European Network of
Transmission System Operators
for Electricity

RESEARCH, DEVELOPMENT AND INNOVATION ROADMAP

DRAFT FOR PUBLIC CONSULTATION

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EXECUTIVE SUMMARY

Why an updated R&I Roadmap?

Research and Innovation move the energy transition forward. Sound research, development and innovation policies have to bring new technologies to the point at which markets will decide about 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.

The proposed Research and Innovation (R&I) activities in this Roadmap aim to enhance the TSOs role as key system integrators of different components and technologies. The TSO should also be prepared to face game-changing environment of new actors entering the electricity market (eg storage, ICT, prosumers, active customers) .

This Roadmap should be seen also in the broader perspective of R&I activities taken by ENTSO-E together with DSOs (EDSO for Smart Grids) and the storage community (EASE) into an Integrated Roadmap 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, possibly amended after this public consultation.

Similarly 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 transmission system operators (TSOs). Owing to fast technological and policy changes, a midway update/revision of the first edition of the Roadmap (spanning the decade 2013–2022) is needed, now spanning from 2017 to 2026. The revision is also supposed to enable alignment with the process of the European Commission's Integrated Roadmap, which requires a more holistic vision and expanded cooperation with other actors. This Roadmap is submitted for public consultation to get stakeholders view on the proposed ENTSO-E R&I activities[1], The 10-year Roadmap is complemented by Implementation Plans, issued yearly on a rolling 3-year horizon, in which the R&I areas here identified are prioritised and translated into focused topics to be addressed by concrete projects.

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 energy consumer 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 Platform (ETIP). These structures merge the former SET Plan European Industrial Initiatives (EIIs) and the European

[1] Including through direct contacts with European Energy Research Alliance, partners of the Grid+Storage project (EASE, RSE, EDSO for Smart Grids), ETP Smart Grids, Members States (through ERANET+)

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 are providing the society with security of electricity supply and are supporting the market and integrating sustainable energy sources. Hence, while they are enabling the transformative change, TSOs are performing R&I activities for the ultimate benefit of their consumers and stakeholders. In particular, TSOs have a key role as system integrators of different components based on technologies (e.g., ICT, materials, storage, 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.

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

Horizontal cooperation**:** The coordination of R&I efforts is a paramount added value of this Roadmap, being the main instrument for coordinating and/or harmonising R&I programs carried out by different actors and with different motivations. Even with the 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, whereas some TSOs have limited R&I activities. Therefore, cooperation, synergies, overlap avoidance, and common goals can be reached only with a strong, uniform and possibly joint approach to R&I activities.

Priorities and ENTSO-E vision

The priorities for R&I are driven both by energy/climate policies and power system overall trends on one side and by shorter-term TSO needs also fitting 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.

In recent years, the primary objective was the modernisation of the European Electricity Grid in areas such as integration of power technologies, demand-side response, smart asset management, and flexible operations. In the coming years, the objective is to transform the European Energy System into an integrated one, with emphasis on flexibility, storage, the use of ICT to integrate different technologies and market services. At the same time, links among electricity, transport, gas and heat networks must be identified, modelled and used.

The active consumer (and prosumer) will need smart grids integrating smart meters, highly developed home automation systems and appliances enabling 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. No business model for digital energy can flourish without a strong interface between the distribution and transmission, between wholesale and retail. On the operation side, innovative solutions will be needed for substation digitalisation, fault analysis and location, dynamic line rating, the use of optical or nanotechnologies, and digital breakers. At the same time, the power system must be secure and safe through better controllability, which requires more observability.

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.

Structure of R&I planned activities

In line with the overarching R&I framework set by the European Commission[2], 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 4.3; each FO is described in Appendix 1. An overview is given in the figures below.

N.	Name	Expected Outcomes
C1	**Modernisa-tion of the Network**	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, 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 its 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, DSOs, energy storage etc.
C3	**Power**	This cluster supports the deployment of existing and new system flexibility options

[2] in Horizon 2020 Programme

	System Flexibility	such as: -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 the 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) 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. Whereas the grid architecture was the object of previous projects, new steps must be taken to integrate new technologies and devices that bring enhanced flexibility. A novel grid architecture and models must be developed to consider all flexibility means.
C4	**Economic Efficiency of the Power System**	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	**Digitalisa-tion 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 cybersecurity issues. ICT is an enabling technology for managing the flexible energy system described in C3.

Figure 1 Description of Clusters of ENTSO-E R&I Roadmap

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Clusters		Functional Objectives	FO contents
C1 Modernization of the Network	T1	Optimal grid design	Optimal grid design: planning, adequacy, tools
	T2	Smart Asset Management	Smart Asset Management; predictive and on-condition maintenance; capex optmisation
	T3	New materials & technologies	Use of new materials and power technologies; new construction and maintenenance methods
	T4	Environmental challenges & stakeholders	Environmental impact, public acceptance, stakeholders participation
C2 Security and System Stability	T5	Grid observability	Observability of the grid: PMUs, WAM, Sensors, DSO information exchange
	T6	Grid controllability	Controllability of the grid: frequency and voltage stability, power quality, synthetic inertia
	T7	Expert systems and tools	Decision support tools, automatic control and expert systems
	T8	Reliability and resilience	Reliability and resilience: defense and restauration plans, probabilistic approach, risk assessment, self healing
	T9	Enhanced ancillary services	Enhanced ancillary services for network operation; cross-border supply of services
C3 Flexibility of Power System	T10	Storage integration	Storage integration, definition and use of storage services; system added value from storage
	T11	Demand Response	Demand Response, tools to use DSR; Load profile, EV impact
	T12	RES forecast	Improved RES forecast and optimal capacity operation
	T13	Flexible grid use	Flexible grid use: dynamic rating equipment, power electronic devices; use of interconnectors
	T14	Interaction with non electrical energy networks	Interaction/coordination with other energy networks (gas, heat, transport)
C4 Economy & Efficiency of Power System	T15	Market - grid integration	Integration of market and grid operation across timeframes (up to real time)
	T16	Business models	Business models (for storage, grid extension, distributed generation) for optimal investments in the network
	T17	Flexible market design	Market design for adequacy, flexibility use, cross border exchanges, rationale use of RES, demand management
C5 ICT & Digitalization of Power System	T18	Big data management	Big data, data mining, data management
	T19	Standardization & data exchange	Standardization, protocols for communications and data exchange with DSOs and other grid operators
	T20	Internet of Things	New communication technologies, Internet of Things
	T21	Cybersecurity	Cybersecurity

Figure 2 Clusters and Functional Objectives of ENTSO-E R&I Roadmap

Where we are today—assessing results

An important aspect introduced in this updated Roadmap is the monitoring and assessment of R&I efforts, to which Section 5 and Appendix 3 are dedicated, presenting several complementary perspectives:

- monitoring roadmap advancement—i.e., if and how the clusters and FOs of the original Roadmap have been addressed by ongoing 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 professional consultants);

- 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 all the multiplicity of short-term, lower-profile challenges and innovation needs that TSOs also 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

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efficiency mechanisms and 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 Europe-wide legislative and regulatory levels.

Another opinion claims that research institutes and universities are more suitable 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.

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1 INTRODUCTION

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.

1.1 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)[3] 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[4]. 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.

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[3] C(2015)61317 final

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

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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[5].

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 statutory 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.

[5] EEGI is one of the EEIs 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.

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

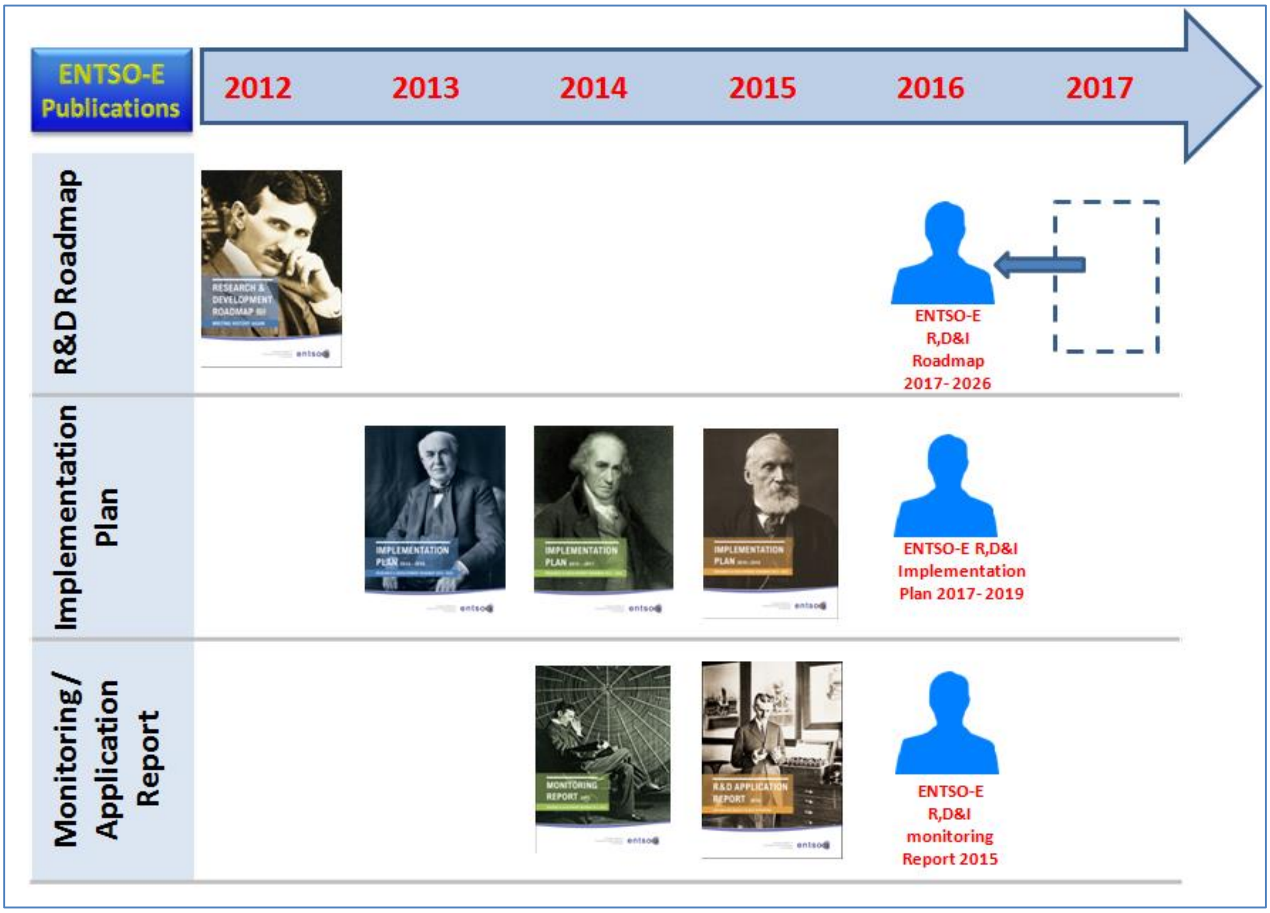

FIGURE 3: ENTSO-E PUBLICATIONS ON R&I

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1.2 PROCESS OVERVIEW

Figure 4 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.

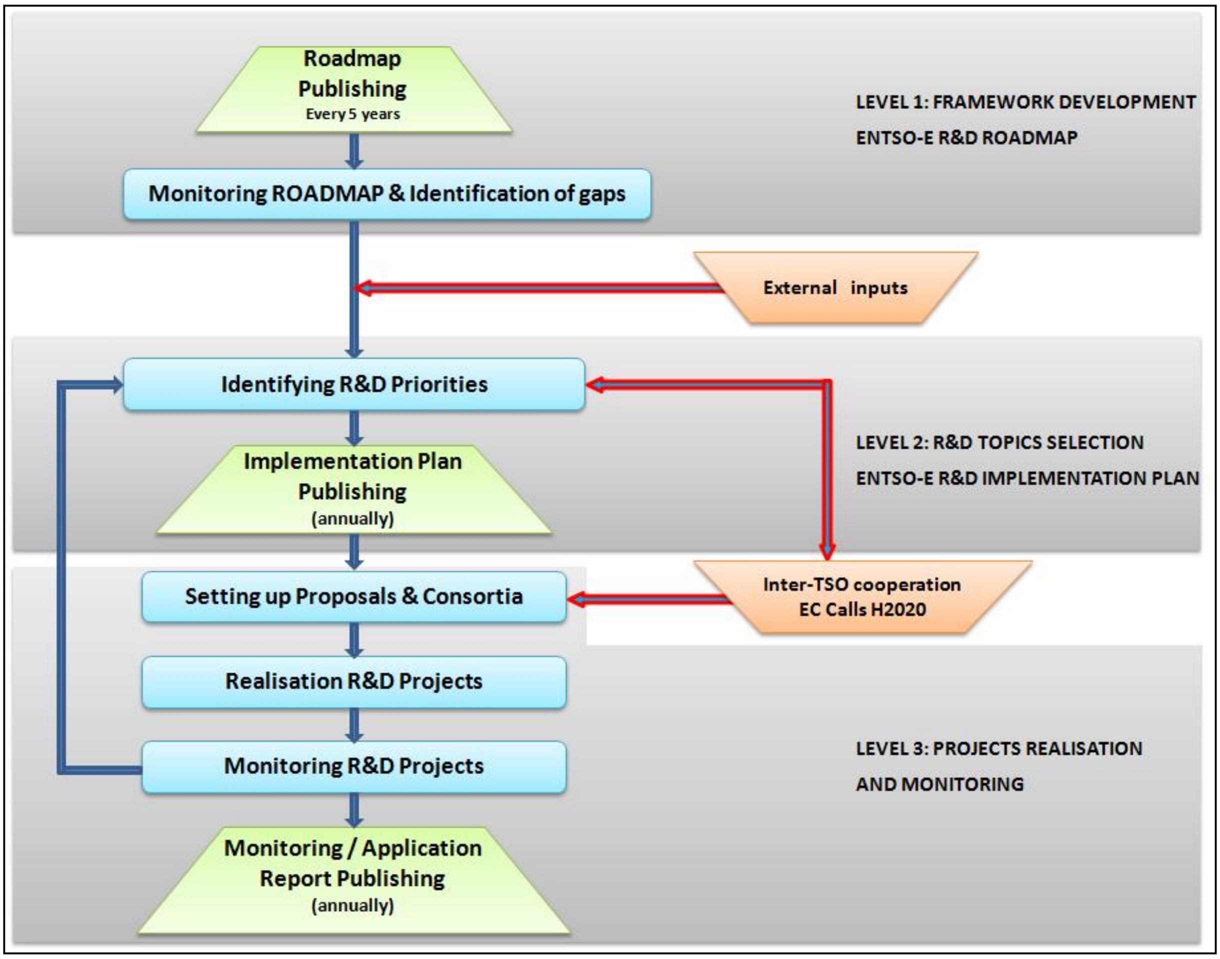

FIGURE 4: ENTSO-E PUBLICATIONS AS THE KEY LINK AMONG R&I FRAMEWORK DEVELOPMENT, TOPIC SELECTION AND PROJECT CREATION

1.3 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 5. 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)), 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.

