storage, power electronics and other technologies will be demonstrated and validated. **Specific tasks:** » To demonstrate the degree to which transfer capacity and asset performance can be increased through the implementation of different approaches (materials) and technologies. Assessment of new storage technologies. » To investigate emerging technical solutions in the construction of new infrastructure and maintenance of existing networks, and perform cost benefit analysis of different case studies. » To demonstrate controllable off- and onshore solutions for vendor-independent, HVDC multi-terminal networks used to coordinate power flow. » To investigate the influence of parallel routing of DC and AC lines in the same tower or parallel paths to facilitate existing infrastructure paths in an optimal manner. » To develop the technologies to coordinate with storage infrastructure and gas and heat networks. » To investigate lower and higher frequency networks as an alternative to DC links. » To standardise strategic components and system and multivendor applications for all PE interfaced devices (generation, load, storage) connected to the transmission network. » To develop superconductor Fault Current Limiter in order to avoid strong Short Circuit currents in the new grid architectures. » To assess the need for new components and systems to reduce the effect of extreme environmental stressors (extreme winds, rapid rainfall, storms, floods, wet snow, saline pollution etc.), both for AC and DC applications. » To assess the possibility of substituting SF6 in stations equipment and circuit breakers with a suitable and environmental-friendly substance.
Expected outcomes	Introduction of new materials and technologies that allow the development of infrastructure with higher performance and/or lower costs.
Expected impacts	Improved energy security, increased quality of service and optimised costs. Definition of standards for the transmission system equipment. Integration of new materials to increase asset efficiency. Adaptation and extension of lifetime of existing infrastructure.
Contributors	TSOs, Technology providers, Research institutes, Laboratories
Additional information	Interdependent with T1, T10, T11, T12, T13. Also builds on previous projects: Twenties, BEST PATHS, Realisegrid
Budget estimated	120 million €
Timeline	2017 – 2022

T4	Environmental challenges & Stakeholders
Contents	**Challenges:** The realisation of a secure, sustainable and competitive European electricity system requires the development of underlying transmission infrastructure. Hence, there is a need to develop new ways and means to address the public reluctance toward infrastructure investments and to increase public awareness about future long-term energy challenges. Therefore, the current public consultation processes needs to be revisited to both better appraise and understand the reasons for public reluctance to support infrastructure investments. **Objectives:** To improve public acceptance and stakeholders' participation in transmission infrastructure, while also reducing environmental impact. **Scope:** Improvement of public awareness of long-term energy challenges and the need to build and protect transmission infrastructure to increase the social benefit of electricity use. Assessment of new environmental challenges and improvement of the transmission infrastructure land use and environmental integration. Possible directions include exploiting new channels for the public consultation processes. Alternatives to SF6, allowing for the compact design of electric power stations with efficient insulation properties. New design measures to minimise high-voltage equipment noise, visual impact and sag of overhead lines. Improving the physical protection of the grid infrastructure against potential dangers, e. g., natural catastrophes, terrorism or cyber-attacks. **Specific tasks:** » Increase communication campaigns, develop social impact studies and increase the involvement of local and territorial bodies in the early stage of planning of the infrastructure. » Deepen studies on human and animal exposure to EMF. » Develop holistic approaches for maintenance accounting of the environmental (e. g., tree growth rate, wind) and operational (e. g., hazard rate) effects on assets' lifetime. » Analyse new technologies that have reduced conductor visibility and reduced sag. » Propose new tower and stations designs with less visual impact, audible noise and EMF. » Implement pilot projects for demonstration and assessment of the methodologies and software developed to protect the grid infrastructure. » Conduct pilot projects concerning the implementation of the guidelines for improving the relationship between TSOs and the public, namely consumers. » Investigate the environmental impact of partial undergrounding solutions (cables) and new technologies. » Update the European guidelines on good practice in transparency and public engagement and the permit process. » Produce guidelines for the construction and maintenance of overhead lines, with the goal of improving public acceptance. » Mapping bird-sensitive areas and developing new bird savers to minimise birds collision and nurturing bird nests.
Expected outcomes	Recognition of the general public's need for new infrastructure to be developed in an open, participatory and environmentally sensitive way, and for it to ensure the security of the supply with low carbon emission.
Expected impacts	Improved stakeholder engagement by improving the understanding between TSOs and the public and reducing the environmental impact of the infrastructure. Acceleration of the permission and construction processes required to build new infrastructure or refurbish existing infrastructure.
Contributors	TSOs, DSOs, Technology providers, Industries, NGOs
Additional information	Interdependent with T1, T2, T3, T14, and T20. Also builds on previous projects, namely BESTGRID and Life ELIA.
Budget estimated	20 million €
Timeline	2017 – 2026

» CLUSTER C2: SECURITY AND SYSTEM STABILITY

T5	Grid Observability: PMU, WAM, Sensors, DSO information exchange
Contents	**Challenges:** Utilisation of wide area monitoring systems (WAMS) is critically important for increasing transmission system observability, but this has yet to be done on a pan-European scale. European transmission systems are currently being operated under increasingly stressed working and weather conditions, approaching their stability limits. Massive integration of RES and DER, mostly connected at the distribution level, potential deployment of hybrid networks (AC/DC grid), expected migration of the heat and transport sectors to the electricity sector, increasing levels of interconnectivity, and future demand response mechanisms all require new monitoring methods and tools. PMUs and wide-area schemes open up new possibilities in power system control and protection design, including the implementation of model-based (or model-predictive) and/or adaptive controllers that previously have not been feasible or sufficiently useful. The pan European electricity system has become one of the most complex safety-critical, cyber-physical system (CPS) which will benefit from the increasing pervasiveness of ICT and the development of the Internet of Things. The challenge of CPS is to design and implement highly distributed and connected digital technologies that are embedded in a multitude of increasingly autonomous physical systems with various dynamics and satisfying multiple critical constraints including safety, security, power efficiency, high performance, size and cost. Such combination of several CPSs in a "system of systems" may lead to unpredictable behavior and even new properties. The pan European electricity system should become a critical case study to test new design and programming methodologies developed. **Objectives:** The main focus is to improve transmission system observability at the pan-European level by developing new methods, technologies and tools capable of handling the process and interchange of an immense amount of measured and forecasted data in real time, both horizontally between TSOs and vertically with distribution grids/demand. **Scope:** Use of technologies such as PMUs, intelligent sensors and integrated communications to gather information from transmission systems, and combining this information with data obtained from DSOs and weather stations in order to improve the observability of the pan-European system. **Specific tasks:** » Assess and validate the performance of intelligent local sensors and data processing equipment (with sensor manufacturers) against the requirements for state estimation and dynamic simulation. » Develop tools utilising new sensors for distributed observability of the transmission system (e.g., voltage sensors, position sensors, event sensors. These are very cheap and simple to use in a distributed approach, and can derive conditions and state estimations from statistical analysis of the acquired data.) » Optimise the existing toolbox to increase the awareness of pan-European operation, allowing for optimisation of local and » regional approaches » Develop local state models with a sufficient level of intelligence and autonomy at the substation level, and link them with state estimators and dynamic simulation tools. These models will be aggregated to assess the observability at the required level, and should help infer automatic rules for operations at the local level (decentralised intelligence). » Increase observability and improve state estimation accuracy (both steady-state and dynamic) through adequate modelling (not only through modelling protection and automatic system schemes, but also by merging transmission and distribution models). » Exploit the information provided by forecasts of variable generation and flexible demand for observability purposes. » Enhance the TSO/DSO communication interface and design new architecture for data exchange and processing at various system levels, e.g., TSO/DSO boundary substations, and in different time frames, from short-term to long-term, i.e., from real-time operational planning to network planning.

T5	Grid Observability: PMU, WAM, Sensors, DSO information exchange (continued)
Contents	**Specific tasks:** » Investigate and develop methodologies, procedures, protocols, standards and tools for inter-TSO communication, in view of determining the amount and type of data exchange which is required to enable an extension of the observable area to neighboring TSO, and, ultimately, to provide detailed and accurate data to regional initiatives. This should aim at mitigating possible negative impact of switching actions from one TSO to other TSOs, and at finding possible efficient cross border remedial actions. » Investigate and develop the methodologies, procedures, protocols, standards and tools for inter-TSO communication, which will determine the amount and type of data exchange required to enable an extension of the observable area to neighbouring TSOs. The aim is to mitigate a possibly negative impact of switching actions from one TSO to other TSOs. » Develop effective data-mining algorithms capable of extracting important information in real time from massive amounts of data. » Implement solutions for WAMS and demonstrate how to utilize such information in a coordinated manner during operations. Observability should also be seen from the operators' point of view, i.e., how to operate a network in new situations with new sets of information resulting from increased data and new tool availability (e.g., iTesla). Critical situations might become even more complex as operations become increasingly automated.
Expected outcomes	Improved monitoring of the electricity system will allow TSOs to make appropriate decisions regarding system operational planning and real-time operation. Validation of the increased role of corrective actions.
Expected impacts	Enhanced security and stability of pan-European transmission system having a high amount of variable RES generation.
Contributors	TSOs, DSOs, Technology providers, Service providers, Generation companies, Regional initiatives
Additional information	Interdependent with T18, T19. Also builds on previous projects: PEGASE, TWENTIES, Real-Smart, UMBRELLA , iTESLA
Budget estimated	70 million €
Timeline	2018 – 2021

T6	Grid controllability: frequency and voltage stability, power quality, synthetic inertia
Contents	**Challenges:** Contemporary electricity systems are already facing a massive integration of inverter-based renewable generation. This generation is mostly of stochastic nature. Moreover, the inverters decouple the inertia of rotating machinery from the power system. Lack of inertia may impair the intrinsic capability of the system to react to large frequency excursions, which in turn may impact system stability and control. Interaction between different control systems must be taken into account and a more holistic view is necessary which includes among others the controllability of the power system integrating and coordinating power electronic devices with the interaction of RES production. The harmonic content of power electronic devices could also lead to instability problems under certain operational conditions. Power quality is also affected since the increasing number of power system components (such as HVDC interconnectors) and loads are based on power electronics, injecting harmonic pollution into the system.

T6	Grid controllability: frequency and voltage stability, power quality, synthetic inertia (continued)
Contents	**Objectives:** Propose new tools and methods to monitor, control and protect an electricity system with low inertia. Identification of suitable methods for building dynamic system-security models and developing the appropriate tools. Existing control and protection schemes must be reviewed and may need to be redefined to allow secure, stable and reliable operation of the network. Methods and tools to ensure the required level of inertia to the transmission system, and connection of relevant equipment's to the networks. Identification of possible links between the electricity system and the other energy systems in the specific view of help increasing inertia (real or synthetic). Deployment of Wide Area Control (WAC) devices at the pan-European, system-wide level, which will enable the operators to operate the system close to its stability margins without jeopardising its security. **Scope:** Power control devices (FACTS, PST, HVDC, VSC), storage and other technologies are to be demonstrated and validated, as well as single-phase auto-reclosure, and point-on-wave switching. **Specific tasks:** » Provide demonstrations of power flow control devices and storage that offer increased flexibility with respect to energy flow across multiple transmission zones and borders. » Increase network controllability by proposing methods and tools for optimal and coordinated use of flexible equipment such as FACTS, PSTs and HVDC links, resulting in safe and cost-effective system operations (thus maximising the global social welfare). » Assess the contribution to controllability of large-scale new power technologies (incl. new materials) such as HVDC, VSC, superconductivity, energy storage, fault current limiters and other promising technologies for joint control of on- and off-shore networks, using fibre-optic temperature monitoring and DLR. » Validate the contribution of RES to voltage and frequency control, as well as balancing, using different concepts, especially for direct-drive machines: VPP, inertia provided by the rotors, PE-based reactive power control, local storage, etc. » Develop new technology and control concepts for providing synthetic inertia from power electronic converters and additional damping of oscillations, for instance conventional rotating machine concepts like the VFT (Variable Frequency Transformer) since these produce no harmonics pollution in the grid. » Assess and demonstrate innovative solutions to counteract the decrease of short circuit current » Consider the large-scale intra-zone oscillation topic, assessing the deployment of the optimal infrastructure, the study and analysis of the data and the measurement of the impact of these intra-zone oscillations » Assess stability in grids with multiple control systems
Expected outcomes	Control procedures will be provided for system security and ancillary services and will involve not only central power plants but also energy from wind, solar and DER, as well as DSR and energy storage systems. Refinement, adoption and implementation of a wide range of efficient and practical control methods to enable wind plants to provide ancillary services.
Expected impacts	» Maximising the volume of renewable generation input whilst keeping the system stable. » Clarification of how this may lead to new control/protection schemes and the definition of grid connection rules.
Contributors	TSOs, DSOs, universities, research institutes, technology providers, utilities
Additional information	Interdependent with T3 and T14. Also builds on previous projects: TESLA , MIGRATE, UMBRELLA
Budget estimated	60 million €
Timeline	2020 – 2026