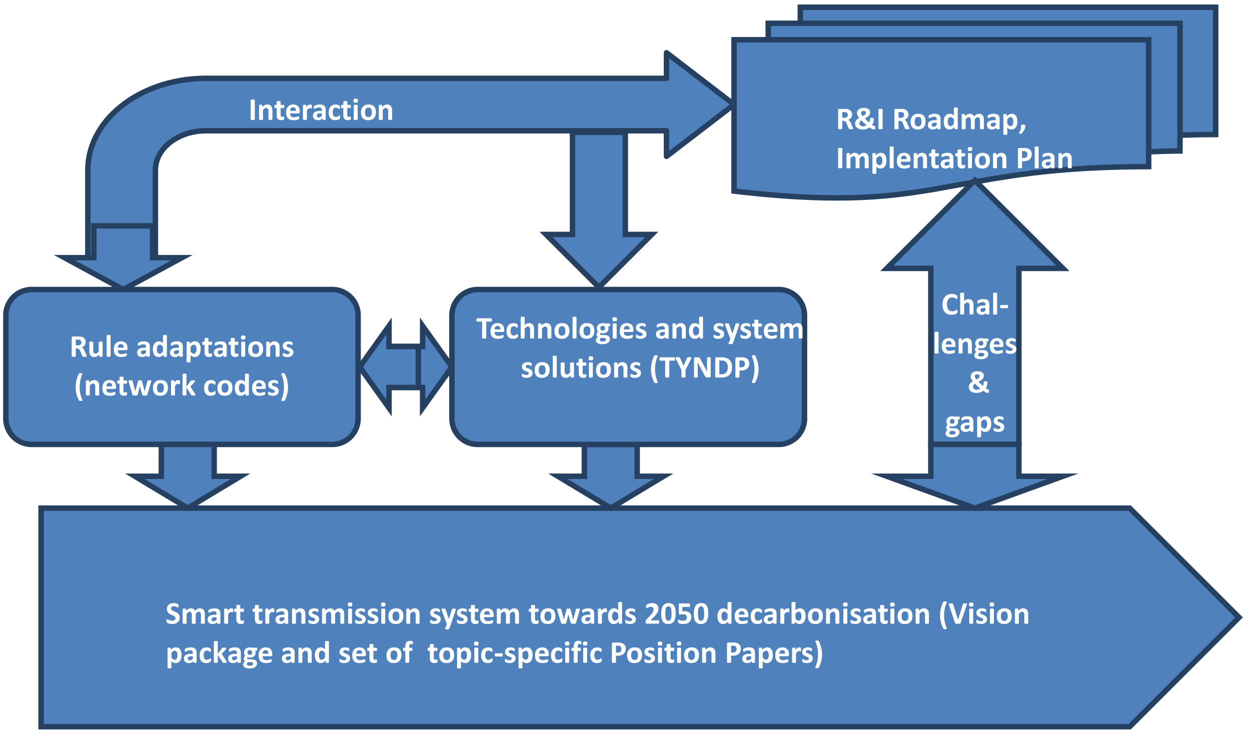

FIGURE 5: INTERACTION BETWEEN R&I ROADMAP AND OTHER ENTSO-E MANDATES

1.4 ROADMAP UPDATE / REVISION

The process for updating and refining the ENTSO-E R&I Roadmap and Implementation Plan is presented in Figure 6.

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 6, 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

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planning instruments of other stakeholders. Finally, loop L3 is the formal internal approval process of the deliverables to be published for the general public.

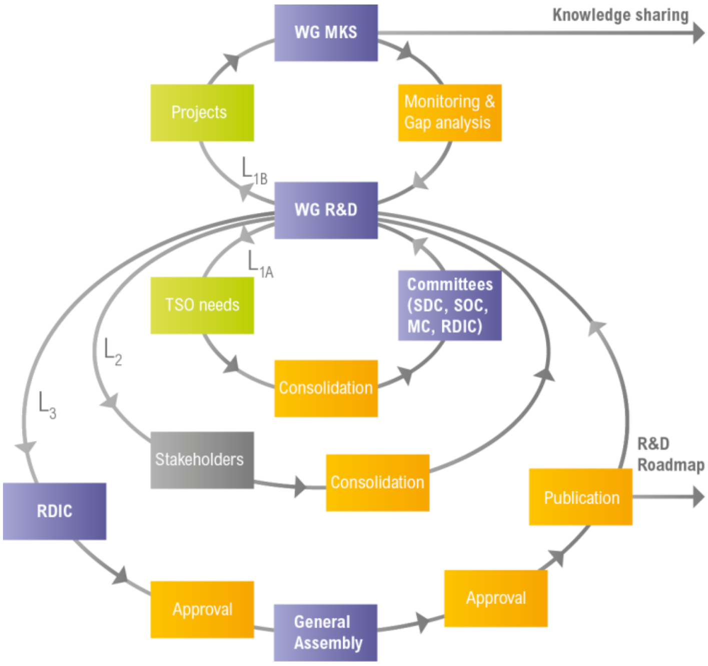

FIGURE 6: ENTSO-E PROCESS FOR UPDATING R&I ROADMAP

1.5 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.

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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.

2 EVOLVING IN A CHANGING CONTEXT

ENTSO-E 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 affordable and competitiveness, and on the three targets defined in the Climate and Energy Package[6]:

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

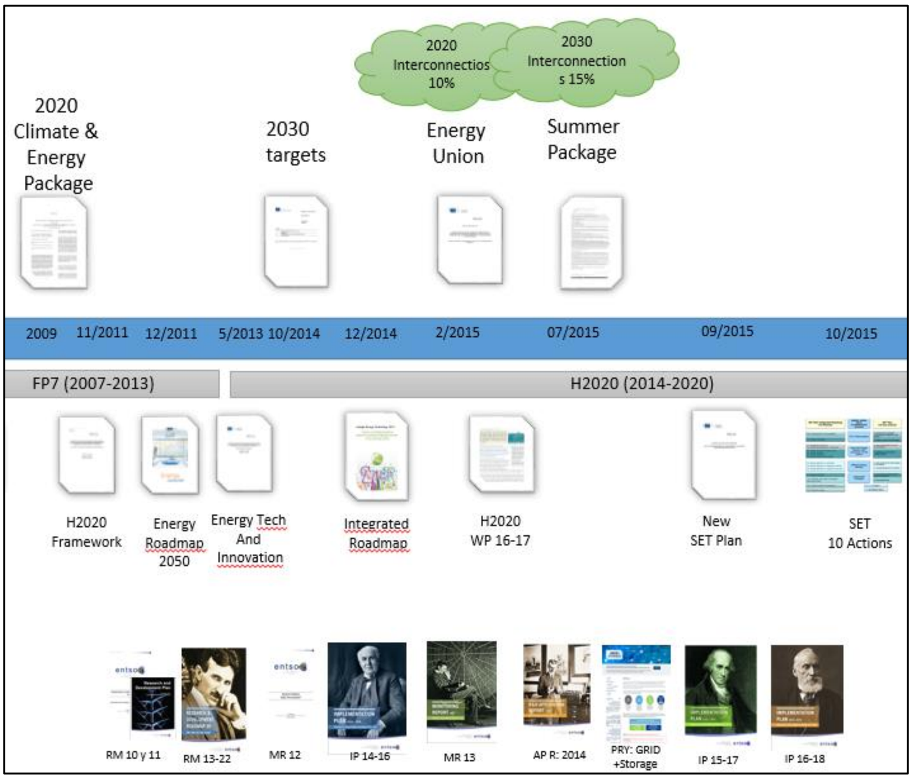

FIGURE 7: EVOLVING CONTEXT AND ENTSO-E REACTION

[6] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

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 7). 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.

2.1 POLICY-RELATED ISSUES

2030 climate and energy policy targets[7]

The concern about the climate and environment determines the need to establish demanding objectives for 2030 (Figure 8):

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

Strengthen 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.

[7] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

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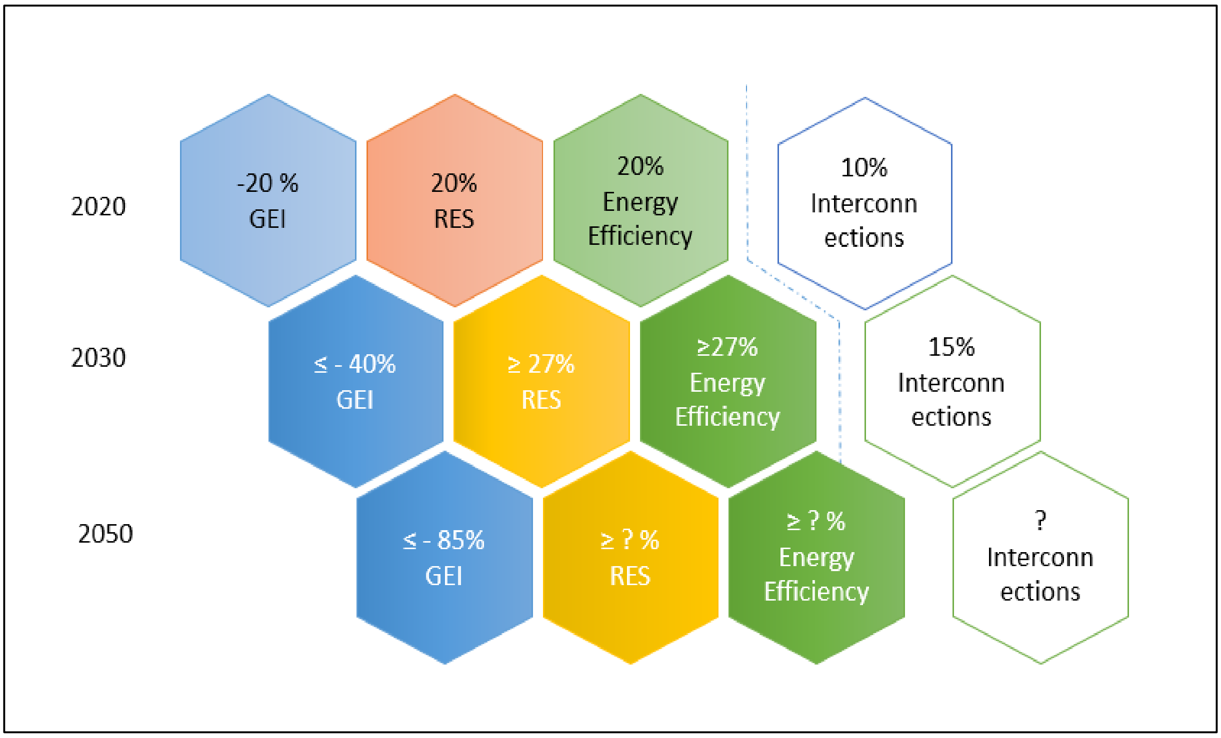

FIGURE 8: EU CLIMATE/ENERGY TARGETS

Energy Union

In February 2015, the European Commission released the Communication of the Energy Union[8], 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

[8] COM(2015) 80 final

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.

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.

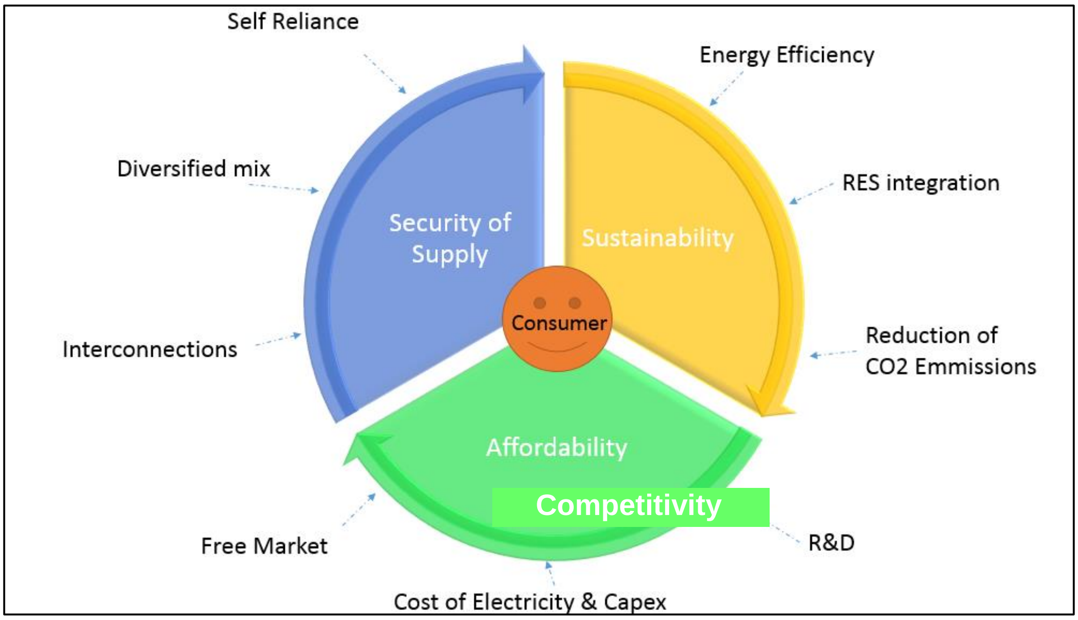

FIGURE 9: ENERGY UNION FOCUS

Figure 9 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.

2.2 SET PLAN-RELATED ISSUES

"Business as usual is not an option for the electricity system as a backbone of the future European Energy System." This statement, arising from the Energy Union, pushes innovation and research and development activities to the frontline of the electricity paradigm change.

Integrated roadmap

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The challenges and R&I needs of the EU energy system are defined in the Integrated Roadmap[9] 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[10].

2.3 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.

[9] https://setis.ec.europa.eu/system/files/Towards%20an%20Integrated%20Roadmap_0.pdf

[10] “Smart Cities and Communities”

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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.).

2.4 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 10.

FIGURE 10: SWOT ANALYSIS IN A NUTSHELL

2.5 ENTSO-E VISION AND POSITION PAPERS

ENTSO-E's 'Vision Package' is its response to the Energy Union Communication[11]; it includes four executive 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.

[11] *https://www.entsoe.eu/Documents/Publications/ENTSO-E%20general%20publications/entsoe_vision01_web.pdf*

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

3.1 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.

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) and the storage community (represented by EASE) towards more integrated solutions.

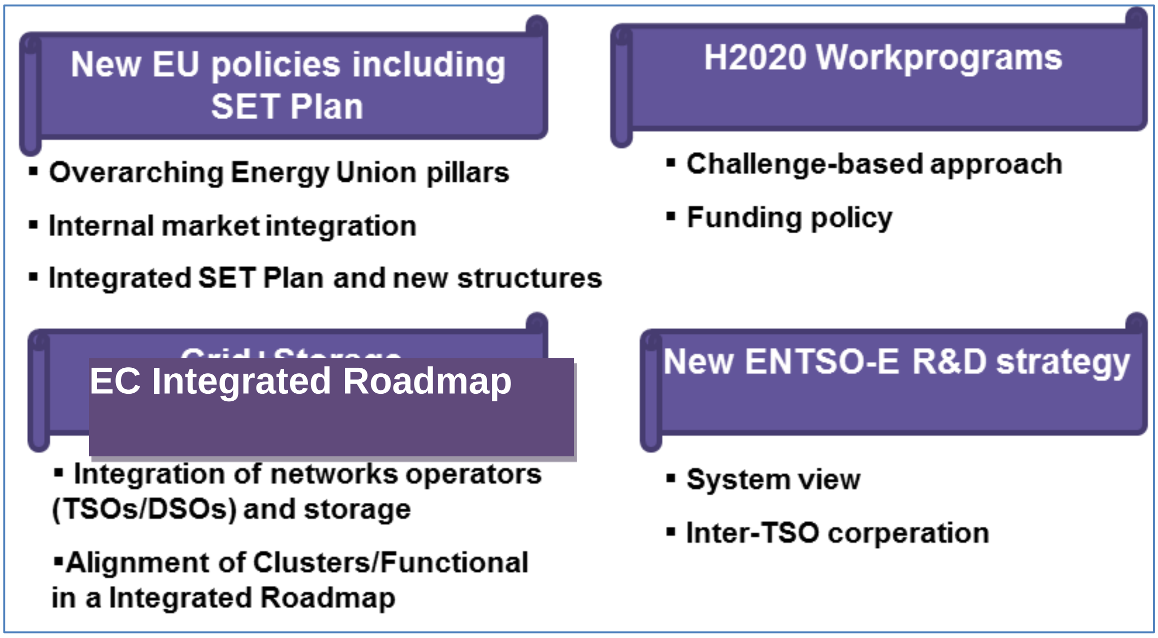

FIGURE 11: DRIVERS FOR UPDATING THE ENTSO-E R&I ROADMAP

Figure 11 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.

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3.2 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).

3.3 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&I 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 an integrator of different technologies (ITC, 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 TSOs' involvement 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 the cooperation with the ICT sector in activities to smarten the grids by having more intelligence.

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.

3.4 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 the 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 of 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 state of the art.

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:

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- 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.

3.5 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 . 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.

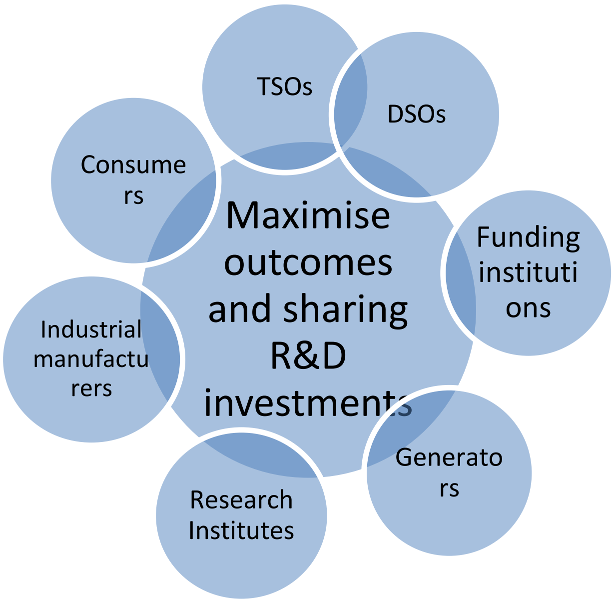

FIGURE 12: MAXIMISATION OF BENEFITS, SHARING OF INVESTMENTS AND DUPLICATION AVOIDANCE AS A RESULT OF COLLABORATIVE R&I ACTIVITIES

4 IDENTIFICATION AND STRUCTURE OF RESEARCH AND INNOVATION ACTIVITIES

The priority for R&I activities is driven by the transformation of the power system as well as by policy changes. 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.

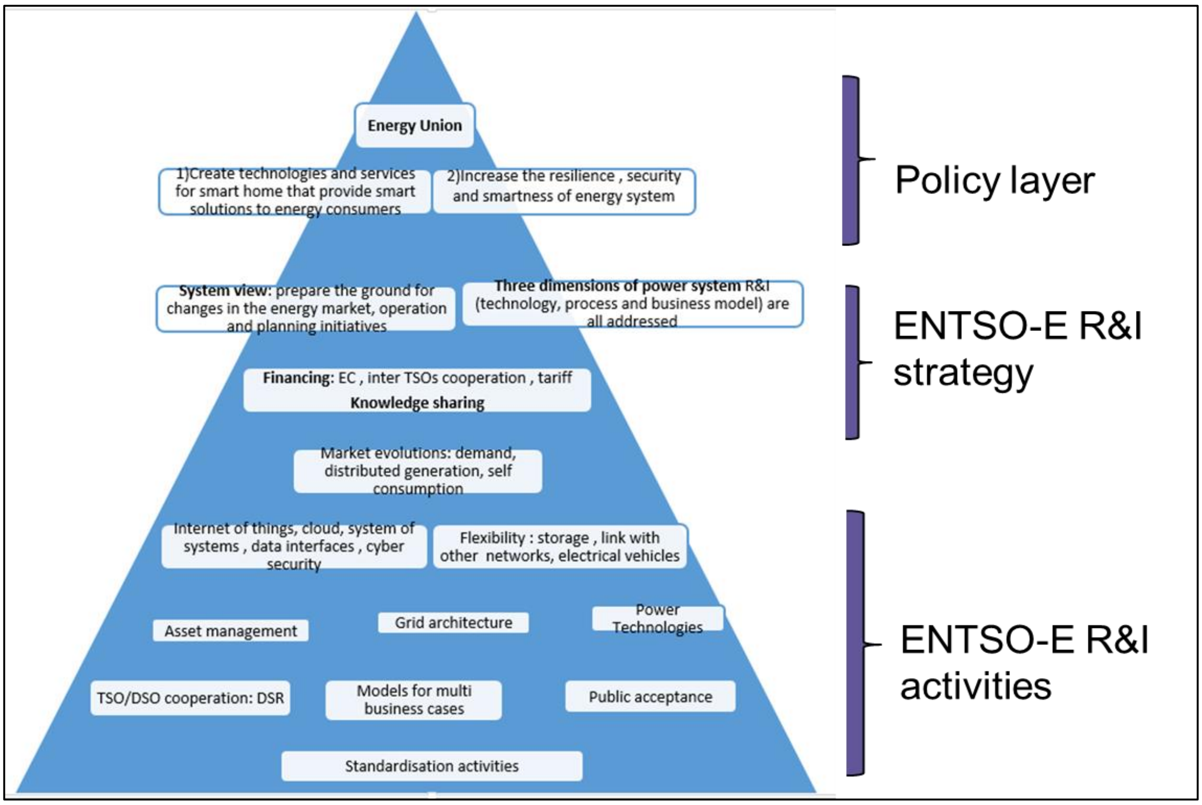

FIGURE 13: CHANGED CONDITIONS AND ENTSO-E REACTIONS

The R&I activities proposed in this Roadmap had to take into account: policy developments, ENTSO-E R&I strategy, the needs of TSOs (Figure 13).

4.1 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.

For ENTSO-E and TSOs, the developments that position the consumer at the centre of the energy system and the challenges brought by increased use of variable RES raise the issue of **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.

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 more extensively integrates the ICT, data management and data hubs and considers cyber-security issues is paramount. These new developments should be considered and even completely integrated 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.**

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 address **security and system stability**.

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 **economic efficiency of the power system.**

4.2 Identification of Areas of Activities

In the Roadmap 2013–2022 edition, 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 of 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.

4.3 Structure of Activities in Clusters and Functional Objectives

ENTSO-E R&D Roadmap 2013–2022 and the previous editions of 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 R&I activities.

Moreover, ambitious scenarios for RES development by 2030 and 2050 for R&I activities are at the base 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 14

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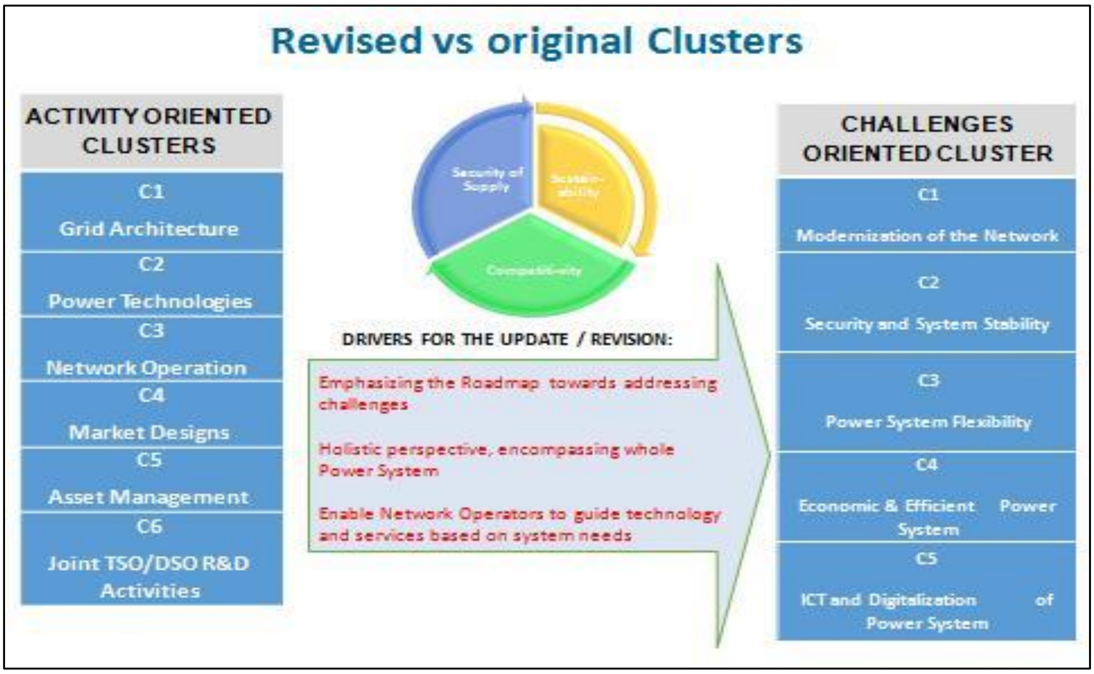

FIGURE 14: MAIN DRIVERS FOR THE REVISION OF ENTSO-E R&I ROADMAP STRUCTURE

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 15.

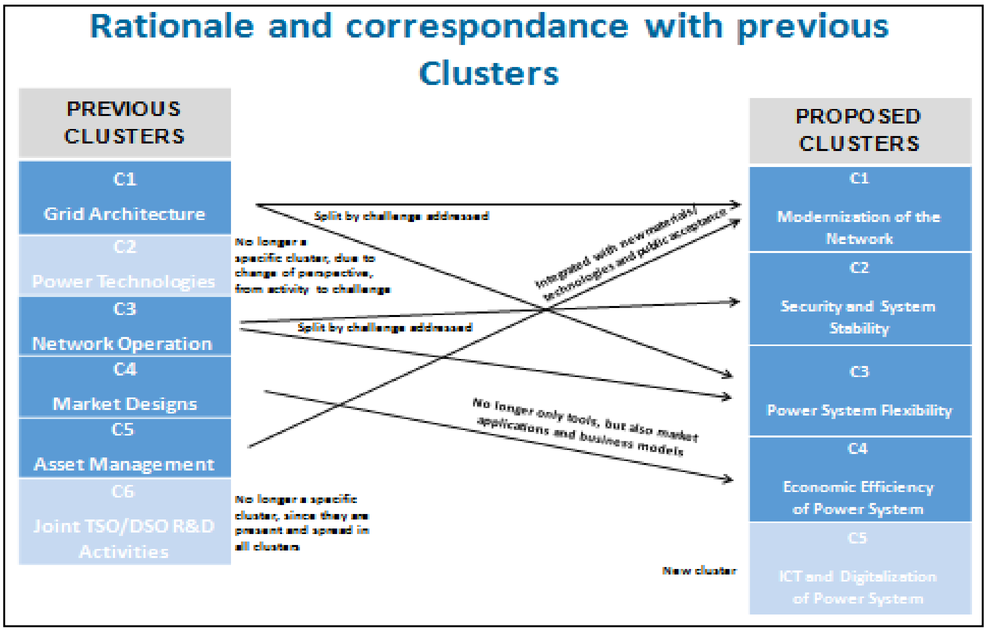

FIGURE 15: *CORRESPONDENCE BETWEEN THE PREVIOUS AND THE NEW ROADMAP CLUSTERS*

CLUSTERS / Challenges

The proposed clusters are expected to deliver the following outcomes.

N.	Name	Expected Outcomes
C1	**Modernisa-tion of the Network**	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, 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 technolog**ies 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 its 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, DSOs, 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** is 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 (eg 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 of. 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. Whereas the grid architecture was the object of previous projects, new steps must be taken to integrate new technologies and devices that bring enhanced flexibility. **A novel grid architecture** and models must be developed to consider all flexibility means.
C4	**Economic Efficiency of the Power System**	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	**Digitalisa-tion of Power System**	This cluster aims at considering **Big Data** management through datamining 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 cybersecurity issues. ICT is an enabling technology for managing the flexible energy system described in C3.

The exhaustive list of FOs is given in Figure 16, which offers more details regarding the types of activities to be carried out in each cluster.

Clusters		Functional Objectives	FO contents
C1 Modernization of the Network	T1	Optimal grid design	Optimal grid design: planning, adequacy, tools
	T2	Smart Asset Management	Smart Asset Management; predictive and on-condition maintenance; capex optmisation
	T3	New materials & technologies	Use of new materials and power technologies; new construction and maintenenance methods
	T4	Environmental challenges & stakeholders	Environmental impact, public acceptance, stakeholders participation
C2 Security and System Stability	T5	Grid observability	Observability of the grid: PMUs, WAM, Sensors, DSO information exchange
	T6	Grid controllability	Controllability of the grid: frequency and voltage stability, power quality, synthetic inertia
	T7	Expert systems and tools	Decision support tools, automatic control and expert systems
	T8	Reliability and resilience	Reliability and resilience: defense and restauration plans, probabilistic approach, risk assessment, self healing
	T9	Enhanced ancillary services	Enhanced ancillary services for network operation; cross-border supply of services
C3 Flexibility of Power System	T10	Storage integration	Storage integration, definition and use of storage services; system added value from storage
	T11	Demand Response	Demand Response, tools to use DSR; Load profile, EV impact
	T12	RES forecast	Improved RES forecast and optimal capacity operation
	T13	Flexible grid use	Flexible grid use: dynamic rating equipment, power electronic devices; use of interconnectors
	T14	Interaction with non electrical energy networks	Interaction/coordination with other energy networks (gas, heat, transport)
C4 Economy & Efficiency of Power System	T15	Market - grid integration	Integration of market and grid operation across timeframes (up to real time)
	T16	Business models	Business models (for storage, grid extension, distributed generation) for optimal investments in the network
	T17	Flexible market design	Market design for adequacy, flexibility use, cross border exchanges, rationale use of RES, demand management
C5 ICT & Digitalization of Power System	T18	Big data management	Big data, data mining, data management
	T19	Standardization & data exchange	Standardization, protocols for communications and data exchange with DSOs and other grid operators
	T20	Internet of Things	New communication technologies, Internet of Things
	T21	Cybersecurity	Cybersecurity

FIGURE 16: *ENTSO-E R&I ROADMAP CLUSTERS AND FOs*

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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 17.

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

Figure 17: Two-dimensional matrix mapping the cluster topics and TSO duties

The customer is specifically considered into Research and Innovation activities of this Roadmap . As such, some Functional Objectives are oriented towards the customers as presented in the figure below.