T7	Expert systems and tools: expert systems, decision-making support tools and advanced automatic control
Contents	**Challenges:** Expert systems simplify the problems faced by complex power systems by processing large amounts of data in a structured way and in a short period of time, enabling high level planning, operation and design decisions. Many TSOs apply restoration strategies based on the operator's experience, with no specific decision support tools. As a consequence, there is no common strategy for system operators and operation planners regarding the restoration of the pan-European system; restoration for interconnected power systems is decentralized. The increased penetration of variable generation sources in the grid can introduce unexpected power flows in both the transmission and distribution systems. Therefore, it is important for TSOs to integrate various decision support tools for RES (e. g., forecasting, contingency analysis, dispatch, security assessment) to help control engineers assess network stability. The contemporary systems broadly utilise local automation, protection and control. However, rapidly changing electricity systems call for better coordination and the use of advanced automatic control. This necessitates the development and massive deployment of smart meters, sensors, control devices, PMUs, and weather measurement, as well as the establishment of a high speed communication infrastructure for monitoring the condition of each element in a power system. TSOs will use these data not only to operate the system optimally, but also to anticipate emerging issues with system stability and security. The internal European energy market will also benefit from this practice, since the market participants will be provided with estimated locational marginal prices in real time that are based on actual system conditions. **Objectives:** Develop expert systems and decision-making support tools to anticipate potential emergencies, provide early warning to system operators and suggest possible solutions based on the estimated probability of success in real time. The developed tools will include, but not be limited to, suggesting changes to network topology based on intelligent switching operations, protective relay settings and dynamic rating of the power system elements according to the actual system conditions. In order to deal with this vast amount of data, as well as with the uncertainty and variability associated with RES, innovative expert systems, highly sophisticated decision-making support tools and advanced automated control systems should be used. **Scope:** Research, innovation, development and demonstration of: » intelligent electronic devices; » sophisticated automatic control devices; » advanced methodologies and algorithm solutions for decision-making support tools with reduced decision cycle time; » integrated expert systems, artificial intelligence, enhanced inference engines, heuristic optimisation techniques and neural networks. **Specific tasks:** » Develop expert systems to assist in transient stability analyses of both voltage and frequency; » Develop advanced decision support tools that integrate the probabilistic nature of variable generation in real time applications such as stochastic power flow, stochastic unit commitment, probabilistic reserve allocation, optimal power flow with RES forecasting, etc; » Assist with solving decision problems regarding reactive power and voltage control, determination of loads when applying load shedding schemes, etc; » Incorporating RES into operation processes via aggregation schemes, utilizing forecasts and benefitting from controllability of RES (for coordinated reactive power/voltage control, congestion management, etc.); » Develop tools for pan-EU system restoration based on coordination of Tie Lines and/or Black Start units, whilst taking into account the system condition, system constraints and available resources to support the decision; » Combine sophisticated sensing technologies, automation and control methods with high-performance, high-speed communication infrastructure through the utilisation of multi-agent system architecture; » Develop new methods that will reduce decision cycle time in decision-making analysis, especially in the case of increased variability, uncertainty of input data, and multiple conflicting evaluations; » Develop and demonstrate innovative expert systems that take into account the uncertainties in the power system using artificial intelligence techniques and probability approaches such as Bayesian analysis. » New control room environment must be developed to enable operators to handle complex decision-making situations (such an evolution could be compared to the aeronautical industry, in which there are automatic pilots and a fully digitalised environment). Specific trainings should also be adapted to the new ergonomic framework. In the tools listed above, the reliability of the ICT system(s) must be accounted for.

T7	Expert systems and tools: expert systems, decision-making support tools and advanced automatic control (continued)
Expected outcomes	Advanced automatic control, effective decision-making tools and innovative expert systems will be validated. This will include not only conventional units but also energy from variable generation sources, providing TSOs with real-time assessment of transmission system conditions.
Expected impacts	Implementation of advanced decision tools will increase the overall system's reliability and improve quality of service, at the same time maximising the utilisation of system components.
Contributors	TSOs, ICT providers, Technology providers, Research Institutes
Additional information	Interdependent with T1, T14. Also builds on previous projects: iTesla, UMBRELLA, PEGASE. Interdipendent with T21(Cybersecurity) in C5.
Budget estimated	50 million €
Timeline	2020 – 2026

T8	Reliability and resilience: defence and restoration plans, probabilistic approach, risk assessment, self-healing
Contents	**Challenges:** Although some damage to physical infrastructure could be expected to occur during extreme weather or operational conditions, a smart grid should be able to not only react and isolate damage to mitigate the impact, but also recover quickly. In this sense, the smart grid should be able to utilise data and all control and ICT technologies to enable self-healing of the transmission system. Gaining knowledge of enhanced stresses to the transmission system is the first step. While the stressors linked with the RES integration and reduced inertia are known, further work needs to be carried to understand the threats linked with extreme environmental events due to climate change (e. g., extreme winds, snowfall, rainfall, flooding, pollution, and desertification). Specific R&I activity should address these threats before considering the related risks and consequences and setting up mitigation measures. Moreover, the integration of RES combined with the presence of both AC and DC links will make planning and operation of the pan-European system even more challenging. From this perspective, it is relevant to analyse whether the N-1 criterion is still adequate for planning and operating transmission grids, or whether a probabilistic approach is needed to enhance the assessment of the grid's state from a reliability point of view, estimating also the dynamic performance of the system (e. g., including the probability of overloads in dynamics). Research is needed in order to develop, among other things, new power system restoration planning methodologies that may incorporate interactive graphics and optimisation algorithms. In order to harmonise an emergency strategy in connection with RES and DER management,¬ simulation tools for detecting weak points in the pan-European system are needed, together with operational guidelines that include acceptable reconnection scenarios. The end consumer could also participate in defence plans by using domestic intelligent electrical appliances that can sense changes in network frequency and respond according to the order of priority set by the user (e. g., selective load shedding). The probabilistic approach should also be utilised to develop tools and methods for normal operation. New stochastic models should incorporate all trading floors: day-ahead, intraday, balancing markets, etc. New tools applicable to the above-mentioned markets should address and identify, using a risk-based approach, the probabilities of different scenarios, the probabilities of faults, and the probability of failure of corrective actions. More accurate forecasts will allow market players to react to the latest information more efficiently. **Objectives:** The main objective is twofold. The first aspect is to create an improved defence and restoration plan for the pan-European grid. To enhance the resilience of this grid, new approaches and technologies to reduce the probability of failure (including those failures stemming from climate change), as well as the consequences of such failures and time to recovery, should be developed and applied. The second aspect is the development of new tools to help TSOs to increase their reliability, consequently enhancing their role as market facilitators.

T8	Reliability and resilience: defence and restoration plans, probabilistic approach, risk assessment, self-healing (continued)
Contents	**Scope:** New procedures and tools will be developed that encapsulate a probabilistic approach as well as components at the distribution level. **Specific tasks:** » Address regulatory and technical challenges in the implementation of restoration plans at the pan-European level. » Include risk analysis in TSOs' daily business. » Identify specific resilience/vulnerability indicators. » Develop special tools for quantifying resilience. » Investigate the effects of extreme climate events as increasing threats to the transmission system of the future. » Evaluate the current performance of the (N-1) criteria security principles and the required level of reliability from the customer's perspective. Provide an appropriate approach for risk assessment based on probabilistic analyses of both normal and abnormal operations, taking into account correlations in the power system. » Evaluate new stochastic models with respect to market operations on different timescales in order to improve reliability. » Use a system approach to identify possible options for replacing (or complementing) the current reliability principles for different aspects of TSOs' business: grid development, markets, etc. » Define the additional information to be exchanged and the additional coordination needed to support deploy¬ment. Ensure effective and sufficient security margins during operation and operational planning. » Develop indicators for the evaluated criteria to help network operators make decisions for preven¬tive and curative actions. » Develop simulation tools and methods for assessing the risk of breakdowns during reconnection. » Develop simulation tools and methods that detect weaknesses in the system with respect to reconnecting DER and storage systems. » Develop simulation tools for interactive system restoration, including advanced forecast tools for wind, solar PV and other variable RES. Assess the system state during the restoration process, and expected RES in-feed of DSO at reconnection. » Engage storage in defence and restoration tools and plans. » Investigate the contribution of DER to system restoration and immediate power reserves; this is relevant from the TSO perspective (e.g., black start capability and coordination of wind turbine genera¬tors). This will be assessed considering efficiency and cost-effectiveness when compared to the traditional or usual black-start approach. » Investigate the impact of micro-grids and islanding capabilities, taking into account efficiency and cost-effectiveness. » Train the system operators regarding the evolution of national regulatory schemes in order to foster coordination efforts. » Account for failure modes of ICT (including sensors) in the different simulation tools. » To develop effective and coordinated restoration plans specifically for ICT and software systems, in order to keep running the grid operation in case of natural catastrophes, terrorism and cyber-attacks.
Expected outcomes	» A framework that relates probability functions, normal operations, asset management and planning weakness and resilience into a single integrated approach. » A simulation framework that detects weaknesses in reconnection scenarios involving DER units. » Assessment of the potential contributions of RES, DER , storage and micro-grids to defence plans (black-start capabilities, islanding capabilities). » A joint TSO/DSO approach for defence plans involving DER and micro-grids.
Expected impacts	Regulatory and technical solutions to implement restoration plans at the pan-European level to lessen the impact of power shortages for end users.
Contributors	TSOs, DSOs, ICT companies, Manufacturers, Generation Companies
Additional information	Interdependent with T6, T13. Also builds on previous projects: GARPUR, AFTER, ICOEUR, iTesla, NetzKraft
Budget estimated	50 million €
Timeline	2019 – 2024

T9	Enhanced ancillary services for network operation
Contents	**Challenges:** TSOs are responsible for the secure and reliable operation of their systems, as well as for the interconnections with other transmission systems. As the penetration of variable generation sources rapidly increases, enhanced ancillary services will be required to cope with the increased variability and uncertainty. Flexibility reserves are being developed on different (longer) timescales than contingency and regulating reserves, in order to account for new ramping requirements. In these circumstances, the ancillary services from conventional generation will not be sufficient; such services should also be provided from RES and DG, which must participate more actively in controlling the system, potentially at the same level as conventional plants. This presents the main challenge for future network operation. Storage might also play an important role in providing specific services such as dynamic frequency control (< 1 s). In this context, the necessity of a multi-level process involving both TSOs and DSOs, generation connected to DSOs, and utilities, becomes apparent. Distribution companies previously contributed to ancillary services in transmission systems (reactive compensation on the MV side of the HV/MV transformer, load-tripping schemes, etc.). The evolution of the electricity sector and the expected arrival of aggregators will strongly affect the roles of TSOs and DSOs. The role of conventional generation might also evolve, with power plants used to provide ancillary services as much as to provide energy. **Objectives:** To address technical and regulatory aspects of providing enhanced ancillary services for TSOs from DER, and storage through a new framework involving the services provided by units connected at DSO networks and by DSO facilities. To allow cross-border provision of ancillary services. To allow new players to provide valuable services. **Scope:** New procedures and strategies will be developed to provide new ancillary services from RES combined with those provided by DSOs, new actors such as storage, and existing power plants (natural gas, thermal etc.). **Specific tasks:** » Increase the visibility of variable RES for TSOs (to enable more accurate forecasting). » Perform dynamic calculations of RES production using short-term forecasting models or by continuous updating of the data. » Develop new common security provisions that enable the definition of a reliable and efficient amount of reserves and the sharing of these reserves based on acceptable and measurable risk (cf. to project GARPUR) » Assessing processes, principles, and strategies for new ancillary services to manage the high penetration of RES and balancing demand (faster ramping services, frequency response, inertia response, reactive power, and voltage control) » Determine novel ways of providing ancillary services through loads and their impact on transmission networks; the highly variable and unpredictable nature of DER and RES places new constraints on these ancillary services. » Determine novel ways of providing ancillary services through storage systems, and their impact on transmission networks. » Develop simulation environments to test the viability and options of ancillary service provision by aggregated loads at the DSO level. » Technologies and tools for active and reactive power control of DER, with TSO/DSO coordination to provide extra power flow control, load management and islanding. » Create robust optimisation algorithms for coordinated control of DER (robust against uncertainties and variability). » Introduce new actors and market models that enable DER and storage to provide ancillary services. » Develop new models that describe products and services to be tested on selected segments of customers, and determine their impact on future ancillary services in the presence of large-scale DER integration. » Create new market models that account for the price-sensitive nature of loads and their resulting flexibility. » Analyse the legal, contractual and regulatory aspects of ancillary services provided by distributed generation and/or loads, allowing for more aggregated business models. » Share best practices between TSOs and DSOs for the ancillary services provided by units connected at distribution networks.
Expected outcomes	» New ancillary services with more active contributions from demand and units connected at DSO networks and from DSO facilities in terms of active and reactive power reserves, flexibility reserves (short-term and long-term), voltage and frequency control and network restoration. The inherent flexibility of the loads can contribute effectively to ancillary services and can be traded on the market. » Replacement of load shedding through new provided services.

T9	Enhanced ancillary services for network operation (continued)
Expected impacts	New recommendations for grid code evolution, based on new ancillary services that can be provided by TSOs
Contributors	TSOs, DSOs, ICT providers, Manufacturers, Service providers, Generation companies, Aggregators, Commercial retailers
Additional information	Interdependent with T10, T11, T12. Also builds on previous projects: SMARTNET, MERGE
Budget estimated	60 million €
Timeline	2022 – 2026

» CLUSTER C3: POWER SYSTEM FLEXIBILITY

T10	Storage integration, use of storage services
Contents	**Challenges:** Energy storage technologies and integration have become key elements in smart grid structures. The landscape of the generation field has changed dramatically with the integration of high amounts of variable renewable electricity generation in European electricity systems. In addition, in the electricity sector's new model, demand response will play a relevant role in the future, introducing variability in demand behaviour. A growing challenge exists in balancing the power grid, since these clean power sources lack additional reserves and can be located anywhere in the network. This requires adapting the grid to store electricity more effectively and flexibly through optimal use of disposable conventional and innovative sources, while maintaining the provision of reliable and quality power to customers. **Objectives:** Develop storage availability schemes for system planning and operation purposes, while analysing in parallel the integration of storage technologies, in close contact with the relevant manufacturers, in order to maximise their application possibilities in terms of both performance and time-to-market development. **Scope:** Activities should focus on storage systems that aim to support the balancing of the power system and the security of supply. It is imperative to address all the technical concerns regarding improvement of the power storage process for the purpose of balancing. The economic, regulatory, market and environmental aspects associated with the deployment of storage systems in the power system should also be explored.