Figure 18: Customer in the Functional Objectives of the Roadmap

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A rough estimation of timing to address the various FOs is given in Figure 19; 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. Indeed, a proper prioritisation process shall be deployed in the yearly implementation plans, where more detailed topics are identified according to the following criteria:

- gap analysis vs. Roadmap advancements

- Innovation level and feasibility

- Technology Readiness Levels

- economic value added

- European value added

The above criteria, of a top-down nature, shall also be merged with a bottom-up approach encompassing TSO needs and innovation programs.

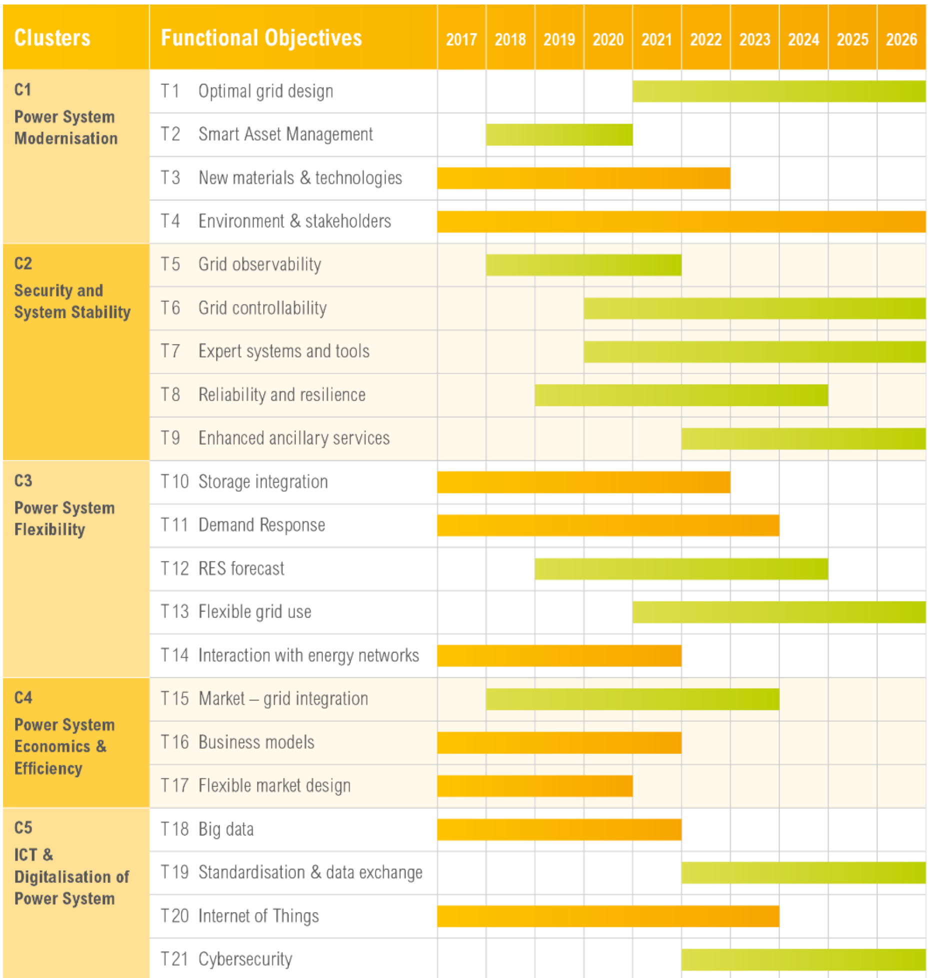

Figure 19: OVERVIEW OF TIMETABLE OF CLUSTERS AND FOs (BROWN BLOCKS REFER TO HORIZON 2020 ALREADY KNOWN INDICATIONS)

5 WHERE WE ARE TODAY

Figure 20 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	T1	Definition of scenarios for pan-European network expansion
	T2	Planning methodology for future pan-European system
	T14	Towards increasing public acceptance of transmission infrastructure
C2 Power Technologies	T3	Demonstration of power technology to increase network flexibility and operation means
	T4	Demonstration of novel network architectures
	T5	Interfaces for large-scale demonstration of renewable integration
C3 Network Operation	T6	Innovative tools and methods to observe and control the pan-European network
	T7	Innovative tools and methods for coordinated operation with stability margin evaluation
	T8	Improved training tools and methods to ensure better coordination at the regional and pan-European levels
	T9	Innovative tools and approaches for pan-European network reliability assessment
C4 Market Designs	T10	Advanced pan-European market tools for ancillary services and balancing, including active demand management
	T11	Advanced tools for capacity allocation and congestion management
	T12	Tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation
C5 Asset Management	T15	Developing approaches to determine and maximise the lifetime of critical power components for existing and future networks
	T16	Development and validation of tools that optimise asset maintenance at the system level, based on quantitative cost/benefit analysis
	T17	Demonstrations of new asset management approaches at the EU level
C6 Joint TSO/DSO R&D Activities	TD1	Increased observability of the distribution system for transmission network management and control
	TD2	The integration of demand side management at DSO level into TSO operations
	TD3	Ancillary services provided through DSOs
	TD4	Improved defence and restoration plan
	TD5	Methodologies for scaling-up and replicating

FIGURE 20: ENTSO-E R&D ROADMAP 2013–2022 STRUCTURE

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5.1 MONITORING OF THE R&I ROADMAP

In March 2016, ENTSO-E published the R&I Monitoring Report 2015[12]. 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 21. 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

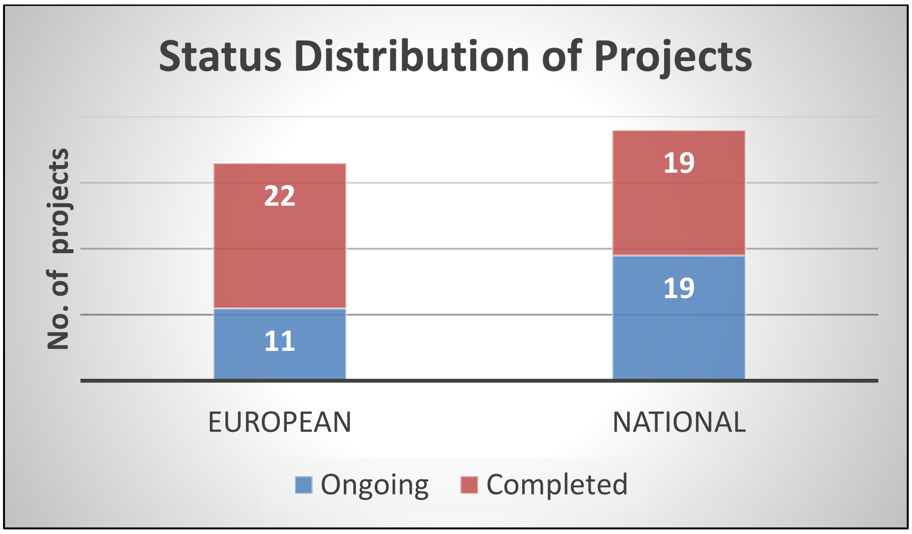

FIGURE 21: EUROPEAN AND NATIONAL PROJECTS MONITORED IN R&I MONITORING REPORT 2016

[12] https://www.entsoe.eu/publications/research-and-development-reports/Documents/entsoe_mon_rep_2015_web%20(1).pdf

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 WindGrid) 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, FutureFlow, 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.

5.1.1. 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 22 and 23. 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 23, Clusters 1, 2 and 3 have achieved a high degree of completion, especially Cluster 1.

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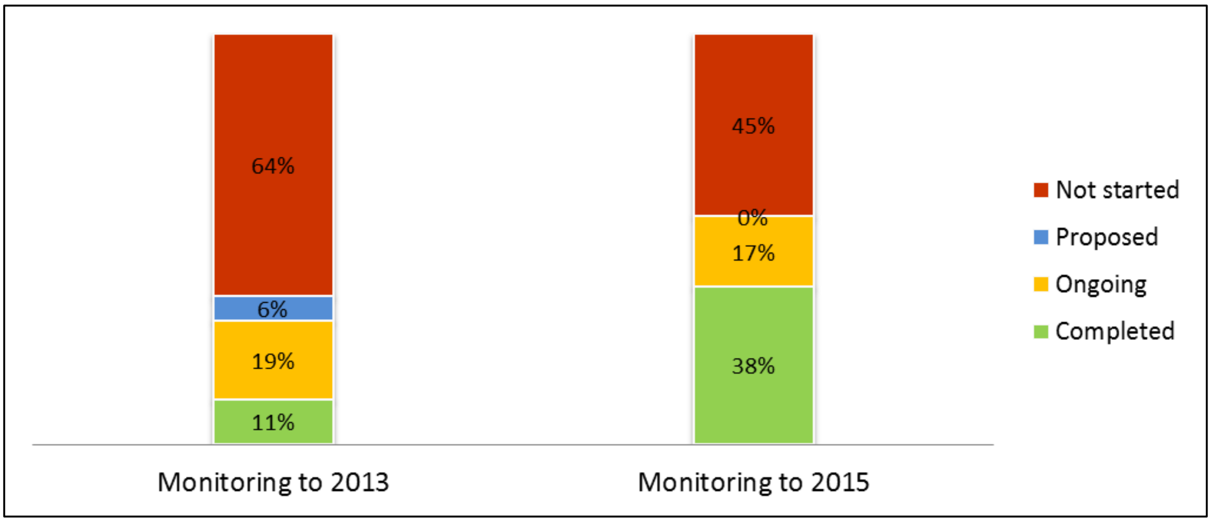

FIGURE 22: CLUSTER PROGRESS OF R&D ROADMAP 2013–2022 IN DECEMBER 2013

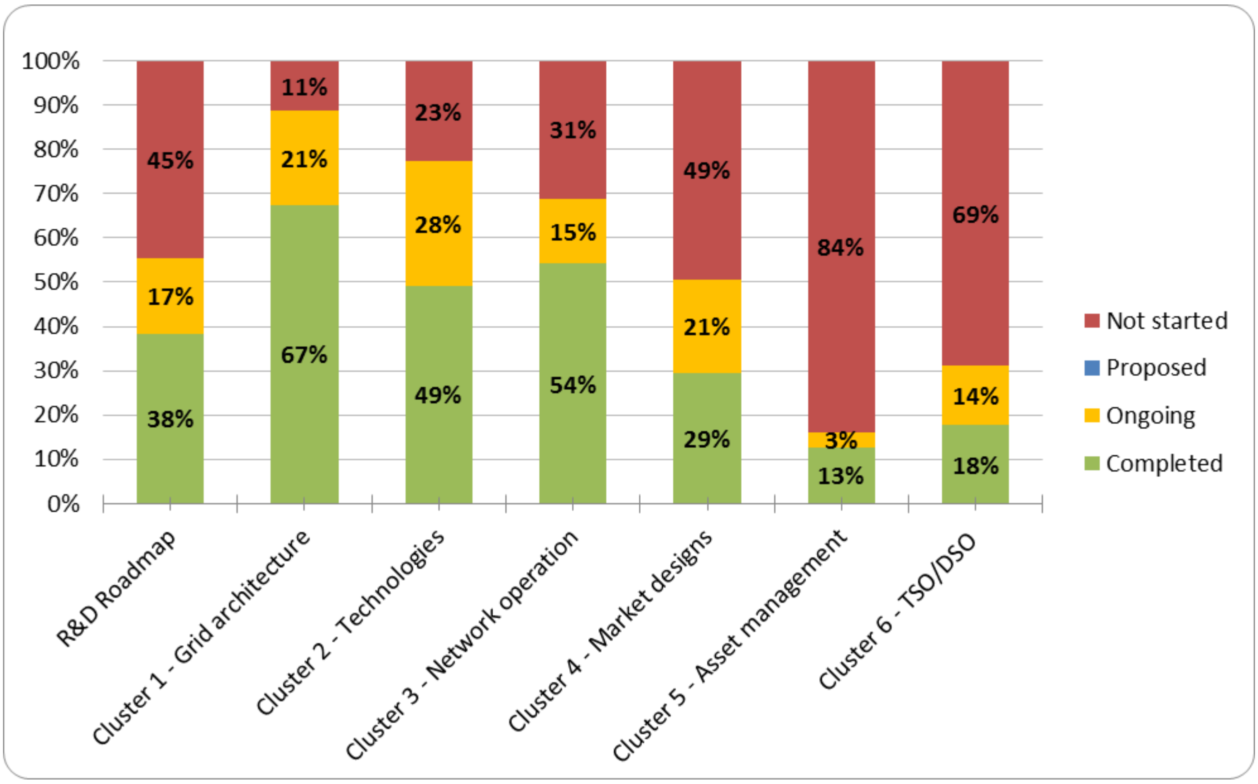

FIGURE 23: CLUSTER PROGRESS OF R&D ROADMAP 2013–2022 IN DECEMBER 2015

5.1.2. 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.

5.2 Assessing Results of R&I Projects

5.2.1. Application Report

The R&I Application Report, published by ENTSO-E in March 2015[13], 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

[13]https://www.entsoe.eu/Documents/Publications/RDC%20publications/150305_RD_application_report_2014.pdf),

report addresses nine relevant EU-funded projects that were finalised between 2009 and 2013 and involved one or more TSO members of ENTSO-E (ANEMOS Plus, EWIS, ICOEUR, MERGE, OPTIMATE, PEGASE, REALISEGRID, TWENTIES and WINDGRID).

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 and ANEMOS Projects) and load simulation tools (MERGE Project) by REN. Through inter-TSO cooperation, support from the EC and 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

5.2.2. 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 analyzed, 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

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 7 (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.

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). 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.

The chart in Figure 24 shows the number of R&I projects (amongst the 50 projects studied in this report) in which ENTSO-E members are involved.