T10	Storage integration, use of storage services (continued)
Contents	**Specific tasks:** Address technical and regulatory aspects such as: » Power-to-power cycles with optimal efficiency and minor losses; integration with other energy systems that can regenerate losses, e.g., heat. » Novel solutions for fast power response and energy storage at different voltage levels in the power system; novel solutions for where supplementary services will be located in the storage facility. » System planning tools to determine the optimal distribution of the energy storage to facilitate transmission system operations, as well as in the distribution grids. » Defining technical requirements/specifications to allow storage integration to provide system services. » Simulation tools to better appraise the cycling profiles associated with the envisaged applications and business models. This will, in turn, allow an accurate estimation of the lifespan of the storage system (and the failure modes) and profitability. » Improvement of current system modelling tools to better account for the benefits of storage and to optimise the balancing; measuring the impacts of OPEX and CAPEX using stochastic modelling. » Tools to assess potential revenues from storage, in both liquid markets and non-liquid markets. » Assess the contribution of power-to-gas technologies as a means to store electricity on large scale; use of gas turbines to cover long periods with low RES generation in scenarios with very high penetration of wind and solar generation. » Develop methodologies to integrate new bulk storage solutions (e.g., power-to-gas, marine storage, CAES). » Asses the value of hybrid technology projects, for example mixing technologies able to perform a high number of cycles with other less CAPEX intensive technologies » Assess and quantify the value for the system of services provided by energy storage
Expected outcomes	Deployment of low carbon technologies, together with encouragement of increased energy efficiency through storage solutions and services, will lead to cooperation programs amongst the European countries, manufacturers, research institutions and the EC. The timely integration of storage-based solutions will assist with flexible management of the grid and will support development of innovative market models and terms for a more efficient system. Assessment of regulatory and economic impacts and opportunities for the storage facility made possible by analyses and recommendations
Expected impacts	» Support the power system with fast response power and energy storage, as assessed by feasibility studies of several technologies. » Unleashing of the potential for balancing, congestion management and/or support with ancillary services through pilot demonstration. » Deferred investments for transmission and distribution grid reinforcements, and lower social costs associated with high penetration of fluctuating renewable power generation.
Contributors	TSOs, DSOs, Research institutes, Storage manufacturers and operators, Utilities
Additional information	Interdependent with C4, T3, T6, T9, T7, T12, T14, T15, T16, T17. Also builds on previous projects: ANEMOS Plus, OPTIMATE, From wind power to heat pumps, GridTech, Store
Budget estimated	100 million €
Timeline	2017 – 2022

T11	Demand response, tools for using DSR, load profile, EV impact
Contents	**Challenges:** The potential benefits of load control, such as peak shaving, and energy savings, must involve large-scale participation of industry, the tertiary sector and end consumers in order to assess the impact on TSO planning and operations. Usage of technologies such as smart meters and energy boxes must be included to add value to traditional demand side response (DSR), raise awareness about consumption patterns and foster active participation of manufacturers, services/ businesses and the customer in the energy market. **Objectives:** The main objective is to develop and integrate demand response mechanisms to provide services to the system. Add flexibility to the system (modulate the load curve) in order to increase overall system efficiency. Foster active customer participation in the system. **Scope:** Integration of demand-side management tools will allow customers at different levels to make more informed decisions about energy usage and will support TSOs and DSOs in electricity operations. The demand response mechanism will impact the market by offering economic incentives and optimising investments and the use of current assets in the network. Flexible generation needs to be considered as well with increased efficiency at both low and base loads, and faster ramp up times. **Specific tasks:** To achieve these goals, demonstration projects are required for demand-side management: » Define demand requirements and data required by TSOs for optimal DSR utilisation. » Demonstrate active customer (industry, tertiary sector and end consumers) involvement using “indirect” (provided post-consumption) and “direct” (real-time) feedback, in order to achieve a reduction in peak demand . » Integrate and demonstrate DSR and storage solutions, including the impact of transport system electrification (e. g., transport EVs, etc.) for off-peak hours, and their use in system balancing. » Develop simulation tools to include Vehicles to Grid capacity » Model customer/load behaviour and segmentation, and quantify the degree of flexibility provided by distribution networks, e. g., through reconfiguration or other methods. » Test DR models that bring demand response from private customers by, e. g., limiting the rated power during a specific period of time » To increase communication campaigns, to develop social impact studies and increase the involvement of local and territorial bodies in the early stage of planning of the infrastructure. » Assess the value for the system provided by flexible generation
Expected outcomes	The existence of load control provided by distribution at the TSO level allows TSOs to plan and operate the network in an efficient and economical way. In the short term, this will assist in reducing technical constraints and power collapse in the electricity grid; in the long term, it will reduce the expenses for energy reserve and prevent bottlenecks at the network level. Demand side management will boost the development of pay-out schemes for participants in demand response. Tools and models shall be developed for demand response and for customer behaviour to facilitate the forecasting and operational processes.
Expected impacts	Increased level of flexibility in TSO planning and operations will allow increased integration of RES while maintaining the security of supply at the pan-European level.
Contributors	TSO, DSOs, Manufacturers, Customers, Service providers, Research institutes, Industries, Energy companies
Additional information	Interdependent with T7, T8, T9, T15, T16. Also builds on previous projects: ANEMOS Plus, MERGE, eStorage (still on-going project), ‘From wind power to heat pumps’, GridTech, OPTIMATE, Ecogrid EU, Gredor, Cell Controller Pilot Project
Budget estimated	80 million €
Timeline	2017 – 2023

T12	Improved RES forecasting and optimal capacity operation
Contents	**Challenges:** Renewable energy sources such as wind, solar or marine generation are characterized by fluctuating output due to the changing nature of the primary energy sources. With increasing variable RES integration, reserves must be increased in order to maintain the stability of the system, thus avoiding the curtailment of wind or PV production. Forecasting the production of RES with a high level of accuracy is key for optimising of the system, especially in situations of high penetration of variable RES. Better forecasting can be achieved by utilising hybrid approaches that combine weather forecasts, local ad-hoc models, historical data, and on-line measurement. **Objectives:** The goal is to determine the best method for deploying and demonstrating different concepts using ICT, ancillary services and models for reliable energy output so that clean energy can be integrated, forecasted and smart managed in the network. **Scope:** The main focus is to improve the forecasting of RES to ensure optimal capacity operation and maintain the quality and security of supply. At the same time, focus should be placed on building up the structure to handle the large amounts of data that need to be collected, processed and analysed. Specific tasks: » Improve RES forecast accuracy by testing hybrid approaches that combine weather forecasting, local ad-hoc models, historical data, and on-line measurement. Measure improvements in accuracy due to use of high performance computers. Validate integration scenarios in which the network becomes more user-friendly and can cope with variable generation from RES. » Develop and demonstrate methods for dynamic capacity management and reserve allocation that support system operations with large amounts of RES integration. » Estimate secondary/tertiary power reserves against RES forecast accuracy/error. » Design and demonstrate market tools and investment incentives that support and promote RES generation flexibility, together with conventional sources of energy, for optimal balancing of the power system and ensuring system adequacy and efficiency.
Expected outcomes	Effective mechanisms, instruments and rules will be validated for the management of variable sources in system operation and power markets: » RES generation will be balanced cost-effectively over longer periods of time by optimising the entire value chain, including central and local assets. » Control procedures will be provided for system security and ancillary services, and will involve not only central power plants but also energy from RES (e.g., wind, solar).
Expected impacts	More RES will be integrated into the pan-European system without impacting its reliability. RES will deliver new value streams to the electricity system.
Contributors	TSOs, DSOs, Generation companies, Technology providers, ICT providers Customers
Additional information	Interdependent with T7, T10, T11, T13, T15, T16. Also builds on previous projects: OPTIMATE, ANEMOS, SAFEWIND, BEST PATHS, GridTech, Realisegrid, Seetsoc, WindGrid, EWIS.
Budget estimated	40 million €
Timeline	2019 – 2024

T13	Flexible grid use: dynamic rating equipment, power electronic devices, use of interconnectors
Contents	**Challenges:** The complexity of the pan-European network requires the development of transmission capacity and system operation to ensure flexibility and therefore security of supply in the presence of increasing volatility. Moreover, the advent of a single pan-European electricity market with a free flow of energy across multiple borders has led to increased cross-border power flows. Advanced transmission technologies must be tested and the management of existing lines must be improved. The integration of new technologies into existing infrastructures presents interoperability issues that must be solved. **Objectives:** Emerging power and information technologies will be developed and made ready for deployment to increase the flexibility and capacity of the existing power grid. Interconnectors should no longer be seen merely as fixed load/injections according to the underlying trading mechanisms, but they should also be able to provide grid operators with dispatching resources, both in contingencies and in normal situations. Achieve increased network flexibility for grid users at optimised OPEX, which allows for a larger share of RES and increased security of supply. **Scope:** The scope includes all devices that can be used to increase the flexibility of grid operation, new services rendered by interconnectors, and new materials/operating modalities that can broaden the palette of tools for use by grid operators to achieve secure and efficient network management. **Specific tasks:** » To demonstrate the degree to which transfer capacity can be increased by means of new operating schemes available through the implementation of different approaches and technologies; to investigate all possible technical solutions within the domain of each application; to perform cost-benefit analyses of different case studies. » To demonstrate power flow control devices that offer increased flexibility with respect to energy flows across multiple transmission zones and borders. » To demonstrate controllable off- and on-shore solutions for the vendor-independent, HVDC multi-terminal networks used to coordinate power flow, frequency control and coordinate protection and communications requirements. » Apply more DLR solutions, to become a standard practice for short term congestion and peak transmission line overloads. » To investigate the influence of parallel routing of DC and AC lines in the same tower or parallel paths to utilise existing infrastructure paths in an optimal manner. » To investigate HVDC reliability, especially for multiterminal and/or meshed DC grids.
Expected outcomes	Validation of new methodologies for upgrading the existing grid and increasing transmission capacity in a cost-effective and environmentally friendly manner. This will provide relief at network bottlenecks and help bridge short-term investment delays. Furthermore, power flow control devices shall favour new parallel options for transmission line development. Standards shall be set for health monitoring equipment for power system components at the pan-European level.
Expected impacts	The flexible use of the grid, through smart and optimised utilisation of its components, together with new services from storage, demand side and RES generation (see FOs T10, T11 and T12), shall provide to grid operators valuable tools for efficiently operating the system and synergistically leveraging all means available. At the same time, the environmental impact and the use of resources shall be minimised, also benefitting grid users and tariff-payers through more cost-effective operation, in terms of both OPEX and CAPEX. New methodologies will be validated for upgrading the existing grid and increase transmission capacity in a cost-effective and environment-friendly manner. This provides relief at network bottlenecks and helps bridge short-term investment delays. A more flexible grid will be implemented that integrates RES and helps cope with demand enabling of a low-carbon economy by preparing investment strategies based on least-cost asset replacement strategies.
Contributors	TSOs, Equipment manufacturers, Interconnector companies
Additional information	Interdependent with T6, T9, T10, T11, T12, T17. Also builds on previous projects: BEST PATHS, PROMOTION, PEGAS
Budget estimated	30 million €
Timeline	2021 – 2026

<table>
<tr><th>T14</th><th>Interaction with non-electrical energy networks</th></tr>
<tr><td>Contents</td><td>Challenges:

Decarbonisation is essential for coping with long-term EU sustainability targets, and electricity is one of the main vectors leading this transition.

From the demand-side perspective, electrification of the transport, heating and cooling sectors provides a pathway to fulfil this objective. On the generation side, it could be efficient for the energy system to coordinate and couple electricity generation with the gas supply for the combined cycles.

These issues show the increased complexity of trying to balance and manage network problems while still maintaining the security of supply.

Objectives:

» Promote actions that foster the transition towards a new model for a European energy system (heat, transport, gas, electricity).
» Develop tools to analyse balancing and congestion issues across the entire energy system and to support gas technologies in restoration plans.

Scope:

» Modelling the interfaces between different energy systems and analysing the mutual benefits among different energy systems (e. g., when utilizing power-to-gas for balancing and for electrification of the heating and transportation sectors).
» Exploration and demonstration of power-to-gas/heat projects and other interaction projects.

Specific tasks:

» Develop methodologies and tools to assess the impact of the transition towards a new model for a European energy system (heat, transport, gas, electricity)
» Joint planning.
» Study complex dynamics of the coupled systems when producing large quantities of methane (power-to-gas) to be injected into the gas grid and later used for the production of electricity.</td></tr>
<tr><td>Expected outcomes</td><td>Models and tools to manage balancing and congestion problems.

Methodologies and tools for assessing the impact of the transition towards the new energy model.

Valuable results from pilot projects.

Coordination of activities with other system players.</td></tr>
<tr><td>Expected impacts</td><td>Better and more optimal decision making tools.