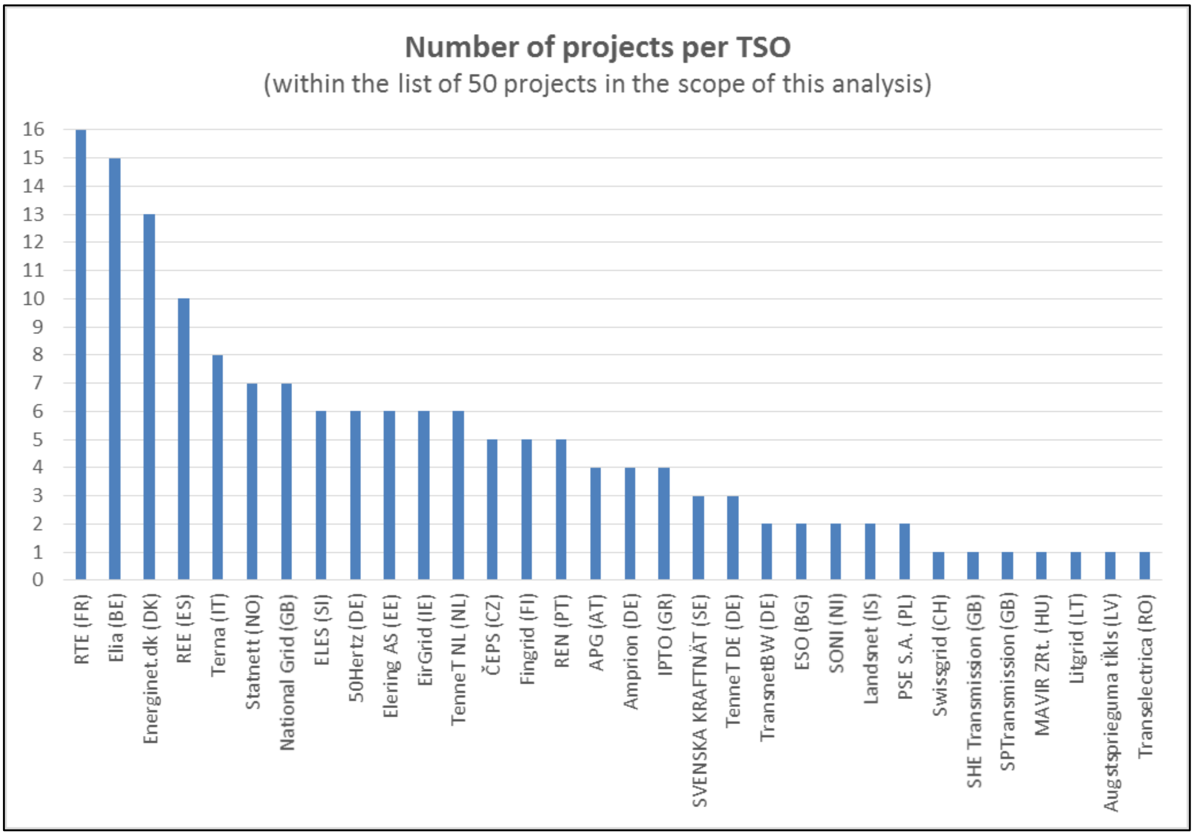

FIGURE 24: PARTICIPATION OF ENTSO-E MEMBERS IN R&I PROJECTS

Figure 25 shows the corresponding budgets of the projects as well as the grant from public funds (European and national). Note that this distribution does not provide any information about the share of the TSOs' grant in this budget. In addition, the public funds coming from national grants do not count the TSO's own funding, even if the TSO is publicly owned.

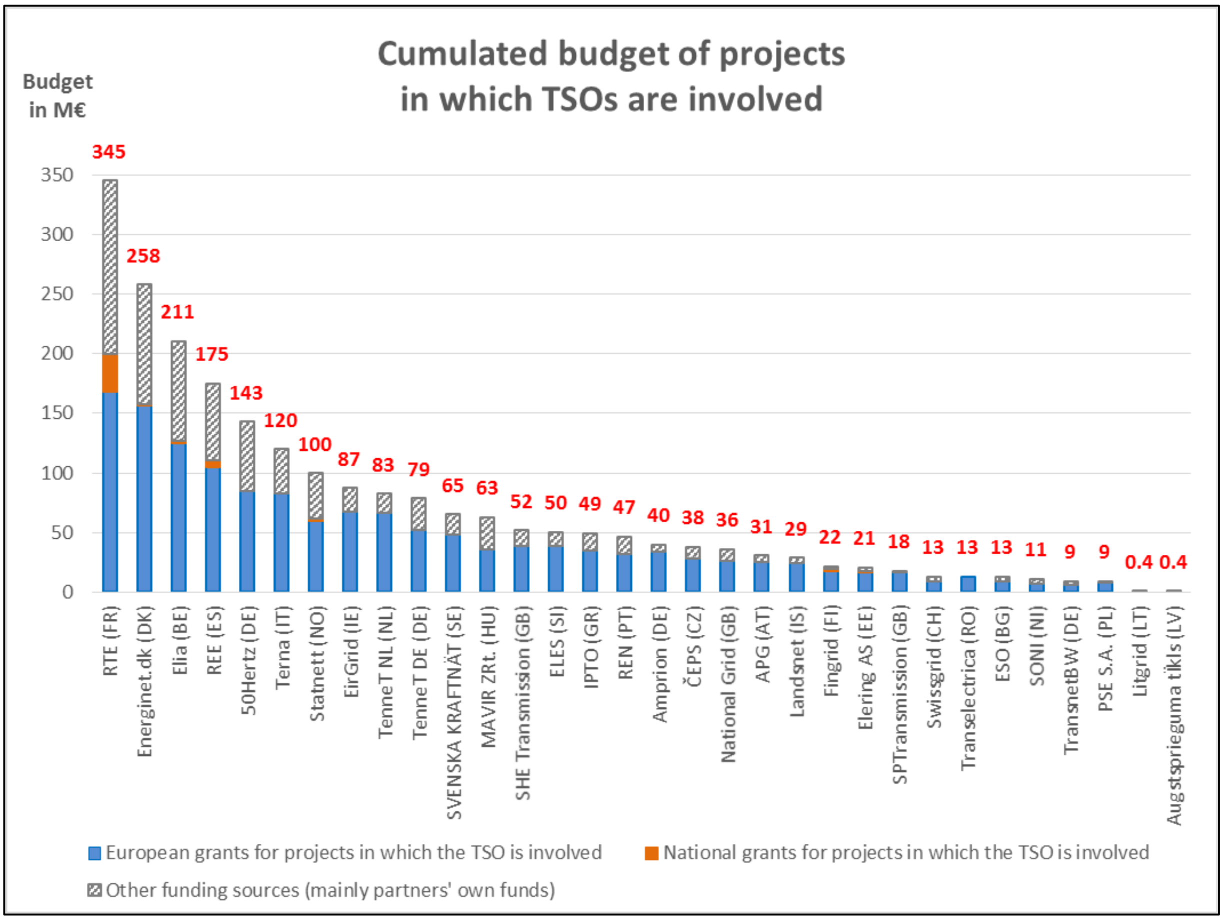

FIGURE 25: DISTRIBUTION OF BUDGET FOR R&I PROJECTS INVOLVING TSOs[14]

[14] *This distribution does not provide any information about the share of the TSOs' grant in this budget. In addition, the public funds coming from national grants do not count the TSO's own funding, even if the TSO is publicly owned*

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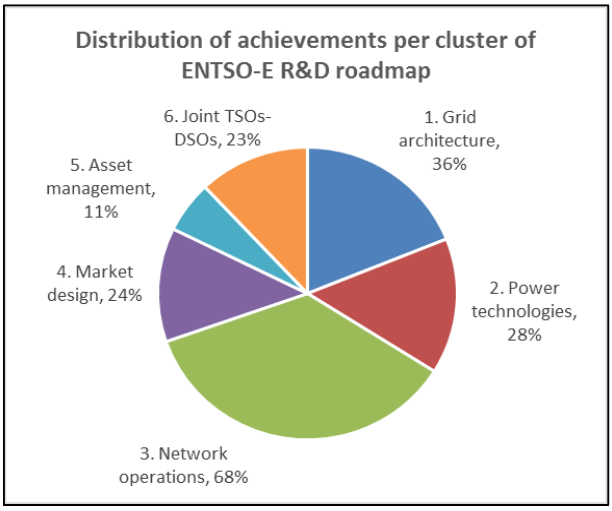
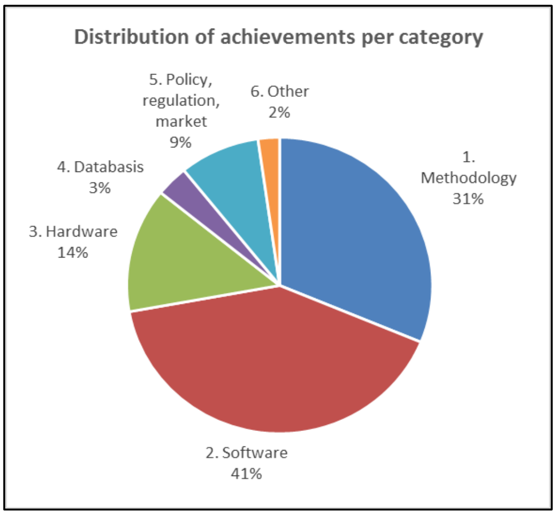
5.2.3. ACHIEVEMENTS

The projects' main achievements are distributed within each cluster of ENTSO-E R&D Roadmap 2013–2022 as presented in 26 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 26 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) B)

FIGURE 26: A) ACHIEVEMENTS PER CLUSTER OF ENTSO-E ROADMAP 2013–2022; B) ACHIEVEMENTS PER CATEGORY

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 offshore 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.

6 IMPACTS AND BENEFITS FOR EUROPE

6.1 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 27. 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 innovations 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.

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 European member states.

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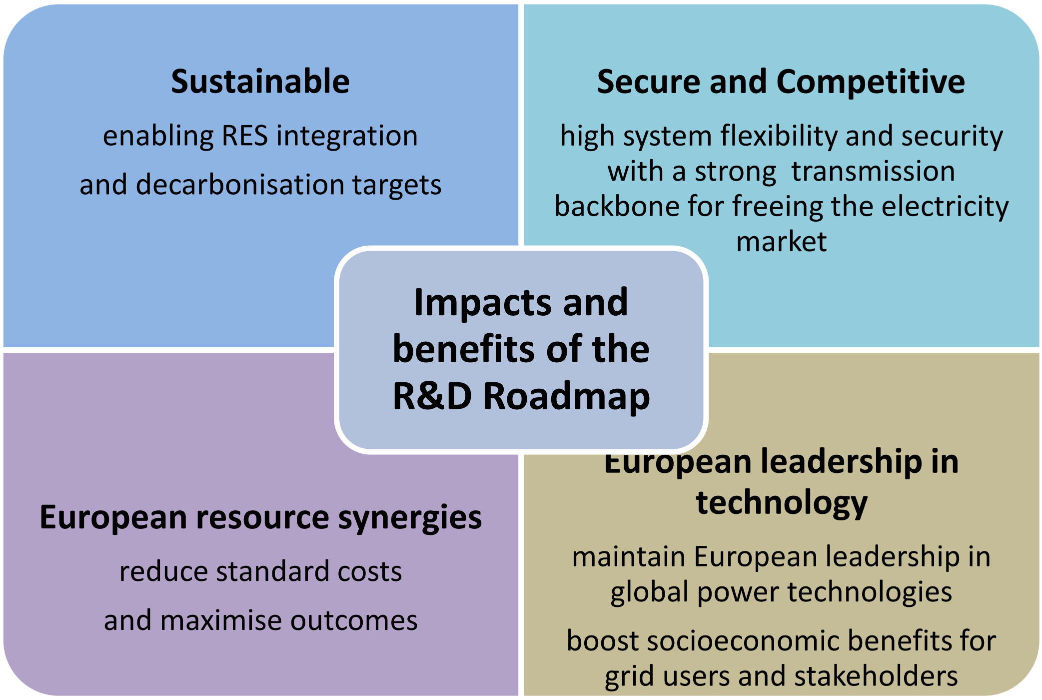

FIGURE 27: OVERVIEW OF R&I BENEFITS AND IMPACTS

6.2 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 WG 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.

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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 28). 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.

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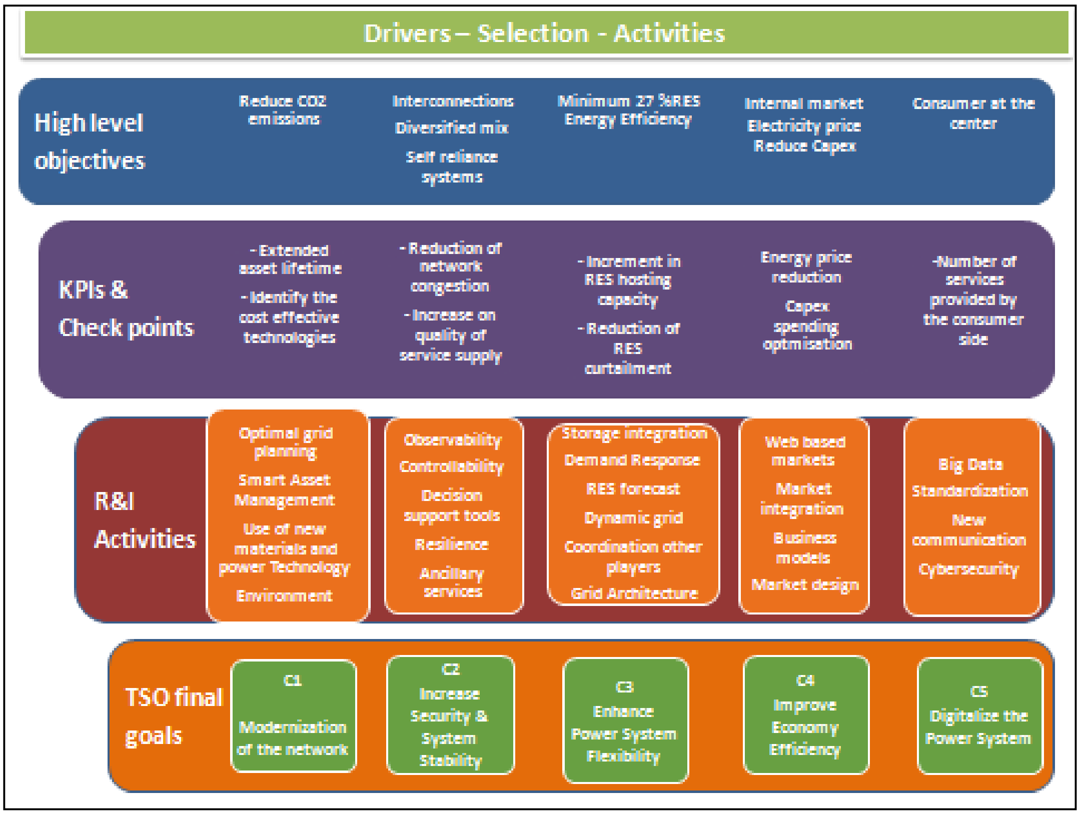

FIGURE 28: Mapping among KPIs, R&I clusters and EU policy goals

7 INVESTMENTS, FUNDING, RESOURCES

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 29).

Clusters		Functional Objectives	Budget per cluster (M€)
C1 Modernization of the Network	T1	Optimal grid design	220
	T2	Smart Asset Management	
	T3	New materials & technologies	
	T4	Environment chalanges & stakeholders	
C2 Security and System Stability	T5	Grid observability	290
	T6	Grid controllability	
	T7	Expert systems and tools	
	T8	Reliability and resilience	
	T9	Enhanced ancillary services	
C3 Flexibility of Power System	T10	Storage integration	280
	T11	Demand Response	
	T12	RES forecast	
	T13	Flexible grid use	
	T14	Interaction with non electrical energy networks	
C4 Economy & Efficiency of Power System	T15	Market - grid integration	70
	T16	Business models	
	T17	Flexible market design	
C5 ICT & Digitalization of Power System	T18	Big data management	90
	T19	Standardization & data exchange	
	T20	Internet of Things	
	T21	Cybersecurity	
		TOTAL	950

FIGURE 29: 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 Appendix 3. This gap analysis was performed by 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 of potential number of projects required.

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7.1 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 a 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"[15] 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.

Based on the same report, in the period 2008–2013, investment in smart grid projects was consistently above €200 million per year, reaching €500 million in 2011 and 2012. This document shows that the number of demonstration and deployment (D&D) projects is relatively close to the R&I projects, but the total investment in D&D is almost three times larger than at in R&I.

Public funding still plays a crucial role in stimulating private investment in smart grid R&I and D&D projects. Corresponding 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 30, based on a recent survey among TSOs, shows that 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 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.

[15] http://ses.jrc.ec.europa.eu/smart-grids-observatory

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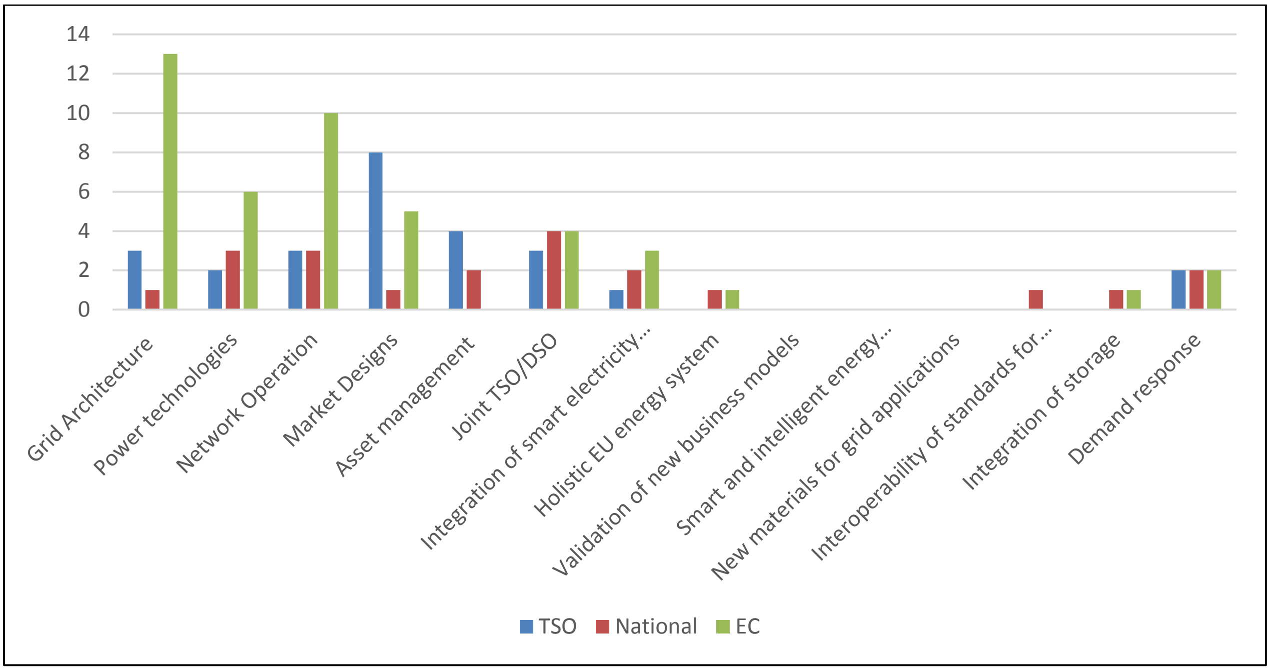

FIGURE 30*: SOURCE OF FUNDING BY TOPIC*

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 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.

7.2 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, which is far below Europe's 2020 objective of 3% (R&I expenditure as a percentage of the GDP; see Figure 31).

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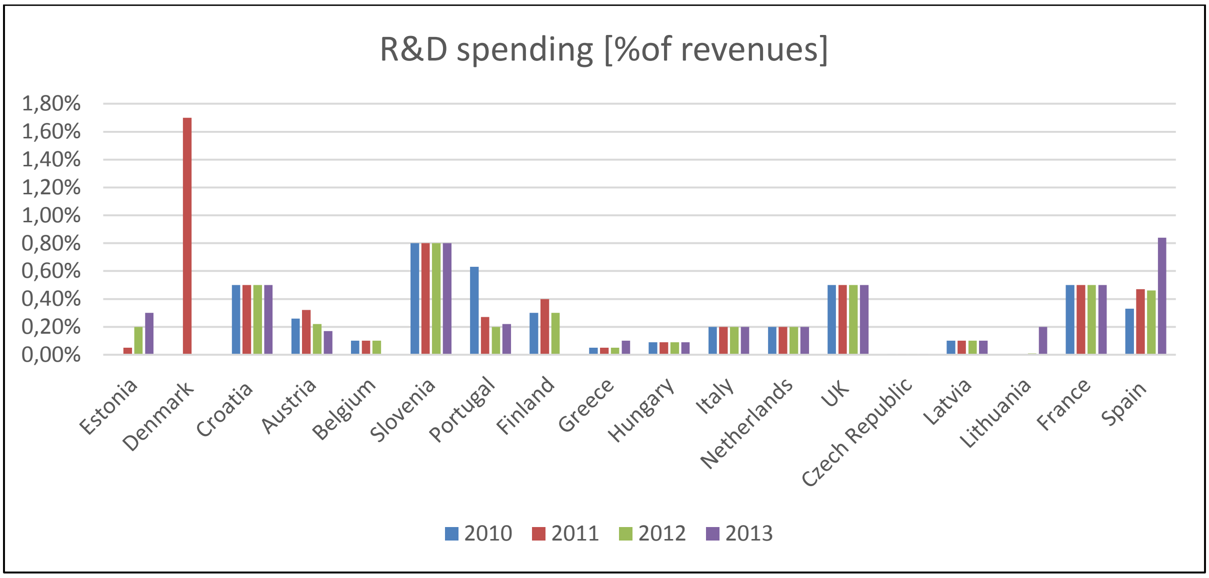

FIGURE 31: R&I SPENDING IN PERCENT OF TSO REVENUE

7.3 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.

Despite this provision—and five years after adopting Third Internal Energy Market Package—only a few EU countries[16] currently account for R&I expenses explicitly through tariff structures. 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 the TSOs have no means of getting new R&I expenses included in their allowed costs, thus making it extremely 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

[16] *Denmark, Belgium, Germany, UK and France*

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[17], 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.

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 in line with European/regional developments of the power system. An overview of the desirable regulatory framework for R&I is reported in Appendix 4.

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[17] *In Denmark and Ireland, for example, TSOs are responsible for electricity-related research programmes.*

Appendix 1 - Description of the Functional Objectives

CLUSTER C1: MODERNIZATION OF NETWORK

T1	**Optimal hardware grid design**
Contents	***Challenges:*** New planning methodology and tools for network infrastructures are needed to connect energy generation sites involving variable RES and DER with demand, as well as to integrate Demand Response, storage and integrate interface with other energy/transport networks. The grid design approaches at European level must be developed taking into account r a broad spectrum of novel technologies (for generation, transmission, storage, Demand Response as well as . the evolution of boundary conditions (Single European Energy market, new business models, climate changes etc.). ***Objectives:*** The objectives are to develop planning tools methodologies and simulation software to asses options for the pan-European power system, in particular, for the transmission system infrastructure. It should also facilitate system simulations at European level able to compare several design options based on different technical, economical economic and environmental criteria and accounting for emerging technologies and business models. ***Scope:*** This challenge addresses the medium-term adequacy and the long-term planning of system development, particularly accounting for the energy scenarios provided by TYNDP and e-Highways2050. ***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 validating impact on grid planning for coordinated design of architecture, power flow control devices and other expected technologies - To develop planning software to optimize location, coordination, control and integration of technologies within the existing and future system architecture and operation - To develop planning methods combining 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, in view of strengthening expected weak points on the grid - To develop probabilistic planning methods respecting the variability of RES, Demand response, storage, self consumption and their uncertainty

	- Proposal of network investments at EU level - Account for the coupling with other energy networks (especially gas) in the planning studies (simulations), e.g. dynamic coupling between gas and electricity networks (link with T14). - Maintenance operations should be accounted for in the new planning tools (the system must remain operable when maintenance operations are performed). - The flexibility brought by software must be taken in to account in the flexibility means (for example smart substations).
Expected outcomes	TSOs will be able to optimize network development and identify the most cost-effective technologies based on recognized optimization goals, constraints and maximize 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 TSOs will be enable to take better decisions leading to • less investments,/cost, • higher reliability, maximised RES integration
Expected impacts	This long-term planning approach enables manufacturers, DSOs, energy retailers and other energy companies to create provisional development plans. Investment signals will be sent to energy generation, load centers, TSOs and DSOs taking into account European network investments.
Contributors	TSO, DSO, Research institutes, Technology providers
Additional information	Interdependent with T4, T10, T13. It also builds on previous project: e-HIGHWAY, Realisegrid
Budget est.	40 M€
Timeline	2021 – 2026

T2	**Smart asset management**
Contents	***Challenges:*** The power network is continuously challenged to choose from implementing maintenance procedures to extend lifetime, upgrading equipment to increase lifetime or replacing failing subsystems or partial replacement of infrastructure. These actions must take into consideration the worker's safety and the quality of service, OPEX and CAPEX negotiated

	with the regulator. Therefore, there is the need to revisit the lifetime prediction modeling based on extended parameters and define new 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 managed costs and that the expected benefits are realized. ***Objectives:*** The objective is to maintain robust and cost effective network infrastructures with reliable performance, by optimizing asset management through: • validation of new monitoring concepts for components and systems in view of scheduling maintenance that maximizes 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, by enhanced monitoring systems or 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:*** Maximizing the value for money through enhanced monitoring of health and improved methodologies that support preventive and selective maintenance decisions; new means for line and substation inspections and monitoring. ***Specific tasks:*** - To identify parameters (climate conditions, operating conditions, potential for hardware and software, among others) that impact the life span 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 assessment 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 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 is hostile environments and avoid the need for human maintenance. , also including live line maintenance and working practices and 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 modeling of rare events with a severe impact by inter-TSO collaboration on related data - Link with standardization is key, in terms of assessment of the validity of the diagnostic methodologies investigated, validation of the measuring chain, safety of operation (especially for Live Line Work)
Expected outcomes	New approaches to extend the lifetime of existing power components thanks to improved monitoring and measurement of their health New maintenance approaches to manage critical assets based on risk and optimization that are shown to reduce operational costs while increasing network flexibility and ensuring adequate power quality New specifications and guidelines for interoperability and standardization for manufacturers of sensors and IT systems able to further support health monitoring, selective maintenance and enhanced asset management Optimized maintenance approaches for new power technology should be assessed with adapted CBA methodologies. And consequently develop new training methodologies 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	Increase the share of renewables in the supply mix due to greater grid flexibility and availability provided by optimal asset management. Increase the grid capacity for the same level of quality and security of supply, thus leading to a more efficient electricity market. Optimised costs of asset maintenance activities while increasing the performance of the existing assets. Integration of new power technologies with optimum asset management methodologies
Contributors	TSO, Technology providers and Research institutes
Additional information	Interdependent with T7, T13, and T18. It also builds on previous project: Realisegrid Linked to IoT and big data: use of the data to estimate life span and establish ageing/failure models (probabilistic models, cf. needs for GARPUR for instance).
Budget est.	40 M€
Timeline	2018 - 2021

T3	New materials & technologies
Contents	***Challenges:*** The increasing integration of variable RES and the advent of the single European electricity market increase the free flow of energy at regional level, in addition, assets are reaching the end of its lifetime. The social opposition hinders the deployment of new infrastructures, therefore there is the need to upgrade the existing assets, that usually are performing close to its limits. Advanced transmission technologies must be tested and existing lines must be improved. The integration of new technologies into existing infrastructures 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 and extend the lifetime or even improve the maintenance of current assets and find efficiency opportunities and set standards for the transmission system. ***Scope:*** New types of conductors (using nanotechnologies or superconducting materials), high-temperature conductors, composite core conductors, coatings and superficial treatments, composite supports, energy storage, power electronics and other technologies to be demonstrated and validated. ***Specific tasks:*** - To demonstrate the degree to which transfer capacity and performance of assets 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 vender-independent, HVDC multi-terminal networks used to coordinate power flow - To investigate the influence of parallel routing of DC and AC lines on the same tower or parallel paths to facilitate existing infrastructure paths in a an optimal manner - Develop the technologies to coordinate with storage infrastructure and Gas as well as Heat network - Investigate lower (and higher) frequency network as an alternative to DC links - Standardization of strategic components and system and multivendor applications with all PE interfaced devices (generation, load, storage) connected to the transmission network - Superconducting FCL in order to avoid strong SC currents in new grid architectures

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	- Assess the need for new components and systems to reduce the effect of extreme environmental stresses (extreme winds, rapid rainfalls, storms, floods, wet snow, saline pollution etc.), both for AC and DC applications.
Expected outcomes	Introduction of new materials and technologies to develop infrastructure with higher performances and/or lower costs.
Expected impacts	Improvement of energy security, quality of service and optimized costs. Definition of standards for the transmission system equipment. Integration materials to increase the asset efficiency. Adaptation and extended lifetime of existent infrastructure.
Contributors	TSO, Technology providers, Research institutes, Laboratories
Additional information	Interdependent with T1, T10, T11, T12, T13 . It also builds on previous project: Twenties, BEST PATHS, Realisegrid
Budget est.	120 M€
Timeline	2017 - 2022

T4	**Environmental challenges & Stakeholders**
Contents	***Challenges:*** The realization of the secure, sustainable and competitive European electricity system requires the development of underlying transmission infrastructure. Hence, there is the need to develop new ways and means to address the public reluctance to infrastructure investments and to increase public awareness about future long-term energy challenges. Therefore, current public consultation processes need to be revisited to both better appraise and understand the reasons for public reluctance to infrastructure investments. ***Objectives:*** The objective is to improve public acceptance and stakeholders' participation in transmission infrastructure while also reducing its environmental impact. ***Scope:*** Improve public awareness of long-term energy challenges and of the necessity to build and protect the transmission infrastructure for improving the social benefit of using electricity. Assessment of new environmental challenges and improve the transmission infrastructure land use and environmental integration. Possible directions are exploiting new channels for public consultation processes mapping bird sensitive areas and develop new bird savers to maximize gains from fitting bird savers to existing lines studying. Alternatives to SF6 allowing for the compact design of electric power stations with efficient insulation properties.