More holistic models that make use of the most cost effective solutions for supplying energy.</td></tr>
<tr><td>Contributors</td><td>TSOs, DSOs, Utilities, Gas companies, Other system players and stakeholders (Transportation)</td></tr>
<tr><td>Additional information</td><td>Interdependent with T6, T8, T10, T12. Also builds on previous projects: Real-Smart, GridTech</td></tr>
<tr><td>Budget estimated</td><td>30 million €</td></tr>
<tr><td>Timeline</td><td>2017 – 2021</td></tr>
</table>

» CLUSTER C4: POWER SYSTEM ECONOMICS & EFFICIENCY

T15	Market/grid operation integration
Contents	**Challenges:** Pan-European power flows within a liberalised energy market, plus massive integration of variable RES, have resulted in local and regional bottlenecks, possibly causing a significant decrease in the capacities available for the market. A fair cost charging mechanism for network capacity use is needed. Regardless of the methods used to calculate and allocate cross-zonal capacities, risk assessment approaches must be implemented to control the costs derived from counter-trading measures. Risk assessment should be used to evaluate the trade off in economic surplus between the costs of redispatch and counter-trade on the one hand and the benefits of the resulting increase in capacity on the other hand. The main challenges to be addressed lie in the management of congestion and deviations from planned opera¬tions resulting from such a solution. This will require not only new transmission capacity and flexibility in power flow control, but also new tools for market and network analysis including for instance, stochastic approaches that enable better coordination between the day ahead market and the network. **Objectives:** Network-constrained market simulation tools should be developed to provide recommendations about specific network management and market designs. This will make it possible to manage congestion within the pan-European grids without affecting system reliability and while taking into account uncertainties, all possible corrective actions and dynamic ratings. The resulting simulation tools need to be synchronized with current market coupling initiatives. More specifically, evolution of the flow-based model for capacity calculation, with, for instance, stochastic approaches that enable better coordination between the market and the network, will be proposed. **Scope and tasks:** This FO consists of several steps that integrate the various elementary research results generated by the activities in Cluster 4: » Validate a flow-based market coupling approach that can be extended geographically and temporally (intraday horizons). » Define and validate a stochastic flow-based approach that enables better coordination between the market and the real network capacities. » Introduce simulation options that account for interactions between the various regulatory frameworks. » Define the modelling approaches and the associated data on transmission and generation that are vital to delivering meaningful results.
Expected outcomes	» Enhancement of the modelling of network flexibility and capacities (PST, HVDC, DLR and associated corrective actions) in market couplings. » Enhancement of the coordination between day-ahead and intraday markets (explicit modelling of uncertainties and risk assessment decisions).
Expected impacts	A more efficient IEM that takes into account grid flexibility, and an explicit modelling of uncertainties to increase cross-border exchange
Contributors	TSOs, Generation companies, Research institutes, Service providers, Regulatory authorities
Additional information	Interdependent with T9, T12. Also builds on previous project: OPTIMATE
Budget estimated	30 million €
Timeline	2018 – 2023

T16	Business models
Contents	**Challenges:** Huge investments will be necessary for the European energy system in the forthcoming years. These investments, necessary to achieve the energy transition, will be effective if they are financially acceptable to both the consumers and the investors. Synergies between the different energy sectors (electricity, gas, heat, etc.) and the different infrastructures should be identified in order to meet the conditions of acceptability. On the long-term horizon, electricity market designs should drive cost-effective investments in a coordinated cross-border approach; one can no longer ignore the impacts of intermittent energy sources on other parts of the power system. Investment is therefore one of the key issues in the forthcoming years for EU28. **Objectives:** The objective is to switch from tools that very precisely model the electricity sector under the assumption that the market is pure and perfect, to tools that take into account the entire energy sector and consider different actors that have various business models and strategies. **Scope and tasks:** Various tools will be developed to model globally the energy sector, taking into account the different roles and actors (carrying these roles) with their own interests, various regulatory frameworks and market designs. The interactions between the roles/actors should be modelled as well. Several tools need to be designed and developed: they involve a global modelling of the major energy carriers, able to account for the different roles and players involved, with their own interests and within different regulatory frameworks and market designs that shape their interactions. All capacity means ought to be considered (demand response, energy storage, generation), regarding their contribution to security of supply.
Expected outcomes	New mechanisms pushing towards the "optimal" investments needed to achieve the energy transition.
Expected impacts	Reduce the investment burden for the end consumer
Contributors	TSOs, Generation companies, Research institutes, Service providers, Regulatory authorities, Consumer associations
Additional information	Interdependent with T9, T10, T11, T12. Also builds on a previous project:
Budget estimated	20 million €
Timeline	2017 – 2021

T17	Flexible market design
Contents	**Challenges:** The European transmission grid has been evolving constantly for many years. More recently, markets have been changing with the growth of on- and offshore renewable production at different locations, and with different shares of various technologies. The integration of variable generation requires additional security margins. Additionally the present development of Distributed Energy Resources (DER) at local level raises the issue of both the integration of these resources in the markets and the way they can provide services to the electrical system. Therefore, consideration should be given to the development of improved market models on all time horizons and simulation tools that allow for the system capacity necessary to host a large share of RES generation in a cost effective wayand the most efficient integration of DER in the system More specifically, the monetisation of curtailments of wind/solar power generation with zero marginal cost remains an open issue. The criteria of security of supply in Europe must also be reviewed and made more consistent within a new context in which demand response, DER could play a more important role. This will lead from a situation where each member state define its own criteria to a more harmonised framework. **Objectives:** On the short-term horizon, market models will provide recommendations of specific rules for integrating renewables/DER in power, balancing, and system services, therefore enabling massive integration of RES/DER . For the long-term horizon, the impacts of intermittency of energy sources on other generation means due to zero marginal costs cannot be ignored. Investment issues will be the key issues in the forthcoming years. **Scope:** This FO will be based on what has been achieved in previous projects related to the integration of RES. The goal is to develop a toolbox that utilizes the building blocks from on-going projects. Therefore this will study the detailed impact of scalable and replicable solutions for renewable integration, using not only power markets but also system services. The toolbox will cover all the time horizons, from the investment horizon to balancing. **Specific tasks:** » **Short term:** Develop models and simulation tools to demonstrate the results of enforcing specific market designs for integrating renewables into power balancing and system services, while accounting for infrastructure development. In this way, RES can be freely integrated into the electricity market and the generation shift and power balance can be improved without interrupting the quality and reliability of service. » **Longer term:** Develop market models to drive more cost effective investments in a coordinated approach. Design mechanisms that assure both system adequacy and system security.
Expected outcomes	A simulation toolbox will be delivered that quantifies the economic impact of multiple renewable integration routes through large-scale experiments. The toolbox will consider all time horizons and will explicitly take into account the various regulatory frameworks implemented (some countries with strategic reserves, others with capacity mechanisms). The toolbox will help with proposing new designs at the European level.
Expected impacts	RES integration, security of supply, a more cost effective coordination of investments at the pan-European level.
Contributors	TSOs, Research institutes, Generation companies, DSOs, Power exchanges, Regulatory authorities
Additional information	Interdependent with T9, T10, T11, T12, T13. Also builds on a previous project: OPTIMATE
Budget estimated	20 million €
Timeline	2017 – 2020

T18	Big Data Management
Contents	**Challenges:** Data sets are growing rapidly, in part because they are increasingly gathered by cheap and numerous information-sensing mobile devices, aerial (remote) sensing, software logs, cameras, microphones, radio-frequency identification (RFID) readers and wireless sensor networks. The world's technological per-capita capacity to store information has roughly doubled every 40 months since the 1980s; as of 2012, 2.5 Exabytes (2.5×10006 Bytes) of data are created every day. One question for large enterprises is how to determine who should own big data initiatives that affect the entire organisation. What has really caused Big Data to go mainstream is the ability to connect not just with data scientists and technologists, but also business people. One of the keys to doing that is visualisation, or being able to show people – not just telling people or showing numbers or charts, but having those charts and graphs and visualisations come alive. The “Internet of Things” (IoT) (T22) is also expected to generate large amounts of data from diverse locations, with a resulting need to quickly aggregate the data, and an increased need to index, store, and process such data more effectively. IoT is one of the platforms of today's Smart City, and Smart Energy Management Systems. Accuracy in big data may lead to more confident decision making, and better decisions can result in greater operational efficiency, cost reduction and reduced risk. Most parties are reluctant to share the information hidden in the available data. Big Data management tools could be the key to opening the door to more professional sharing. **Objectives:** Develop ENTSO-E strategy for the application of Big Data management tools and applications in selected areas within the electricity sector. The expected value of the strategy shall be quantified/justified via descriptions of cases with high impact and/or increased efficiency resulting from use of the available information and/or prognostic information, thanks to improved data management practices/data processing technologies and intuitive visualisation. The aim of the strategy shall be to enhance TSOs decision making. The primary approach will be to identify and describe cases for transmission system operation, asset management and market facilitation. Integrate the big data management tools into the planning, asset management and operation activities of TSOs, taking all relevant stakeholders into account. **Scope and tasks:** » Develop a strategy for beneficial and relevant Big Data management initiatives within ENTSO-E through the use of relevant case studies. Develop, together with DSOs, ICT providers protocols for data transfer, utility business models and decision making support. Develop interfaces between Big Data management and the existing planning and operational tools. » Develop infrastructures or tools able to manage bigdata from different sources: planning tools, management tools, Smart-meters, social medias, etc. » Supporting advanced market platforms.
Expected outcomes	» Development of applications beneficial to the ENTSO-E stakeholders » A strategy for the ENTSO-E organisation regarding how to apply Big Data management tools and applications in future energy optimisation and operation of the energy system. » Improve awareness within the ENTSO-E organisation of the benefits of applying the concept of BigData management.
Expected impacts	» Long-term cost reduction and more efficient use of the existing electricity network » Increased transparency in operation and price setting. » Motivate sharing of know-how. » Improved advanced asset management. » Improved system analysis on a more advanced level. » New application of distributed energy resources » Lowering of entry barriers.
Contributors	Universities focusing on the topic of Big Data. Companies providing Big Data tools, applications and related services.
Additional information	Create a link to standardisation of data object – link to IEC 61850 and to information security for power system control IEC 62351 Interdependent with T5, T19, T20.
Budget estimated	20 million €
Timeline	2017 – 2021

T19	Standardisation, protocols for communication, and data exchange
Contents	**Challenges:** The long-term European energy vision (2050) requires a paradigm shift in communication that must be assessed at the pan-European level. Installation of a large amount of RES integration, inclusion of DER, new consumption demands, flexible demands, and energy storage will require a massive amount of communication and coordination among the parties involved, including system balance providers, transmission system operators, distribution system operators, service providers, production units, demand units, market operators, market platform providers, etc. Exchange and sharing of information will be crucial for an efficient use of all energy resources in future scenarios. Standardisation is key and could generate a highly competitive market to find the best technical solution, provided that deploying in the different countries incompatible systems is avoided. **Objectives:** The purpose of standardising a harmonised and limited set of protocols to support pan-European communication within the energy sector from a single generating unit to the market platform, as well as the transmission and distribution of energy to demand units, is to provide energy in an efficient manner by lowering the system integration barrier. An additional objective is to lower the integration cost and ease the system integration process through the use of standardised protocols. In order to lower the entrance cost of protocol stacks, it could be relevant to analyse the use of open source societies. The parties with the greatest interest in the outcome of this work stream will be actors in the electricity sector. Manufactures, system integrators, system operators and project developers will have a major interest in the deliverables. Scope: To select the most efficient and flexible communication protocol technologies, focusing on integration cost, flexibility and scalability in use. Apply experience from EU FP7 project M/490. **Specific tasks:** » Create recommendations regarding protocols to be promoted for specific communications purposes within the energy communication network system, e.g., the IEC 61850 standard series, IEC 61970 (CIM) standard series, IEC 61968 (CIM) standard series, IEC 62325 (CIM), IEC 61400-25 standard series, ISO/IEC 9594 standard series, ITU-T X500 standard series. » Application guidelines and recommended practices for implementation. » Identify needs for maintaining existing standards. » Develop standards for new needs in protocols services or extensions to existing standards. » Promote standardized information exchange solutions based on standardized protocols. » Promote use of open source initiatives. » To specify and define the specific interchange Data model between TSO-DSO, TSO-other agents (such as demand aggregators, EV charging managers…) in order to ensure the flexible operation of the network.
Expected outcomes	A common recommendation for a limited list of standardised communication protocols applicable to the entire European energy sector. Lowering the integration cost for distributed energy resources. Ease the way for integrating renewables. Promoting solutions with a reasonable information security level at a reasonable cost.
Expected impacts	» Request for maintenance on several standard series. » Creation of several liaisons to the various working groups within the standardisation bodies. » Increased allocation of resources for attending the various working groups, creating proposals for solutions, and proposing corrections to various standard series.
Contributors	IEC, CENELEC, ISO standardisation bodies and their relevant technical committees, e.g. IEC TC57, CENELEC CLC/TC57 ISO/IEC JTC 1/SC6, ITU X500
Additional information	» ENTSO-E statement on the application of IEC 61850 in Smart Grid applications » ENTSO-E application of IEC61970 and IEC 61968 (CIM) to exchange Common Grid Model (CGM) data » ENTSO-E application of IEC 62325 for energy market communications » Results from EU FP7 project M/490.
Budget estimated	20 million €
Timeline	2022 – 2026

T20	New technologies, Internet of things
Contents	**Challenges:** The Internet of Things (IoT) is the network of physical objects – devices, vehicles, buildings and other items embedded with electronics, software, sensors, and network connectivity – that enables the collection and exchange of data. The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems and resulting in improved efficiency, accuracy and economic benefit. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which encompass technologies such as smart grids, smart homes, intelligent transportation and smart cities. Each” ”Thing“ is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020. In addition to aiding the expansion of Internet-connected automation into a variety of new application areas, IoT is expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data, and an increased need to index, store, and process data more effectively. IoT is one of the platforms of today's Smart City and Smart Energy Management Systems In the future, the IoT may become a non-deterministic and open network in which auto-organised or intelligent entities like web services, service oriented architecture (SOA) components, objects standardised by the Organisation for the Advancement of Structured Information Standards (OASIS), and virtual objects (avatars) will be interoperable and able to act independently (pursuing their own objectives or shared ones), depending on the context, circumstances or environment. For the past six years, the European Commission has worked actively with Member States towards the development and future deployment of the IoT technology, creating a European Single market for a human-centred IoT and investing in fostering an innovative IoT ecosystem. The European Commission has also set in its Communication “Advancing the Internet of Things in Europe” the Digitalisation of the Energy sector as a key area of research and applications of the IoT approach . **Objectives:** Create awareness in the ENTSO-wE organisation of the benefits of applying IoT technologies in combination with Big Data applications. Recommend an ENTSO-E strategy for application of IoT in selected areas within the electricity sector. The expected outcome/value of the strategy will be quantified/justified via descriptions of cases involving a high number of distributed sensors and an increased efficiency due to use of IoT. The aim of the strategy shall be to enhance decision-making in targeting the TSOs in the first round. **Scope:** » To study the available IoT applications and expected services. » To recommend a strategy to ENTSO-E for the application of IoT in selected areas within the energy sector. **Specific tasks:** » Assess the potential benefits of intensifying the use of IoT in TSO activities. » Develop an ENTSO-E whitepaper and/or a technical report on the benefits of applying IoT and related tools in the electricity sector. » Create study and white paper regarding the secure application of IoT technologies through the public internet, taking both risks and privacy into account. » Develop the interface tools needed to intensify the use of IoT in TSO planning, asset management and operational activities.
Expected outcomes	Development of applications beneficial to the stakeholders of ENTSO-E. A strategy for how the ENTSO-E organisation can apply IoT in the future energy system.
Expected impacts	Increased network security
Contributors	» Universities focusing on the topics of IoT » Companies providing IoT services and tools. » ITU-T study group SG17 – smart grid devices » Interdependent with T18, T21. Also builds on the JRC report on Smart Grid projects
Additional information	Interdependent with T18, T21. Also builds on the JRC report on Smart Grid projects.
Budget estimated	30 million €
Timeline	2017 – 2023

T21	Cybersecurity
Contents	**Challenges:** Computer security, including cyber security and information security, refers to the protection of IT systems from theft or damage to the hardware, software, and the information on them, as well as from disruption or misdirection of the services they provide. This includes controlling physical access to the hardware, as well as protecting against harm that may come via network access, data and code injection, and malpractice by operators, whether intentional, accidental, or due to being tricked into deviating from secure procedures. This field is of growing importance due to the increasing reliance on computer systems in most industrial sectors and societies. Computer systems now include a wide variety of "smart" devices, including smartphones, televisions and tiny devices, as part of the IoT, and networks include the Internet and private data networks. **Objectives:** The objectives to be dealt with for this task, among others, include the following: » Security measures, monitoring, detection and reactions » Reducing vulnerabilities » IT Security by design for power system security » Security architecture » Hardware protection mechanisms » Secure and robust controls and operating systems » Secure coding and encryption » Secure cross-sector identification and authentication » Network and information access control » Response to breaches, and warnings to actors within the sector » Cross-border coordination within the electricity sector. **Scope:** » Publish a strategy for the cybersecurity area within TSO businesses. » Publish a best practice guideline for TSO substation and ICT system security design. » Publish a dissemination plan for promoting the strategic initiatives. **Specific tasks:** » Create a strategy for cybersecurity within ENTSO-E. » Create a best practice guideline for TSO substation and ICT system security design. » Create a dissemination plan for promoting the strategic initiatives.
Expected outcomes	A recommended strategy and design guideline for ENTSO-E to achieve a secure solution based on state-of-the-art information security technologies and the best theory and practices, combining information and power system security.
Expected impacts	Increased network security
Contributors	ITU-T, IEC TC 57, CENELEC TC57X, EC Connect, ENISA, ISO JTC 1, ISO/IEC JTC 1/SC 6, IETF
Additional information	Interdependent with T6, T17, T16. Also builds on: » ITU-T strategy for the IT and banking sectors » EU digital single market – related aspects of the programme » EU digitalisation of the power system program initiatives » EU cyber security project reports – strategy outcome
Budget estimated	20 million €
Timeline	2022 – 2026

Public

APPENDIX 2 CONSULTATION OUTCOMES

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Opinion

» APPENDIX 2: Consultation outcomes

The present Roadmap has been submitted to a consultation process prior to publication, including several steps:

- » Inputs and directions from the TSO community through RDIC members and individual TSOs;
- » Internal consultation within all ENTSO-E Committees (Market Committee, System Operation Committee, System Development Committee) and Secretariat bodies;
- » External consultation with particularly involved stakeholders (EERA, EDSO for Smart Grids, EASE, Technofi), through bilateral interaction and constructive joint analysis;
- » External consultation with ETP Smart Grids and Member States through the Grid+Storage project
- » Public consultation via website procedure open to the general public, as well as through proposed questions to focus the comments.

The Roadmap also builds on the wide public consultation project carried out in 2015 regarding the 2016 – 2018 Implementation Plan and on the qualified opinions received from ACER, which has been mandated inter alia to provide opinions about R&I deliverables from ENTSO-E.

Comments were received from: EASE, IPE, INESC, USTRATH, Fraunhofer, SINTEF, RSE, Technofi, EDF, TSO Bosnia and Herzegovina, Schneider Electric.

The public consultation also proposed to "score" the relevance and urgency of the FOs, with the result summarised in the following table (Figure 31).

The main outcomes of these consultations, as well as the consequent reactions, are reported in the following tables (Figure 32). The comments are classified into three categories: methodology & planning process, research and development general topics, and clusters/functional objectives

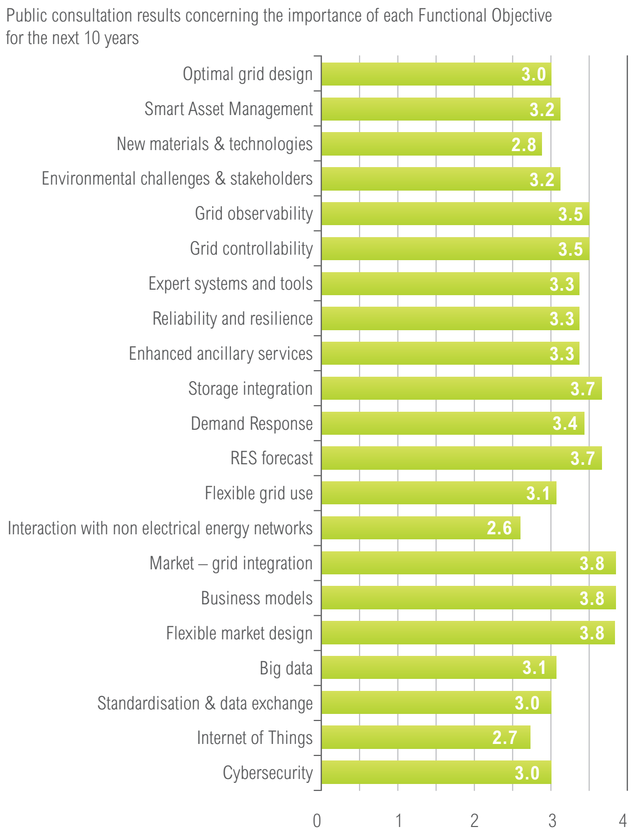


Fig. 31: Relevance of FOs from Public Consultation

Type of comment	Issue & rationale	Reaction towards this Roadmap
Multiple R&I planning instruments (from several respondents)	Mutual consistency and/or hierarchy among the several others R&I planning instruments for power sector at European level: Strategic Research Agenda of ETP Smart Grids, EEGI Roadmaps, EC Horizon 2020 Work Programs, SET Plan Integrated Roadmap, JRC map, etc.	With a highly cooperation effort, this Roadmap is the first one fully coordinated with the Integrated Roadmap and deeply inspired by the overarching trends set by technology and by European energy-climate policies. However, TSOs perspective on R&I has been maintained, as per ENTSO-E mandate, in synergy with other stakeholders' perspectives.
Prioritisation of topics (from several respondents)	Prioritisation of topics and the timetable are not elaborated in detail.	The Roadmap sets the frame for a 10 years period, afterwards the yearly updated Implementation Plans shall point out the priorities on specified topics.
Monitoring of Roadmap	The advancement status of the clusters of Roadmap has been used only partially for setting future Functional Objectives.	Indeed this, together with scenario modifications, triggered the need of revision of the original Roadmap, updating the Functional Objectives .
R&I results' application	A coordinated approach that translates research to innovation, to demonstration, to deployment of results would be very important, also as a way of measuring R&I societal and system benefits.	This issue has been properly addressed in Application Report 2014 and an ad-hoc Impact Assessment in 2015, which is summarised in Appendix 3.
Coordination among national and EU R&I programmes	In order to optimise the use of resources and the sharing of results.	ENTSO-E has recently introduced a further activity, inter-TSO cooperation on R&I, encompassing all R&I projects (not only those European-funded) in order to share best practices and to optimise resources.
Clarifications	Several requests of specific clarifications (e.g. on SWOT analysis, on source of data, on consistency within ENTSO-E deliverables, etc.)	Relevant improvements have been made in the text, figures and data.

Fig. 32: Summary table of consultation No. 1

» RESEARCH AND DEVELOPMENT TOPICS – GENERAL

Type and source of comment	Issue & rationale	Reaction towards this Roadmap
TSO-DSO joint projects	More emphasis should be put on joint TSO-DSO projects and on the promotion of an "Integrated Grid" approach.	Acknowledging the importance of stronger interaction between transmission and distribution networks, the TSO-DSO cooperation is now included in many (if not all) Clusters rather than being a Cluster itself.
Consumers (and prosumers) focus	More emphasis on demand side, consumer focus & related market developments	Although TSOs have little direct relation with consumers, however more and more attention has been placed on these aspects (see sections "Evolving in a changing context", p. 20 and "European R&I framework and new ENTSO-E strategy for R&I", p. 26), which shall bring along further paradigm shifts in the whole supply chain.
TRL level	Include indications on maturity, present and target, of R&I actions	It has been applied in the Impact Assessment of past projects and in the indications of next steps stemming from those projects; next step will be to apply the concept also to the planning stage.
Relevance of FOs	A questionnaire in public consultation tested the relative relevance of FOs	The indications, if shared by TSOs, shall be considered when prioritising topics and proposing R&I projects in the Implementation Plans

Fig. 32: Summary table of consultation No. 2

» CLUSTERS AND FUNCTIONAL OBJECTIVES

Type and source of comment	Issue & rationale	Reaction towards this Roadmap
Market – related topics	More orientation to future business models and to the opportunities deriving from the fully integrated EC power market.	The market Cluster has been changed into Economy and Efficiency of the power system, enlarging the perspective from market rules to include also business models and tools for new market actors and new interactions among them.
ICT	It was suggested to have more emphasis on Information/ICT tools, cyber security, control instruments.	TSOs see themselves as users of such tools/instruments, rather than developers; in any case a whole Cluster has been set-up on digitalisation of the power system, and in particular a specific Functional Objective has been dedicated to Cybersecurity.
Cross-cutting issues	Several topics are overlapping among them and/or are cross-cutting.	In order to make a classification and organisation of topics, which is a useful tool for R&I management, and is in line with the Integrated Roadmap, some assumptions must be taken about cross-cutting issues.
Budget	Many requests about budget identification.	The indicated budget is a general estimation, based on past experience, and it is not a project cost forecast, neither a request to any funding/regulatory entity.
Specific contents	Several comments have specified the state-of-the-art of technologies and tools.	The relevant Functional Objectives Scope and Tasks have been fine-tuned correspondly

Fig. 32: Summary table of consultation No. 3

R&I

APPENDIX 3
ASSESSING R&I PROJECT RESULTS

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Delivers

» APPENDIX 3: Assessing R&I project results

APPENDIX 3.1 APPLICATION REPORT

» APPLICATION REPORT

The R&I Application Report, published by ENTSO-E in March 2015, has addressed the use of R&I project results (with a main focus on EC-funded projects) in the TSOs' daily business. The report addresses nine relevant EU-funded projects that were finalised between 2009 and 2013, and which involved one or more TSO members of ENTSO-E (ANEMOS Plus, EWIS, ICOEUR, MERGE, OPTIMATE, PEGASE, REALISEGRID, TWENTIES and WINDGRID).

The following concrete examples were extracted from the full report (available on ENTSO-E's website): the use of the TWENTIES project results in the development of the interconnector project between Spain and France (HVDC technology, dynamic rating), and the use of new tools for wind generation forecasting (WINDGRID and ANEMOS projects) and load simulation (MERGE project) by REN.

» MONITORING AT THE CLUSTER LEVEL

Through inter-TSO cooperation, support from the European Commission, and clearly defined goals in the ENTSO-E R&I Roadmap 2013–2022 and associated Implementations Plans, the projects carried out have achieved significant results. About 20 projects showing a beneficial outcome and strong involvement of TSOs have been financed or co-funded by the EC in the last six years. On top of that, plenty of started and already-completed projects have been implemented at national level, whose results can be utilised through knowledge sharing activities. A set of significant projects are summarised and presented, grouped by the clusters found in the ENTSO-E Roadmap 2013–2022.

Selection of these projects was done by measuring how the achievements of each project contribute to the tasks described in the ENTSO-E Roadmap 2013–2022. If the project fulfils a particular requirement in the R&I Roadmap and the relevant task is more than 75% completed, the project is described below.

» CLUSTER 1: GRID ARCHITECTURE

The methodology developed in the **e-Highway 2050** project supports the planning of the Pan-European Transmission Network. The project focuses on different scenarios for the grid architecture in 2050. The generated models are used to ensure reliable delivery of renewable electricity and will assist in the development of a pan-European flexible electricity market.

Realisegrid is a project with a target horizon of year 2030. The result will be a set of methods, criteria, metrics, and tools for determining how the transmission infrastructure should be optimally developed to support a reliable, competitive and sustainable electricity supply in the EU.

The outcome of the **REAL-SMART** project is to convert wide-area measurements into information about the real-time performance and operation of the transmission system.