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	New design measures to minimize high-voltage equipment noise, visual impact and sag of overhead lines. Improve the physical protection of the grid infrastructure against potential dangers, e.g. natural catastrophes, terrorism or cyber-attacks. ***Specific tasks:*** - Develop methodologies, methods and software for physical protection of the grid infrastructure, such as to evaluate bird collisions, human and animal exposure to EMF, as well as to protect against natural catastrophes, terrorism and cyber-attacks. - Developed holistic approaches for maintenance accounting for environmental (e.g. tree growth rate, wind) and operational (e.g. hazard rate) effects on the assets lifetime. - Analyze new technologies with reduced visibility of conductors and reduced sag. - Propose new tower designs with less visual impact, audible noise and EMF. - Implement pilot projects for demonstration and assessment of the developed methodologies and software in protecting the grid infrastructure. - Implement pilot projects concerning the implementation of the guidelines for improving of the relationship between TSOs and the public, namely consumers. - Investigate environmental impact of partial undergrounding solutions (cables) and of new technologies. - Update the European guidelines on good practice in transparency and public engagement and permitting process. - Produce guidelines for the construction and maintenance of overhead lines which improve public acceptance.
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 security of supply and a low-carbon
Expected impacts	Improved stakeholder engagement by improving the understanding between TSO and the public. and reducing environmental impact of the infrastructure Acceleration of the permission and construction processes required to build new infrastructure or refurbish existing
Contributors	TSO, DSOs, Technology providers, Industries, NGOs
Additional information	Interdependent with T1, T2, T3, T14, and T20. It also builds on previous project, namely BESTGRID and Life ELIA.
Budget est.	20 M€
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 (WAM) systems are of ultimate importance to increase transmission system observability, but they have not been applied yet at a pan-European scale. European transmission systems are being operated under increasingly stressed working and weather conditions coming closer to their stability limits. Massive integration of RES and DER, mostly connected at distribution level, potential deployment of hybrid networks (AC / DC grid), expected migration of heat and transport sectors to the electricity one as well as the increasing levels of interconnectivity and future demand response mechanisms, 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. ***Objectives:*** The main focus is to improve transmission system observability at the pan-European level by developing new methods, technologies and tools capable to handle process and interchange immense amount of measured and forecasted data in real time, both horizontally between TSOs and vertically with distribution grids/demand. ***Scope:*** Use the technologies such as PMUs, intelligent sensors and integrated communications to gather the information from transmission systems, combine them 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 of state estimation and dynamic simulation - Develop tools utilising new sensors fit for a distributed observability of the transmission system (e.g. voltage sensors, position sensors, event sensors, etc. very cheap and simple to be used in a very distributed approach, deriving conditions and state estimations from statistical analysis of the data acquired) - Optimize the existing toolbox to increase awareness of pan-European operation allowing for optimization 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 for assessing the observability at the required level,

	and should help to infer automatic rules for operations at local level (decentralized intelligence) - Increase observability and improve state estimation accuracy (both steady-state and dynamic) through adequate modelling (including not only modelling protection and system automatic schemes to some extent, 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 exchanging 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 - Investigate and develop the methodologies, procedures, protocols, standards and tools for inter-TSO communication, which will determine the amount and type of required data exchange that will enable an extension of the observability area to the neighbouring TSOs aiming to mitigate a possibly negative impact of switching actions in one TSO to other TSOs. - Develop effective data-mining algorithms capable of extracting important information in real time from massive amount of data - Implement solutions for wide-area monitoring systems and demonstrate how to utilize such information in a coordinated manner during operations. Observability should also be seen from the operators, i.e. how to operate a network in new situations with new sets of information as a result of increased data and new tools availability (e.g. iTesla). Critical situations might become even more complex since the operations will become more and more automatized.
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 with very high amount of variable RES generation.
Contributors	TSOs, DSOs, technology providers, service providers, generation companies.
Additional information	Interdependent with T18, T19. It also builds on previous project: PEGASE, TWENTIES, Real-Smart, UMBRELLA
Budget est.	70 M€
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 against large frequency excursions, which, in turn, impact the system stability and control. The power quality is also affected since the increasing number of power system components (such as HVDC interconnectors) and loads are being based on power electronics, injecting harmonic pollution into the system. ***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 of 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 needed level inertia to the transmission system, and their interconnection with the networks; Identification of possible links between the electricity system and the other energy systems in the specific view of increasing inertia (real or synthetic) Deployment of WAC devices at the pan-European, system-wide level, which will enable the operators to operate the system close to its stability margins, without jeopardizing its security. ***Scope:*** Power control devices FACTS, PST, HVDC, VSC, storage and other technologies to be demonstrated and validated, also: single-phase auto-reclosure, point-on-wave switching. ***Specific tasks:*** - Demonstrate power flow control devices 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 (e. g., maximizing 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, also by using fibre-optic temperature monitoring and DLR;

	- Validate the contribution of RES to voltage and frequency control, as well as balancing, by 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
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. Refined, adopted and implemented 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 definition of grid connection rules
Contributors	DSOs, universities, research institutes, technology providers, utilities
Additional information	Interdependent with T3 and T14. It also builds on previous projects: TESLA , MIGRATE, UMBRELLA
Budget est.	60 M€
Timeline	2020-2026

T7	**Expert systems and tools: Expert systems, Decision-making support tools and Advanced Automatic Control**
Contents	***Challenges:*** Expert systems simplify complex power systems' problems by processing large amount of data in a structured way and in a short period of time enabling for high level planning, operating and design decisions. Many TSOs apply restoration strategies based on operator's experience with no specific decision support tools. As a consequence, there is no common strategy plan 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 (forecasting, contingency analysis, dispatch, security assessment, etc.) to help control engineers to assess network stability. The contemporary systems broadly utilise local automation, protection and control. However, rapidly changing electricity systems impose the necessity for better coordination

	and the use of Advanced Automatic Control. It will necessitate development and massive deployment of smart meters, sensors, control devices, PMUs, weather measurements as well as establishing a high speed communication infrastructure for monitoring the condition of each element of a power system. TSOs will use these data not only to operate the system optimally, but also to anticipate emerging system stability and security problems. Internal European energy market will also benefit from this, since the market participants will be provided the estimated locational marginal prices in real time, being based on the actual system conditions. ***Objectives:*** Develop the expert systems and decision-making support tools to anticipate potential emergencies, give an early warning to the system operators and suggest possible solutions with their estimated probability of success in real time. The developed tools will include, but not be limited to suggesting the changes in network topology based on intelligent switching operations, protective relays 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 induced from RES, innovative expert systems, highly sophisticated decision-making support tools and Advanced Automation 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 voltage stability as well as in transient stability analyses - Develop advanced decision support tools which 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 in 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 and utilizing forecast and take benefit out of controllability of RES (use for coordinated reactive power/voltage control, congestion management,…)

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	- Develop tools for restoration strategies for the pan-EU system based on coordination of Tie Lines and/or Black Start units whilst taking into account system condition, system constraints and available resources to support 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 case of emphasized variability and uncertainty of input data and multi-conflicting evaluations. - Develop and demonstrate innovative expert systems that take into account the uncertainties in the power system, using the Artificial Intelligence techniques and probability approaches such as Bayesian analysis. - New control room environment must be developed to allow the operators to handle these complex situations when they have to make decisions (this evolution could be compared to the aeronautic industry, i.e. automatic pilots with a fully digitalized environment). Specific trainings should also be adapted to the new ergonomic framework. In such tools (enumerated above), the reliability of the ICT system(s) must be accounted (link with cybersecurity in C5).
Expected outcomes	Advanced Automatic Control, effective making-decision tools and innovative expert systems will be validated involving 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 also quality of service will be improved maximising at the same time the utilisation of system components
Contributors	TSOs, ICT providers, Technology providers, Research Institutes
Additional information	Interdependent with T1, T14. It also builds on previous project: iTesla, UMBRELLA, PEGASE
Budget est.	50 M€
Timeline	2020-2026

T8	**Reliability and resilience** **defence and restoration plans, probabilistic approach, risk assessment, self healing**
Contents	***Challenges:***

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	Some damage to physical infrastructure could occur during extreme weather or operational conditions but a smart grid should be able to not only react and isolate damage in order to mitigate the impact, but also to recover fast. In this sense, the smart grid should be able to utilize data and all control and ICT technologies enabling the self-healing of the Transmission System. The knowledge of the enhanced stresses to the transmission system is the first step. If the stresses linked with the RES integration and the reduced inertia is known, work still needs to be carried out in the field of understanding the threat to the electricity system linked with extreme environmental events connected with climate change (e.g. extreme winds, snowfall, rainfalls, flooding, pollution, desertification). Specific R&I activity should address these threats before considering the related risks and consequences and therefore set 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. In this perspective, it is relevant to analyze if the N-1 criterion is still adequate for planning and operating transmission grids or if a probabilistic approach is therefore needed in order to enhance the assessment of 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 to develop, among other, new power system restoration planning methodologies that may incorporate interactive graphics and optimization algorithms that could serve to design the restoration plan. To harmonize an emergency strategy in connection with RES and DER management, simulation tools to detect weak points in the pan-European system are needed together with operational guidelines with acceptable reconnection scenarios. The end consumer could also participate in defense plans by using domestic intelligent electrical appliances that could sense changes in network frequency and respond according to the order of priority set by the user (e. g., selective load shedding). Probabilistic approach should be also utilized for developing 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 abovementioned markets should address and identify, under a risk based approach, the probabilities of scenarios, the probabilities of faults as well as the probability of failure for corrective actions. More accurate forecasts for example will allow market players to react to the latest information more efficiently. ***Objectives:*** The main objective is twofold; one 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 that would reduce its probability of failure (including those stemming from climate change) as well as the consequences from such failures and the time to recovery should be developed and applied. The second aspect is the development of new tools that help TSOs to increase their reliability and consequently to enhance their role as market facilitators. ***Scope:***

	New procedures and tools will be developed encapsulating a probabilistic approach while at the same time involving components at the distribution level ***Specific tasks:*** - Address regulatory and technical challenges that implement restoration plans at the pan-European level - Include risk analysis in TSOs daily business - Identify specific resilience/vulnerability indicators - Develop special tools in order to quantify resilience - Investigate the effects of extreme climate events as increasing threats for 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. Moreover, to provide an appropriate approach to risk assessment based on probabilistic analyses for both normal and abnormal operations which takes into account correlations in the power system - Evaluate new stochastic models with respect to market operations in different timescales in order to improve reliability - Identify the possible options for replacing (or complementing) the current reliability principles using a system approach to be used in different aspects of TSOs business: grid development, markets, etc. - Define the additional information to be exchanged and the additional coordination needed to support deployment, and to ensure effective and sufficient security margins during operation and operational planning - Develop indicators for the evaluated criteria for network operators to help them make decisions for preventive and curative actions - Develop simulation tools and methods of 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, also to assess the system state during the restoration process, expected RES in-feed of DSO at reconnection. - Engage storage in defense and restoration tools and plans - Investigate the contribution of DER for system restoration and its contribution to immediate power reserves; this is relevant from the TSO perspective (e. g., black start capability and coordination of wind turbine generators). 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 operators about the evolution of national regulatory schemes in order to foster coordination efforts - Accounting for failure modes of ICT (including sensors) in the different simulation tools.
Expected outcomes	- A framework which will relate 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 and micro-grids to defense plans (black-start capabilities, islanding capabilities) - A joint TSO / DSO approach for defense 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. It also builds on previous project: GARPUR, AFTER, ICOEUR, iTesla, NetzKraft
Budget est.	50 M€
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 is being increased rapidly, 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 to account for new ramping requirements. In these circumstances, the ancillary services from conventional generation will not be enough, and so they have to be provided also from RES and DG, which must participate more actively in controlling the system, potentially at the same level as conventional plants, which is the main challenge in future network operation. Storage might also play an important role and provide specific services such as a very dynamic frequency control (< 1 s) – In this frame it becomes apparent the necessity of a multi-level process involving both TSOs and DSOs, generation connected to DSOs and utilities. Distribution companies formerly 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 the TSOs and DSOs. The role of conventional generation might also evolve, with power plants used as much to provide energy as to provide ancillary services. ***Objectives:*** To address technical and regulatory aspects to allow enhanced ancillary services for TSOs from DER and storage through a new framework involving the services provided by units connected at DSO networks and from DSO facilities. To allow cross border ancillary services provision. To allow new players provide valuable services. ***Scope:*** New procedures and strategies will be developed to provide new ancillary services from RES combined with those provided by the DSOs, by new actors such as storage, and by existing ower plants (natural gas, thermal etc.) ***Specific tasks:*** - Increase the visibility of variable RES for TSOs (to enable for more accurate forecasting). - Dynamic calculations of RES production using short-term forecasting models or by continuously updating the data. - Procurement of 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). - 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. - Novel ways of providing ancillary services through storage systems and their impact on transmission networks - Simulation environments to demonstrate the viability and options of ancillary services provision by aggregated loads at 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. - Robust optimization algorithms for tool for coordinated control of DER (robust against uncertainties, robust against variability) - New actors and market models that enable DER and storage to provide ancillary services. - New models that describe products and services to be tested on selected segments of customers and their impact on future ancillary services in the presence of large-scale DER integration; - New market models that account for the price-sensitive nature of loads and consequently their increased flexibility.

	- Analysis of legal, contractual and regulatory aspects of ancillary services provided by distributed generation and / or loads, allowing for more aggregated business models. - Sharing 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 contribution from demand and units connected at DSOs networks and from DSO facilities in terms of issues like 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.
Expected impacts	New recommendations on grid code evolutions, based on new ancillary services that can be provided from TSOs
Contributors	TSOs, DSOs, ICT providers, Manufacturers, Service providers, Generation companies, Aggregators, Commercial retailers
Additional information	Interdependent with T10, T11, T12. It also builds on previous project: SMARTNET, MERGE
Budget est.	60 M€
Timeline	2022-2026

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CLUSTER C3: FLEXIBILITY OF POWER SYSTEM

T10	**Storage integration, use of storage services**
Contents	***Challenges:*** Energy storage technologies and integration have become a key element in smart grid structures. The landscape in generation field has been changed dramatically with integration of high amount of variable renewable electricity generation in the European electricity systems. In addition, in the new model of the electricity sector, demand response will play a relevant role in the future, introducing as well variability in the demand behavior. There is a growing challenge in balancing the power grid because these clean power sources don't have additional reserves and can be located anywhere in the network. This requires adapting the grid to store electricity more effectively and flexible using optimal the disposable conventional and innovative sources while keeps providing customer with reliable and quality power. ***Objectives:*** Developing schemes to have storage availability for system planning and operation purposes. In parallel, analyzing the integration of storage technologies in close contact with the relevant manufacturers in order to maximize their application possibilities, in terms of both performances and of time-to-market development. ***Scope:*** Activities should focus on storage systems that aim at supporting the balancing of the power system and ensuring the security of supply. It is imperative to cover the technical concerns for improvement of power storage process for balancing purposes. It should also be evaluated the associated economic, regulatory, market and environmental aspects with deployment of storage systems in the power system. ***Specific tasks:*** This topic will address the technical and regulatory aspects such as: - Optimal power-to-power cycles with optimal efficiency and minor losses or integration with other energy systems offering to regenerate losses as valuable energy services, for example heat. - Novel solutions for fast responding power and energy storage at different voltage levels in the power system calls for novel solutions where supplementary services will be included in the storage facility. - System planning tools to find the optimal dissemination of the energy storage for facilitating the operation in transmission systems 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 to the envisaged applications and business models. This will, in turn, allow to estimate accurately the lifespan of the storage system (and the failure modes) and profitability. - Improvement of current system modelling tools to better take into account the benefits of storage to optimize the balancing : measuring OPEXes and CAPEXes impacts - Tools to assess potential revenues on storage, in liquid markets (day ahead & intraday markets) and or in not liquid markets - Asses the contribution of power-to-gas technologies as a means to store electricity at large scale and cover with gas turbines 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 (eg. power to gas, marine storage , CAES).
	Deployment of low carbon technologies together with encouragement of increasing 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 the flexible management of the grid and will support development of innovative market models and terms for more efficient system. Regulatory and economic impacts assessment and opportunities for the storage facility; made possible by analyses and recommendations
Expected impacts	- Support to the power system with fast response power and energy storage assessed by feasibility studies of several technologies - Unleashing the potential for balancing, congestion management and/or support with ancillary services through pilot demonstration. - Deferred investments for transmission and distribution grids 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. It also builds on previous project: ANEMOS Plus, OPTIMATE, From wind power to heat pumps, GridTech, Store
Budget est.	100 M€
Timeline	2017-2022