Early Warning Systems (PMU/WAMS) is a project in which new algorithms are developed to foresee and select control actions to prevent power system instability and security risks. The project builds up early warning system awareness and real-time operation using PMU-WAMS technologies.

TWENTIES has developed large-scale demonstrations to show the benefits of novel technologies (most of them available from manufacturers) coupled with innovative system management approaches to enable the transmission network to meet the demands of renewable energy while maintaining its present level of reliability and performance.

The tools developed in the project will be used and demonstrated at the pan-European level in different TSOs for different purposes. They could be used to provide system services through aggregated wind farms, scalable IT platforms, overload line control, dynamic system power evacuation capacity operations, and models for full-scale experiments of two different HVDC circuit breaker technologies, etc.

PoStaWind investigates how the 'synthetic inertia' control scheme from RES units can support and influence power system voltage, angle and frequency stability.

The result of **Concept for management of the future electricity system 2025** is a model of the Danish power system for 2025, which includes an integrated 70 % renewable energy source mainly installed in the LV or MV grid. This design provides an opportunity to examine the system behaviour, balance the transmission grid, and secure the supply of ancillary services.

» CLUSTER 2: POWER TECHNOLOGIES

The **EWIS** project has been in operation since 2010 and includes the control of phase shift controllers and a pilot for Flexible Line Management (TenneT North South Corridor, Germany). This project also enables planners to combine grid-market modelling with a cost-benefit analysis.

The **TWENTIES** project affects this cluster through its Demos 5 and 6, dynamic line ratings, coordination of power technology devices, and new power flow management system.

The goal of the **220 kV SSSC device for power flow control** project is to maximise the utilisation of the current electricity system by taking into account renewable energy integration, developing technologies based on power electronics, and explicit application of FACTS and HVDC devices. A full-scale 220 kV Static Synchronous Series Compensator (SSSC) demonstration will be in operation in Spain.

The **Cell controller pilot project** has developed a system for fully automated operation and optimal utilisation of increasing amounts of decentralised production. The project focuses on the import and export of active and reactive power flow, full voltage and frequency control and black start mode.

ANEMOS PLUS is looking at progressive, intelligent management software wmodels based on stochastic approaches used to evaluate the variability and control of wind power under real conditions. These tools perform optimal reserve estimation for a system with high wind penetration, congestion management using localised wind power forecasts, determination of optimal usage of hydro storage, and scheduling of other available generation combined with wind farms and optimal trading of wind power in the electricity market.

The **From wind power to heat pumps** project offers an innovative approach to controlling many intelligent heat pumps at one energy storage facility. It will demonstrate more than 300 interconnected heat pumps in real private homes that can store electricity in the form of heat when wind generation is strong, later using this stored heat energy to heat their houses.

The **REAL-SMART** project will influence this cluster with the results of a work package called "Quantifying the dynamic impact of wind generation on the grid."

The **NETZ:KRAFT** project provides methods, schemes, procedures and controls for RES to contribute to system restoration plans involving all German TSOs as well as RES vendors.

» CLUSTER 3: NETWORK OPERATION

UMBRELLA – This project involves the development of an innovative toolbox prototype to assess and forecast uncertainties in complex system operations resulting from renewable energy in-feeds and market activities. The result is the optimisation of algorithms that provide risk-based assessment in support of short-term trading, ensuring electricity demand and preventing power plant outages.

AFTER – The main objectives of this project are to define methodologies for vulnerability identification, global risk assessment and contingency planning, considering the interdependencies with information communication technology (ITC) systems. The risk-based models and tools already developed in this project will be used for the definition and assessment of defence plan and analysis of the restoration phase.

GARPUR – This project is for the development of a state-of-the-art quantification platform for risk-based security analyses using risk indicators that compare the technical and economic benefits of the different reliability criteria for various TSO businesses and time frames. These new and reliable management tools will support system operators in making decisions in short-term operational planning and real time operations with advanced regulation and diagnostics technologies.

PEGASE – The project deliverables are powerful algorithms and a full-scale prototype of the Pan-European Transmission Network model for state estimation, dynamic analysis, steady-state optimisation and dispatcher training simulations. This project provides an opportunity for TSOs to employ advanced real-time control and operational planning.

Energy Data Feed – The project is establishing metering points that permit detection of irregularities and trigger follow-up research steps to prevent instability and disturbances.

REAL-SMART – The project has been looking at applying probabilistic approaches in wind integration for system planning.

» CLUSTER 4: MARKET DESIGN

The **REAL-SMART** project is related to the market design cluster, with the realisation of a work package called "Interactions between heavy industrial loads and the grid."

Results of the **OPTIMATE** project allow the testing of various configurations of balancing market designs: numerical simulations of cross-border balancing, ability to perform studies on congestion management, and market integration of RES in the pan-EU electricity market.

The achievements of the **ANEMOS Plus** project have had a big impact in this cluster, as well as in power technology development.

The **From wind power to heat pumps** project is looking at storage facilities that provide flexibility and optimisation in the electricity market.

» CLUSTER 5: ASSET MANAGEMENT

GARPUR – The project could provide a strong contribution to asset management and decision processes for system development through a new methodology for risk-based security criteria. Innovative models are being developed to predict the deterioration process of fundamental electrical elements of the grid and to analyse the consequences and probabilities of their failures.

» CLUSTER 6: JOINT TSO-DSO R&I ACTIVITIES

SAFEWIND – This project is developing progressive tools for wind power forecasting, with a focus on difficult weather situations and extremes that can have a crucial effect on power system reliability. The deliverables of the project are innovative solutions to assist in large-scale integration of wind energy, tools for predicting loss of power, alarm systems for large forecast errors, forecast models, and applications that use distributed measurements to improve wind power prognosis at DSO and TSO levels.

ANEMOS Plus – The results of this project within this cluster encourage TSO and DSO participants to quantify the benefits of additional reserves required to cover the volatility of wind generation. The stochastic methods developed in this project for wind power forecasting in the short and long terms aid TSOs and DSOs in processes such as reserve estimation and congestion management.

The **PROBA** project offers a methodology and prototype tool for TSOs in order to estimate the risk indices related to connecting new distributed generation units at the TSO/DSO boundary.

The **Cell controller pilot** project has a big influence in this cluster. The project was established to promote and demonstrate the capability of using distributed generation and other energy resources connected to distribution networks for grid reliability and power-flow-related applications, such as power balancing, voltage control, ancillary services, etc.

Most of these projects have impacts in several clusters because the clusters depend on each other and are strongly connected. Some of the projects have been implemented using EC co-funding, and some are being executed on the national level using self-financing. The results seen so far provide a good base for the development of further goals and projects in research, development, demonstration, and innovation for a reliable pan-European electricity grid.

APPENDIX 3.2 IMPACT ASSESSMENT: ANALYSIS OF ON-GOING AND RECENTLY COMPLETED PROJECTS

» PURPOSE OF THIS ANALYSIS FOR ENTSO-E

This report provides a synthesis of 50 R&I projects in which one or several European TSOs are or have been involved between 2007 and 2019.

The analysis refers to the clusters and functional objectives from the original Roadmap (2012-2023) and serves two purposes:

- » To guide the update of the ENTSO-E R&I roadmap
- » To monitor and facilitate the adoption of the projects' key achievements into TSOs' daily work.

» METHODOLOGY IMPLEMENTED

Selected projects:

- » Finished in 2013 or before
- » Recently finished or finishing (end date between 2014 and June 2016)
- » On-going (end date after 2016)
- » Just started (start date in 2015-2016)

Types of achievement:

- » Methodology (includes methodology for designing new rules, scenarios, …)
- » Software (includes development and demonstration of simulation tools, decision making support tools, …)
- » Hardware (includes development or demonstration of pieces of hardware)
- » Database (includes quantified scenarios, results of cost-benefit analyses, …)
- » Policy, regulation, market (includes business models, policy recommendations, …)
- » Other

Types of next steps:

- » Further research
- » Further development
- » Demonstration
- » Deployment

Technology Readiness Level (TRL):

- » TRL 1 – basic principles observed
- » TRL 2 – technology concept formulated
- » TRL 3 – experimental proof of concept
- » TRL 4 – technology validated in lab
- » TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- » TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- » TRL 7 – system prototype demonstration in operational environment
- » TRL 8 – system complete and qualified
- » TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The completed questionnaires corresponded to 50 projects and their related 176 main achievements, out of which 16 have been identified as the "most promising." Most of the remaining 160 achievements were identified as intermediate results, calling for further research, further development or a demonstration. The 16 most promising achievements are presented below, along with their probable year of implementation in the TSO environment.

2016: Modular plan for pan-European grid architectures 2050

The **e-Highway2050 project** (2012–2015)[1] was aimed at developing a methodology to support the planning of the Pan-European Transmission Network, focusing on 2020 to 2050, to ensure the reliable delivery of renewable electricity and pan-European market integration. The project has resulted in a modular development plan for electricity highways and options for a complete pan-European grid architecture based on various future power system scenarios. ENTSO-E is currently investigating how the project results will be exploited for the 2016 TYNDP. More specifically, TYNDP teams have shown major interest in key components such as the systematic methodology for building 2050 energy scenarios, the methodology for building the equivalent grid model, the methodology for scenario quantification and the methodology for proposing transmission investment needs per scenario.

2018: Towards a probabilistic planning approach

The **GARPUR project** (2013–2017)[2] is designing a new Reliability Management Approach and Criteria (RMAC) for the pan-European electric power system. The methodology takes into account the spatial-temporal variation of the probabilities of exogenous threats, the socio-economic impact of TSOs' decisions, and corrective control measures and their probability of failure. It covers the multiple decision making contexts and timescales (long-term planning, mid-term asset management, and short-term planning for real-time operation). A full implementation of GARPUR is likely to require further research before effective deployment. On the other hand, the new RMAC could be implemented in priority for the grid planning activities; it will be easier for a TSO to implement the GARPUR concepts in an off-line environment (grid planning) than in an online environment such as a real-time operation.

1) Co-funded by FP7. The consortium includes RTE (FR), Amprion (DE), REN (PT), Elia (BE), ČEPS (CZ), Swissgrid (CH), Terna (IT), 50Hertz (DE), APG (AT), Energinet.dk (DK), IPTO (GR), REE (ES) and SVENSKA KRAFTNÄT (SE). See www.e-highway2050.eu.

2) Co-funded by FP7. The consortium includes Statnett (NO), Elia (BE), RTE (FR), Landsnet (IS), ESO (BG), ČEPS (CZ) and Energinet.dk (DK). See www.garpur-project.eu.

From 2014: Preventing overload situations in the 220 kV transmission grid

The **220 kV SSSC Device for Power Flow Control project** (2009–2014)[3] was aimed at designing, constructing, setting up and testing a SSSC (Static Synchronous Series Compensator) device to prevent overload situations in the Spanish 220 kV transmission grid due to increased renewable distributed penetration. SSSC installation will consequently reduce the measures that the Spanish TSO REE needs to take to solve such overloads, like reducing the meshing of the network or curtailing wind production. The project has been successfully completed, as the SSSC (rated 47.8 Mvar, 12.5 kV) has been installed in the Spanish 220 kV transmission grid; it is currently in operation in the 220 kV Torres del Segre substation to control power flow on the 220 kV Torres del Segre-Mequinenza overhead line. This is the first ever implementation of a key FACTS device such the SSSC in the European transmission system. It must be noted, however, that the scale-up of SSSC applications for larger power ratings and higher voltage levels (300–400 kV) may be problematic in terms of protection for short circuit currents and design of the VSC converter, which, instead of being the three-level type as in this project, should be upgraded to a multi-level type. A multi-level VSC converter for series installations at 400 kV has not yet been implemented anywhere in the world.

From 2015: Implementation of technologies for increasing grid capacities

The **TWENTIES project** (2010–2013)[4] included six demonstration projects to remove several barriers preventing the electric system from accepting more wind electricity, and preventing wind electricity from contributing more to the electric system. The full-scale demonstrations were aimed at showing the benefits of novel technologies (most of them available from manufacturers) coupled with innovative system management approaches. In particular, the 5th demonstration aimed to demonstrate that adequate coordination mechanisms between DLR, power flow controlling devices and WAMS provide more flexibility to the electric system at an affordable cost. This has led to the deployment and daily use of 80 DLR devices in Belgium.

2016: A database of power system technology cost and performance

Developed as part of the **e-Highway2050 project** (2012–2015), an open access database of cost and performance over the period of 2015–2050 represents an asset for further collaborative R&I projects, for use in grid planning studies, or more generally, for any type of study involving power technologies and their cost and performance trajectories over the period 2015–2050. It is accessible on the **GridInnovation-on-line platform**[5].

2018: Innovative repowering of AC corridors

The **BEST PATHS project** (2014–2018)[6] is developing novel network technologies to increase the pan-European transmission network capacity and electricity system flexibility. Five large-scale demonstrations are being carried out to validate the technical feasibility, costs, impacts and benefits of the tested grid technologies. In particular, the 4th demonstration will deliver new know-how concerning innovative high-temperature low-sag (HTLS) conductors and insulated cross-arms, DLR, tower design and field work (live-line working) for the repowering of existing AC overhead lines. The results will be packaged into a self-standing line upgrade

3) Granted by PSE and INNPACTO (Spanish R&D Programs). The consortium includes REE (ES). See www.ree.es/en/red21/rdi/rdi-projects/redirection-power-flows.

4) Co-funded by FP7. The consortium includes Elia (BE), Energinet.dk (DK), RTE (FR), 50Hertz (DE), TenneT DE (DE) and REE (ES). See www.twenties-project.eu

5) See www.gridinnovation-on-line.eu

6) Co-funded by FP7. The TSOs in Demo 4 are 50Hertz (DE), Elia (BE), Statnett (NO), REE (ES) and Mavir (HU). The consortium also includes RTE (FR), Terna (IT) and Energinet.dk (DK). See www.bestpaths-project.eu.

package, which will help TSOs deliver overhead lines that are more compact (and therefore more acceptable from a visual standpoint and less demanding in right-of-way), robust against fluctuating power profiles, flexible in terms of exploitation (reducing the need for new AC overhead line corridors), and affordable to run (acceptable CAPEX and OPEX figures, including maintenance). The combination of the solutions will enhance the existing system approach to AC overhead line repowering. It will also help TSOs and utilities to keep overhead lines reliable and resilient in light of the developments in the European energy system, and will allow replication by other ENTSO-E members.

2019: Offshore grid development in northern seas

In order to unlock the full potential of Europe's offshore resources, network infrastructure is urgently required to link the off-shore wind parks and onshore grids in different countries. HVDC technology is envisaged, but the deployment of meshed HVDC offshore grids is currently hindered by the high cost of converter technology, lack of experience with protection systems and fault clearance components, and immature international regulations and financial instruments. **The PROMOTION project** (2016–2019)[7] aims to overcome these barriers by developing and demonstrating three key technologies, a regulatory and financial framework, and an offshore grid deployment plan for 2020 and beyond. This project not only demonstrates all elements needed to build a meshed offshore grid, but also brings together the future workforce in Europe, which will design, build and operate the commercial network. The first key technology presented is the Diode Rectifier offshore converter. This concept is ground-breaking, as it challenges the need for complex, bulky and expensive converters, significantly reducing investment and maintenance costs and increasing availability. A fully rated compact diode rectifier converter will be connected to an existing wind farm. The second key technology is an HVDC grid protection system that will be developed and demonstrated by utilizing multi-vendor methods within the full-scale Multi-Terminal Test Environment. The multi-vendor approach will make DC grid protection a "plug-and-play" solution. The third technology pathway will, for the first time, demonstrate the performance of existing HVDC circuit breaker prototypes to provide confidence and show the technological readiness of this crucial network component. The **PROMOTION project** will take into account the results of the **BEST PATHS** and **TWENTIES** projects.

7) Co-funded by H2020. The consortium includes TenneT NL (NL), RTE (FR), SVENSKA KRAFTNÄT (SE), EirGrid (IE), Energinet.dk (DK) and SHE Transmission (GB)

From 2012: Wide Area Monitoring Systems

The WAMS developed and upgraded within the **ICOEUR project** (2019–2012)[8] have been put into operation by several TSOs worldwide. In Europe in particular, as of 2016, WAMS have been integrated into the systems of the TSOs in Slovenia, Germany, Spain, France, Montenegro and Serbia.

From 2013: Short-term probabilistic forecasting of wind power

The **ANEMOS.plus project** (2008–2011)[9] was aimed at optimising the management of electricity grids with large-scale wind power generation. For this purpose, probabilistic tools that integrate wind power forecasts and related uncertainty in power system's key management functions were developed and demonstrated. The ANEMOS forecasting platform has been implemented by the system and market operator in Australia (AEMO) and is used there as the forecasting tool for all renewable installations.

From 2015: A toolkit for security policy-makers

The **SECONOMICS project** (2012–2015)[10] delivered a toolkit for security policy-makers seeking to understand their policy alternatives and the potential impact of their decisions. It is a methodological revolution driven by a common but diverse set of modelling tools, utilising recent advances in modelling technology that seamlessly transverse the social, economic and technological domains. Part of the methodology resulted in an amendment to the Common Vulnerability Scoring System (CVSS), the worldwide standard for software vulnerability assessment developed by FIRST.ORG. It has already been adopted by the standard body in the CVSS v3.0, issued in December 2014. CVSS is a general methodology used by several TSOs for evaluating the security of their SCADA systems.

2018: Tools to cope with increasingly uncertain operating conditions

The **iTesla project** (2012–2016)[11] has delivered several pieces of software that form a new security assessment tool capable of coping with increasingly uncertain operating conditions and taking advantage of the growing flexibility of the grid. When considering online security analysis tools that simultaneously address the dynamics of the system and the uncertainties, only a limited number of simulations can be run in real-time. This severely limits the scope of analysis and forces system operators to operate in a conservative manner. The iTesla toolbox addresses this issue by carrying out extensive analyses beforehand on system states that are likely to occur, through the use of an online and an offline platform. Further developments are still needed to fully validate the added value of the iTesla prototype toolbox. After the end of the project, RTE (the French TSO) will build full-size (spatial and temporal) use cases to provide insights into system security and demonstrate the added value for operators, both in technical and economic terms. This validation should last two years, with the final goal of introducing an industrial version of the toolbox in an operational environment (control room) for preliminary tests by 2018.

The **Umbrella project** (2012–2015)[12] has also delivered a toolbox prototype that enables TSOs to act in a coordinated European target system, where regional strategies converge to ensure the best possible use of the European electricity infrastructure. Exploitation of the toolbox is being addressed within the framework of TSC. Umbrella and iTesla projects have cooperated to deliver common recommendations to ENTSO-E.

8) Co-funded by FP7, Russian FASI Agency and National institutions. The consortium includes Terna (IT) and ELES (SI). See www.icoeur.eu.

9) Co-funded by FP6. The consortium includes EirGrid (IE), REE (ES), REN (PT) and SONI (NI). See www.anemos-plus.eu.

10) Co-funded by FP7. The consortium includes National Grid (GB). See www.seconomics.org.

11) Co-funded by FP7. The consortium includes RTE (FR), Elia (BE), National Grid (GB), REN (PT), Statnett (NO) and IPTO (GR). See www.itesla-project.eu.

12) Co-funded by FP7. The consortium includes TenneT DE (DE), Amprion (DE), ČEPS (CZ), ELES (SI), TransnetBW (DE) and PSE S.A. (PL). See www.e-umbrella.eu.

2018: Towards the digitalisation of existing substations

Within the **Smart Substation project** (2012–2017)[13], a refurbishment of the existing protection and control systems for two large substations (10 Bays 225 kV, 12 Bays 90 kV) is being carried out. The deployment of the smart substation will allow testing, in real operations, of a local state estimator, weather-based dynamic ratings for transformers and OHL, digital paralleling of voltage regulation, WAC Units and 61850 WAN for extended benefits across neighbouring substations, automatic fault analysis, and location. The deployed solution will allow network operators to better manage congestion thanks to local optimisation and distributed intelligence, and to host more renewables such as wind power. The deployment of the smart substation will also allow the testing of asset management functions in real operations. The deployment is on-going and the substation should be operational for validation by April 2016. Validation of the entire set of functionalities will last until February 2017. The construction of databases for long-term analysis is being done using the latest IT technologies (IoT, Big Data). A cost-benefit analysis will be used to validate the added value for the network operator.

2019: Real-time and short-term forecast assessment of operating limits

Funded by the Slovenian TSO ELES, the **SUMO project** (2011–2019)[14] is developing a system for real-time and short-term forecast assessment of operating limits. Methods and software have been developed to deal with the highest allowable power flows of the transmission line considering all weather situation. The SUMO system uses different heterogeneous subsystems from different vendors, and the results of the calculations are aggregated and shown in the network control centre by means of the visualisation platform ODIN-VIS and the SCADA/EMS system. The main expected outputs are methods and software for evaluating and forecasting Dynamic Thermal Rating (DTR), fast methods for performing N-1 analyses, and implementation of an alarm system for extreme weather conditions that affect transmission lines. All of these are based on weather measurements and forecasts made near the transmission line being analysed. Because the weather stations are not installed along all the lines, weather data are also provided by a (unique) numerical weather model (ALADIN), downscaled from the horizontal resolution of 4.4 km to 500 m by means of the mass-consistent software CALMET, taking into account high-definition terrain elevation data. The intrinsic model's bias is reduced/eliminated by assimilating the real-time measurements from weather stations.

13) Co-funded by ADEME, the French Agency for the Environment, with the participation of RTE (FR).

14) The project is funded by ELES (SI).

2016: Data sharing platform favouring energy efficiency services

The **Estfeed data sharing platform** (2012–2017) [15] is an open software platform for energy consumption monitoring and management from the customer perspective. It is capable of interacting with grids and providing data feeds to service providers to ensure efficient use of energy. It is managed by ELERING, the Estonian TSO. It should facilitate the functioning of the energy market and provide a wider set of options to both consumers and businesses (including new types of stakeholders, like ESCOs, aggregators, and energy cooperatives). Sharing the data on the platform across different countries and regions will enable a better inter-TSO service. The European-wide approach provides even more opportunities for market stakeholders to do business and enables consumers to select between a greater number of services and service providers.

2017: A numerical platform for testing and comparing short-term electricity market design options

The **OPTIMATE project** (2009–2012) [16] has delivered a prototype simulation tool that is able to simulate different market architecture options in the context of high RES penetration. It is based on an innovative approach consisting of modelling different short-term electricity markets in a sequential manner and an extensive database of information on the technical and economic features of thermal plants, half-hourly forecasts of intermittent generation, network parameters, etc. The initial prototype, focused on the day-ahead stage, is currently being upgraded by RTE, the French TSO. It now has a broader functional scope, with intraday and real-time modules, as well as increased robustness and improved computation time. An industrial version of the simulator should be delivered by the end of 2016. This industrial version should allow RTE to perform reliable studies regarding design options for different aspects of the power markets, and should be available to other TSOs in Europe. Regulators and policy makers may also be given access to this tool to perform their own studies. For the time being, the OPTIMATE prototype is being used by the **Market4RES project** (2014–2016) [17], which is investigating the potential evolution of the target model for the integration of EU electricity markets to enable a sustainable, functioning and secure power system with large amounts of renewables.

2019: Cross-border provision of secondary reserve by distributed energy resources

The **FutureFlow project** (2016–2019) [18] is designing a cross-border cooperation scheme for procurement and activation of balancing reserves, including Frequency Restoration Reserves with automatic activation. A prototype DSR and DG flexibility aggregation platform for frequency restoration reserves (FRR) will also be developed and tested in the participating countries, as well as a prototype regional balancing and redispatching platform that allows for cross-border exchanges of reserves. At the end of the project in 2020, these prototypes will be close to implementation in the TSO environment.

15) Co-funded by Norway Grants. The consortium includes Elering (EE).

16) Co-funded by FP7. The consortium included RTE (FR), REE (ES), Elia (BE), TransnetBW (DE) and 50Hertz (DE). See http://optimate-platform.eu.

17) Co-funded by IEE. The consortium includes RTE (FR). See http://market4res.eu.

18) Co-funded by H2020. The consortium includes ELES (SI), APG (AT), MAVIR (HU) and Transelectrica (RO).

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APPENDIX 4
REVIEW OF EU REGULATORY FRAMEWORK

RESEARCH, DEVELOPMENT & INNOVATION ROADMAP 2017–2026

Line

» APPENDIX 4: Review of EU Regulatory Framework for R&I

The wave of technical innovation and the current energy policy objectives of the European Commission and Member States have set in motion the transformation of Europe's energy system. Strong challenges, objectives and policy targets have been defined for 2020 and beyond.

They require significant modernisation and innovation of energy market and system designs, as well as technological and technical enhancement for infrastructures and stakeholders. The development of electricity highways, increased decarbonisation and digitalisation of the energy sector, and the Europeanisation of the energy market, are only some of the challenges that need to be addressed by policy makers as well as new and long-time stakeholders in the energy value chain.

To accompany the transition to this new European energy system, strong needs for R&I have been identified in the transport and energy sectors. This need for R&I at the grid level has been confirmed by the European Electricity Grid Initiative, which identified a requirement of € 170 million per year starting in 2010 in order to cope with future challenges and foster network and system adaptation. Several projects at the grid level have been financed through EC Research Framework Programmes FP7 and Horizon 2020. Finally, the ENTSO-E Research and Development Roadmap 2013–2022 identified a €1 billion R&I budget required for the 2013–2022 period at the electricity transmission and distribution levels. In particular, TSOs are strategically positioned to ensure innovation at the infrastructure, system and market levels. TSOs are also key players in the Europeanisation of the electricity system and the achievement of the European Energy Market.

Still, a strong disconnection is observed between the need and the actual level of research carried out by TSOs. The amount of TSO budget invested in R&I has been limited to only 0.3 % of total revenues, the lowest ratio in the electricity sector and ten times smaller than the objective of the Lisbon Treaty.

Barriers that can explain these limitations are multilevel, encompassing issues of company strategy, financial constraints, technological borders, environmental regulation, and institutional and regulatory frameworks for the electricity system. Among those barriers, the lack of alignment between national and EU policies, regulations and TSO strategies figures as an interesting issue, as it might explain discrepancies in the determination by the different stakeholders of what innovations are necessary. This lack of alignment might also account for issues regarding the financing and implementation (coordination, market uptake, etc.) of research programmes. As regulated monopolies, TSOs are indeed in a unique position and face mixed incentives due to profit maximisation needs, revenue regulation, legal competencies and possible contestability of their role in the system.

1. THE ROLE OF REGULATION IN TSO INNOVATION AND THE ASSOCIATED BARRIERS

In order to identify the role of regulation in TSO innovation and the associated barriers, it is first necessary to understand the rationale behind incentives for innovation and TSO regulation in general. It must first be emphasised that innovation by TSOs is not only an issue for TSOs themselves, but also (and more importantly) for society as a whole.

Indeed, the power system is a system in which externalities between the different parts of the supply chain (generation, transmission, distribution, consumers, suppliers and the other market actors) are so strong that their cooperation is simultaneously very difficult to organise and very beneficial for the entire supply chain and end-users. Being central in the power system, innovating TSOs can thus help integrate the wave of innovations in the power system, which would enable society as a whole to more easily benefit from such innovations.

Market players innovate because they expect benefits in terms of maintaining or increasing market share or profitability in the short or longer term. In order to innovate, they must take into account the demand for innovation, the technological potential of their research programmes, their ability to capture the profits created by innovations, and the opportunity cost linked to the innovation. Innovations with the most value for society should be undertaken at the smallest cost, as long as transparency in the dissemination of results is ensured and the risk of free-riding is minimised.

TSOs face no a priori competitive pressure from competitors that would drive them to invest in innovation. Additionally, they often do not capture the benefits of the innovation they do undertake. The incentives they face come instead from the regulator, which controls their revenue. Indeed, in order to align the behaviour of the regulated monopoly with the economic objectives of social welfare maximisation, regulation is designed so that competition is mimicked and regulated companies are correctly incentivised for a given regulatory period. Over the past 10 years, incentive regulation has hence been applied by NRAs to TSOs and has proven an effective tool for incentivising and supporting operational innovation. Through revenue-cap schemes, reward-penalty mechanisms and performance-based regulation, TSOs have been strongly incentivised to implement cost-reducing measures, and in particular, to carry out innovation towards efficiency, productivity and quality.

The type of innovation or transformation that is required in the current context of Europeanisation, digitalisation, and modernisation of the electricity grids in Europe requires a longer-term strategy for innovation that spans several regulatory periods. From the point of view of the regulator, it is thus more difficult to align the behaviour of the regulated monopoly with the interests of society in this context. The national regulatory frameworks have not yet been adapted to the current transformation of the electricity system. The same observation can be made at the EU level.

2. REGULATORY AND INSTITUTIONAL FRAMEWORKS DO NOT ADEQUATELY INTEGRATE THE RISK OF DISINCENTIVES FOR TSO INNOVATION

Regulatory frameworks should aim to set proper incentives to invest in long-term and transformational innovation. However, it appears that the current design of regulation does not always enable willing TSOs to innovate in an efficient manner and to the right degree. Yet, regulatory frameworks should, at the very least, ensure that TSOs are provided with well-designed incentives for long-term innovation (e.g., treatment of long-term benefits and the risk of stranded assets). Furthermore, regulators should provide safeguards for TSOs, whose global financeability is at stake and comes as a direct cause for postponement of innovation.

Those limitations regarding incentives arise from a non-alignment of regulatory frameworks with the new issues and challenges faced by TSOs. At an even higher level, they stem from misalignments within the institutional foundations of electricity systems and energy regulation. These two main barriers appear interdependent.

A first type of barrier identified by stakeholders concerns the institutional principles that frame the electricity systems and their corresponding regulators.

The institutional basis of NRAs' competencies and of TSOs' missions is often grounded in fundamentals that have not evolved in all countries despite a surge of challenges at the system level and the regionalisation of electricity networks. Immediate and easily quantifiable needs of the end user in terms of cost and benefits (e.g., quality of supply) are sometimes still recognised as the main regulatory concern, and TSOs, as already pointed out, retain a traditional approach with regard to their strategy and willingness to invest in radical innovation. They do not always integrate the other (and possibly new) objectives and challenges regarding the electricity system. As a result, the value of TSO activities and innovation for the system and society can be underestimated.

In some cases, the institutional and regulatory frameworks even lead to the assignment of R&I tasks to separate bodies, neglecting the fundamental role of TSOs in the electricity system.

Meanwhile, some regulatory authorities lack the competencies to enhance multi-TSO or European-level innovation, as they do not perceive it to be relevant to their mission. Besides, regulatory frameworks are not always harmonised with regard to the current policy objectives or the incentives at the national and EU levels.

Another crucial issue is linked with the scarcity of resources of the NRAs to analyse and monitor innovation. Generally speaking, their teams and budgets are too limited to provide more than a high level framework for innovation. NRAs' awareness of TSO innovation is limited with regard to both ex ante and ex post scrutiny, as they may not have the capacity to assess R&I programmes in terms of cost and potential benefits.

A second type of barrier concerns the specific lack of adjustment of NRA frameworks to the new characteristics of TSO innovation. This is a result of the first barrier, as NRAs are not given the directive nor do they have the resources to pursue such treatment.

The new economic characteristics of TSO innovation are thus not always considered in regulatory frameworks. This particularly concerns the long-term nature of innovation, which is not always taken into account, thus preventing TSOs from capturing the benefits of innovation in terms of cost reduction or output improvement over multiple regulatory periods. The specific risks (e. g. cost, delays, and results) are not integrated into the regulation. TSOs also face externalities, as the benefits linked with system and policy-oriented innovation often strongly diverge from TSOs' private interests in terms of allowed revenue and innovation budget. These shortcomings limit the incentive for TSOs to pursue innovation. This lack of adjustment is reinforced in cases where regulatory parameters lead to financeability issues, as TSOs may be forced to postpone or cancel their R&I programmes.

Summary mapping of R&I frameworks in the 10 selected coutries, based on TSO interviews

TSO facts	Annual consumption (2014, in TWh)	< 30	30 – 60	60 – 90	90 – 120	120 – 150	> 150
	TSO revenue (2014, in mil. €)	< 300	300 – 600	600 – 900	900 – 1200	1,200 – 1,500	> 1,500
Typology of R&I programmes	Drivers for R&D	Efficiency	Quality	TSO daily business	Strategic priorities	Society oriented	System oriented
	R&D strategy	R&I as strategy	Coordination with others to lead	Leader approach	Follower approach	Anticipation of LI evolution and risks	
	Coordination	EU/ENTSO-E	National research programme	Regional coordination	National coordination with other stakeholders		
	Incentive toole	EU-Horizon2020	National programme	Regulatory incentive	Industrial partnership		
	Funding	Self funding	Allowed revenue	EU funding			
Regulatory framework	Specific treatment of R&I	Yes	No				
	Incentive for R&I	Yes	No				
	Allowance of R&I costs	Total	Partial (e. g., OPEX, controlable costs)	Little to none			
Barriers to TSO innovation	Mind-sell of TSOs	Limited willingness	Lack of measures				
	Institutional principles	Traditional missions of TSO	Adaptions of regulations to new fundamentals	Coherence of frameworks for multi TSO or EU level	Limited resources of the regulator		
	Regulatory frameworks	Integration of LT nature of innovation	Integration of externalties	Conception defaults	Control of Dissemination and market update		
Opportunities for Improvement	Institutional level	Reform of NRA's missions and competencies	Recognition of the need for TSOs to innovate	Common frameworks and coord./complem. at EU level	Creation or reinforcement of central bodies		
	Regulatory level	R&I coordination when different stakeholders	Safeguard remuneration mechanisms	Specific treatment of R&I	Output treatment of innovation		

Number of TSOs: 0 | 1–2 | 3–4 | 5–6 | 7–8

Fig. 33: Example of the Questionnaire for TSOs

3. RECOMMENDATIONS FOR A PREFERRED FRAMEWORK FOR INNOVATION

A certain number of recommendations can be formulated to address the observed limitations and better align strategies with regulatory frameworks. These recommendations aim to address the identified barriers to TSO innovation from an economic point of view, i.e. to improve the social value of innovation at the least cost to society through both efficient and effective tools. The proposed recommendations aim to:

- » Reduce disincentives for efficient innovation. A "least-regret" solution could be, for example, to make European R&I support schemes and regulatory treatments more complementary. In general, an incremental improvement of R&I support schemes, incentives for innovation, and updated TSO regulations might enable less costly adaptation of innovation.
- » Ensure that TSOs, NRAs and policy makers recognise and integrate the value of radical innovation into their strategies and frameworks. While anticipatory transformation comes at a cost that not all NRAs and TSOs can cope with, a solution based on coordination, awareness and dissemination of results would reduce the misalignment between all positions.
- » Respond to the economic objectives of regulation. Regulation should ensure the selection and implementation of innovation with the highest value for society. It should also set conditions for the efficiency and effectiveness of the implemented innovation.
- » Take into account the specificities of TSOs and the nature of their innovations. The long-term nature of their innovations and investments, the risk of contestability of their monopoly, and the necessity for global financeability should be taken into account. The value of their investments and innovation activities for the system and for society should be taken into account.
- » Assess the value of innovation with regard to the European electricity system as a whole, in order to integrate the consequences of system and market integration as well as European policy objectives.
- » Recognise the risks associated with the transformation of regulators and TSOs. Transformation of the electricity system and its anticipation by stakeholders induces new risks for TSOs, NRAs and policy makers when they modernise their strategies and frameworks. Those stakeholders indeed face uncertainties about the approaches followed to implement the chosen remedies. Experimental and reflexive modernisation should, however, enable the reduction of these risks by ensuring dynamic improvement of frameworks and governance. The table on the left (Figure 33) summarizes the different regulatory frameworks.

ACRONYMS

AC	Alternating Current
ACER	Agency for Cooperation of Energy Regulators
C	Cluster (followed by number, e. g. C3 – Cluster 3 etc.)
CAES	Compressed-Air Energy Storage
CAPEX	Capital expenditures
CEER	Council of European Energy Regulators
CEF	Connecting Europe Facility
CENELEC	Comité Européen de Normalisation Électrotechnique
CGM	Common Grid Model
CIGRE	Conseil International des Grands Réseaux Électriques
CIM	Common Information Model
COP	Conference of Parties
CPS	Cyber-Physical System
CT	Current Transformer
CVSS	Common Vulnerability Scoring System
D&D	Demonstration and Deployment
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DLR	Dynamic Line Rating
DSO(S)	Distribution System Operator(s)
DSR	Demand Side Response
DTR	Dynamic Thermal Rating
EASE	European Association for Storage of Energy
EC	European Commission
EDSO4SG	European DSO Association for Smart Grids
EEGI	European Electricity Grid Initiative
EERA	European Energy Research Alliance
EII(S)	European Industrial Initiatives
EMF	Electro-Magnetic Field
EMS	Energy Management System
ENISA	European Union Agency for Network and Information Security
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
ESCO	Energy Service Company
ETIP	European Technology and Innovation Platform
ETP	European Technology Platform
EU	European Union

EV	Electric Vehicle
FACTS	Flexible Alternate Current Transmission Systems
FO	Functional Objective, named with T standing for “transmission”
FRR	Frequency Restoration Reserves
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HTLS	High-temperature Low-sag (OHL conductor)
HV	High Voltage
HVAC	High Voltage Alternate Current
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEM	Internal Electricity Market
IETF	Internet Engineering Task Force
IOT	Internet of Things
ISO	International Organisation for Standardisation
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardisation Sector; one of the three ITU sectors
JRC	Joint Research Centre (European Commission)
JTC	Joint Technical Committee
KPI(S)	Key Performance Indicator(s)
LV	Low Voltage
MC	ENTSO-E Market Committee
MV	Medium Voltage
NGOS	Non-Governmental Organisations
NRA	National Regulatory Authority
OASIS	Organisation for the Advancement of Structured Information Standards
OHL	Overhead Line
OPEX	Operating expenditures
PCI	Projects of Common Interest
PE	Power Electronics
PMU	Phase-Measurement Units
PST	Phase-Shifting Transformer
PV	Photovoltaic

R&D	Research & Development
R&D&I	Research, Development and Innovation
R&I	Research and Innovation (N.B. for the sake of readability, R&I stands also for R&D and for R&D&I in this document)
RDIC	ENTSO-E Research, Development and Innovation Committee
RES	Renewable Energy Source
RFID	Radio-Frequency Identification
RMAC	Reliability Management Approach and Criteria
SCADA	Supervisory Control and Data Acquisition
SDC	ENTSO-E System Development Committee
SET PLAN	Strategic Energy Technology Plan
SF6	Sulfur Hexafluoride
SOA	Service-Oriented Architecture
SOC	ENTSO-E System Operations Committee
SSSC	Static Synchronous Series Compensator
SWOT	Strength / Weaknesses / Opportunities / Threats
TRL	Technology Readiness Level
TSC	TSO Security Cooperation
TSO(s)	Transmission System Operator(s)
TYNDP	Ten-Year Network Development Plan
UHVAC	Ultra-High Voltage Alternate Current
VFT	Variable Frequency Transformer
VPP	Virtual Power Plant
VSC	Voltage Sourced Converter
VT	Voltage Transformer
WAC	Wide Area Control
WAMS	Wide Area Monitoring Systems
WAN	Wide Area Network
WG	Working Group

GLOSSARY

IMPLEMENTATION PLAN	ENTSO-E deliverable R&I Implementation Plan, published yearly as a follow-up of the ENTSO-E Roadmap
EU28	Group of 28 members of the European Union
FP7	EU 7th Framework Programme for Research and Technological Development for 2007–2013, with a total budget of over € 50 billion.
H2020	Horizon 2020 – EU Research and Innovation program, with nearly € 80 billion of funding available over 7 years (2014 to 2020).
LCE	Competitive Low-Carbon Energy call for proposals within Horizon 2020.
N-1 CRITERION	Transmission system security standard that ensures system availability in the event of a single component failure
PROSUMER	An entity that is capable of both producing and consuming electricity
SRA2035	Strategic Research Agenda 2035 (European Technology Platform on Smart Grids)
T	Stands for Transmission in the naming of Functional Objectives (D for Distribution, etc.)
THIRD PACKAGE	(Third Internal Energy Market Package), legislative package for an internal gas and electricity market in the European Union (ownership unbundling)
T&D EUROPE	European Association of the Electricity Transmission and Distribution Equipment and Services Industry
WG RD PLANNING	Working Group R&D Planning within RDIC Committee

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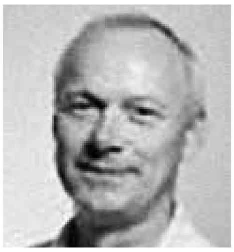

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