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T11	Demand Response, tools to use 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, tertiary sector and end consumers in order to assess their 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 Response (DR) and raise awareness about consumption patterns and foster active manufacturer's , service/business and customer participation in the energy market. ***Objectives:*** The main objective is to develop and integrate demand response mechanisms providing services to the system. And to add flexibility to the system (modulate the load curve) in order to increase overall system efficiency. To foster customer active participation in the system. ***Scope:*** Integration of demand-side management tools will allow the customers at different levels to make more informational decisions about usage of their energy and will support TSO and DSO in electricity operation. Demand respond mechanism will impact market and will offer economic incentives and will optimize investment and current assets of the network. ***Specific tasks:*** To achieve these goals, demonstration specifications are required for demand-side management: - Define demand requirements and data required by TSOs for the best DSR utilisation; - Demonstrate active customer (industry, tertiary sector of economic and end consumers) involvement with "indirect" feedback (provided post-consumption) and "direct" feedback (real-time) and suitable operations designed to achieve a reduction in peak demand (10–15%); - Integrate and demonstrate DR and storage integration solutions including the impact of the electrification of transport system (eg transport – EVs etc.) for off-peak hours and their usage in system balancing; - Model customer/load behavior and segmentation and quantify the degree of flexibility provided by distribution networks, e.g., through reconfiguration or other methods. - Test DR models bringing demand response from private customers by e.g. limiting the rated power during specific period of time.,
Expected outcomes	The existence of load control provided by the distribution at TSO level allows TSO to plan and operate the network in an efficient and economical way:

	In short term will assist the reduction of technical constraints and power collapse in electricity grid; in long term will reduce the expenses in energy reserve and prevent bottleneck in the network at whole level. Also demand side management will boost development of payouts schemes for participants in Demand Response (DR). Tools and models shall be developed for Demand Response and e for customer behavior to facilitate the forecasting and operational processes.
Expected impacts	Increased level of flexibility for TSO planning and operations will allow increased integration of RES while maintaining 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. It builds on previous project: ANEMOS Plus, MERGE, eStorage (still ongoing project), From wind power to heat pumps, GridTech, OPTIMATE, Ecogrid EU, Gredor, Cell Controller Pilot Project
Budget est.	80 M€
Timeline	2017 - 2023

T12	**Improved RES forecast and optimal capacity operation**
Contents	***Challenges:*** Renewables Energy Sources such as wind, solar or marine generation are characterized by a fluctuating output due to the changing nature of their 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 the optimization of the system especially in situations of high penetration of variable RES. Better forecasting can be achieved by resorting to hybrid approaches combining weather forecast, local ad-hoc models, historical data, and on-line measurement. ***Objectives:*** The goal is to determine the best method of deploying and demonstrating different concepts using ICT, ancillary services and models for reliable energy output so that more clean energy can be integrated, forecasted and smart managed in the network. ***Scope:*** The main focus is to improve the forecasting for RES to ensure and for optimal capacity operation and to keep the quality and security of supply. In the same time is good to

	focus on building up structure for handling the large amount of data that is necessary to be collected, processed and analyzed. ***Specific tasks:*** - Improve RES forecast accuracy by testing o hybrid approaches combining weather forecast, local ad-hoc models, historical data, and on-line measurement. Test the improvement of accuracy with access to High Performace Computers. .To validate integration scenarios where the network becomes more user-friendly and copes with variable generation from RES. - To develop and demonstrate methods for dynamic capacity management and reserve allocation that support system operation with large amount of RES integration - To 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 managing variable sources in system operation and power markets: - RES generation will be balanced cost-effectively over longer periods of time by optimizing the entire value chain over 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 (eg. 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	TSO;DSOs; Generation companies; Technology providers, ICT providers Customers;
Additional information	Interdependent with T7, T10, T11, T13, T15, T16. It also builds on previous project: OPTIMATE, ANEMOS, SAFEWIND, BestPath, GridTech, Realisgrid, Seetsoc, WindGrid, EWIS.
Budget est.	40 M€
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 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. Advance 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 demonstrated 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 shall be able to provide grid operators with dispatching resources, both in contingency and in normal situations. Increased network flexibility for grid users at optimized OPEX which allows a larger share of RES and increased security of supply. ***Scope:*** All devices which can increase flexibility of grid operation, new services rendered by interconnectors, new materials/operating modalities which can widen the palette of tools for grid operators' 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 flow across multiple transmission zones and borders - To demonstrate controllable off- and onshore solutions for vendor-independent, HVDC multi-terminal networks used to coordinate power flow, frequency control as well as protection and communications requirements - To investigate the influence of parallel routing of DC and AC lines on the same tower or parallel paths to utilize existing infrastructure paths in an optimal manner
Expected outcomes	New methodologies will be validated for upgrading the existing grid and increase transmission capacity in a cost-effective and environmentally friendly manner. This provides relief at network bottlenecks and help bridge short-term investment delays. Furthermore, power flow control devices shall favor 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 optimized utilization 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 the valuable tools to operate the system in most efficient modalities, leveraging in synergic way from all means available. At the same time the environmental impact and the use of resources shall be minimized, also benefitting grid users and tariff-payers with more cost-effective operation, both in terms of OPEX and CAPEX. New methodologies will be validated for upgrading the existing grid and increase transmission capacity in a cost-effective and environmentally friendly manner. This provides relief at network bottlenecks and help bridge short-term investment delays. A more flexible grid will be implemented that integrates RES and helps to cope with demand enabling of 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. It also builds on previous project: BEST PATHS, PROMOTION, PEGAS
Budget est.	30 M€
Timeline	2021–2026

T14	**Interaction with non-electrical energy networks**
Contents	***Challenges:*** Decarbonisation is essential to cope with long-term sustainability EU targets, and electricity is one of the main vectors that will lead this transition. From the demand side perspective the electrification of the transport, heating and cooling sectors are pathways to fulfill this objective. Whereas in the generation side it could be efficient for the energy system to coordinate and couple the electricity generation with the (gas supply for the) combined cycles. These facts increase the complexity of balancing and managing network problems while still maintaining the security of supply. ***Objectives:***

	The objective is to promote actions to foster the transition towards new model for a European energy system (heat, transport, gas, electricity) . To develop tools to analyze balancing and congestion issues in the entire energy system as well as the support of gas technologies in the restoration plans. ***Scope:*** To model the interfaces between different energy systems and analyze the mutual benefits among different energy systems (when utilizing power to gas for balancing, electrification of heating and transportation sectors To explore and demonstrate Power to gas/heat projects and other interaction projects ***Specific tasks:*** Develop methodologies and tools to assess the impact of the transition towards 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 in the gas grid and later used for production of electricity.
Expected outcomes	Models and tools to manage balancing and congestion problems methodologies and tools to assess the impact of the transition towards the new energy model i Valuable results from pilot projects Coordinated activities with other system players
Expected impacts	Better and more optimal decision making tools More holistic models making use of the most cost effective solutions to supply energy
Contributors	TSOs, DSOs, Utilities, Gas companies, other System players and other stakeholders (Transportation)
Additional information	Interdependent with T6, T8, T10, T12. It also builds on previous project: Real-Smart, GridTech
Budget est.	30 M€
Timeline	2017-2021

CLUSTER C4: ECONOMY AND EFFICIENCY OF POWER SYSTEM

T15	**Market/grid integration**
Contents	***Challenges:*** Pan-European power flows within a liberalized energy market plus massive integration of variable RES are resulting in local and regional bottlenecks possibly causing a significant decrease in capacities available for the market. A fair 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, counter trade on one hand and benefits of the resulting increase in capacity on the other hand. The main challenges that need to be addressed lie with the management of congestion and deviations from planned operations that result from such a solution. This requires not only new transmission capacity and flexibility in power flow control, but also new tools for market and network analysis. ***Objectives:*** Network-constrained market simulation tools are to be developed that provide recommendations about specific network management and market designs. This will make possible to manage congestion within the pan-European grids without affecting system reliability 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 , evolutions of the flow based, with for instance stochastic approaches enabling a 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 ta flow-based market coupling approach that can be extended geographically, temporally (in intraday horizons). - Define and validate a stochastic flow-based approach, enabling a better coordination between the market and the real network capacities. - Introduce simulation options that account for interactions between the various regulatory frameworks - Define the modeling approaches and the associated data on transmission and generation that are vital to deliver meaningful results

Expected outcomes	- Enhancement of the modelling of network flexibilities 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 taking into account grid flexibilities and an explicit modelling of uncertainties to increase the cross border exchanges
Contributors	TSOs, Generation companies, Research institutes, Service providers, Regulatory authorities
Additional information	Interdependent with T9, T12. It also builds on previous project: OPTIMATE
Budget est.	30 M€
Timeline	2018-2023

T16	**Business models**
Contents	***Challenges:*** Huge investments are 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 for both the consumers and the investors. Synergies between the different energy sectors (electricity, gas, heat, etc) and the differents infrastructures should be found to meet the conditions of acceptability. Under long-term horizons, electricity market designs should drive cost-effective investments in a coordinated cross-border approach, where 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 of the forthcoming years in EU28. ***Objectives:*** The objective is to switch from tools modelling very precisely the electricity sector assuming roughly that the market is pure and perfect to tools that take into account the whole energy sector and consider different actors with various business models and strategies. ***Scope and tasks :*** Various tools will be developed to model globally the energy sector, taken into account different actors with their own interests and various regulatory framework. The interactions between actors should be modelled as well.

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	Several tools need to be designed and developed: they involve a global modelling of the major energy carriers, able to account for the different players involved, with their own interests and within different regulatory frameworks 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	Mechanisms pushing towards "optimal" investments needed to achieve the energy transition
Expected impacts	Reduce the investment burden for the end consumers
Contributors	TSOs, Generation companies, Research institutes, Service providers, Regulatory authorities , consumer associations
Additional information	Interdependent with T9, T10, T11, T12, .It also builds on previous project: OPTIMATE
Budget est.	20 M€
Timeline	2017-2021

T17	**Flexible market design**

Contents	***Challenges:*** The European transmission grid has been constantly evolving 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. Therefore, consideration should be given to the development of improved market models at all time horizons and simulation tools which would allow adequate system capacity to host a large share of RES generation in a cost effective way. More specifically, the monetization of curtailments of wind/solar power generation with zero marginal cost remains an open issue. The criteria of security of supply must also be reviewed and harmonized in Europe, within a new context in which demand response could play a more important role. ***Objectives:*** Under short term horizon, market models will provide recommendations on specific rules for integrating renewables in power, balancing and system services and therefore allow massive integration of RES. For long term horizon, the impacts of intermittency of energy sources on others generation means, due to zero marginal costs, cannot be ignored. Investment issues become the key issues for 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 ongoing projects. It is, therefore, required in order to 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 investments horizon to balancing. ***Specific tasks:*** ***- Short term:*** Models and simulation tools to demonstrate the results of the enforcement of 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 improve the generation shift and power balance without interrupting the quality and reliability of service. ***-Longer term:*** 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. It will consider all time horizons and will explicitly take into account the various regulatory framework implemented (some countries with strategic reserves, others with capacity mechanisms). The toolbox will help to propose new design at 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. It also builds on previous project: OPTIMATE
Budget est.	20 M€
Timeline	2017-2020

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CLUSTER C5: ICT AND DIGITALISATION OF POWER SYSTEM

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, every day 2.5 exabytes (2.5×1000^6Bytes) of data are created. One question for large enterprises is determining who should own big data initiatives that affect the entire organization. What's really going to make big data go main stream is the ability to connect not just with data scientists and technologists but business people. And absolutely one of the keys to that is visualization, is being able to show people—not just tell people, not just show numbers or even show charts—but to have those charts and graphs and visualizations come alive. “Internet of Things” (IoT) (T22) is also expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data, and an increase in the 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. All parties involved are reluctant to share the information hidden in the available data. Big Data Management tools could be the key to open the door to a more professional sharing. ***Objectives:*** .Develop ENTSO-E strategy on 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 of using the available information and/or prognostic information, thanks to an improved data management practices / data processing technologies and intuitive visualisation. The aim of the strategy shall be to enhance decision-making in targeting the TSOs in the first round. The primary approach could be to identify and describe cases for transmission system operation, asset management and market facilitation. Integrate the big data management tools in planning, asset management and operation activities of TSOs taken all relevant stakeholders into account ***Scope and tasks :*** Develop a strategy for beneficial and relevant Big Data Management initiatives within ENTSO-E through use of relevant case studies Develop together with DSOs protocols for data transfer

	Develop need interfaces between the Big Data Management and the existing or new planning and operational tools.
Expected outcomes	Applications beneficial for the stakeholders of ENTSO-E. A strategy for the ENTSO-E organization how to apply Big Data Management tools and application in the future energy optimization and operation of the energy system. Improve awareness in the ENTSO-E organization on the benefits 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 knowhow. Supporting advanced market platforms. More advanced asset management. System analysis on a more advanced level. Application of distributed energy resources in a more efficient manner. Supporting a lowering of entry barriers.
Contributors	Universities focusing the topics on Big Data. Companies providing BigData tools, applications and related services.
Additional information	Create a link to standardization of data object – link to IEC 61850 Interdependent with T5, T19, T20.
Budget est.	20 M€
Timeline	2017 - 2021

T19	**Standardization, protocols for communications and data exchange**
	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, energy storage, requires a gigantic amount of communication and coordination among the parties involved 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 the future scenarios.

	Objectives: The purpose of standardizing a harmonized and limited set of protocols supporting a pan-European communication within the energy sector from a single generating unit to the market platform and further on to the transmission and distribution of the energy to demand units, is to provide energy in an efficient manner by lowering the system integration barrier. In addition, the objective is to lower the integration cost and ease the system integration process by using standardized protocols. In order to lower the entrance cost of protocol stacks it could be relevant to analyze use of open source societies. The parties with a great interest in the outcome of this work stream will be all actors in the electricity sector. Especially the manufactures, system integrators, system operators and project developers will have a major interest in the deliverables. ***Scope:*** the scope of the task is to select the most efficient and flexible communication protocol technologies focusing on integration cost, flexibility and scalability in use. Apply experience from the EU FP7 project M/490 ***Specific tasks:*** - Create recommendations on specific protocols to be promoted for specific communications purpose within the energy communication network system, e.g. the IEC 61850 standard series, IEC 61970 (CIM) standard series, IEC 61968 (CIM) standard series, 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 on protocols services or extensions to existing standards. - Promote standardized information exchange solutions based on standardized protocols - Promote use of open source initiatives.
	A common recommendation on a limited list of standardized communication protocols applicable for 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 for a reasonable cost.
Expected impacts	- Request for maintenance on several standard series - Creation of several liaisons to the various working group within the standardization bodies. - Increase allocation of resources to attend the various working groups, create proposals for solutions, and propose correction and comments to various standard series.
Contributors	IEC, CENELEC, ISO standardization bodies and their relevant technical committees – e.g. IEC TC57, CENELEC CLC/TC57 ISO/IEC JTC 1/ SC6, ITU X500

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Additional information	- ENTSO-E declaration on application of IEC 61850 in Smart Grid aplications - ENTSO-E declaration on application of IEC61970 and IEC 61968 (CIM) to exchange Common Grid Model (CGM) info. - Results from EU FP7 project M/490.
Budget est.	20 M€
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 these objects to collect and exchange 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 ensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which also encompasses 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. " As well as the expansion of Internet-connected automation into a plethora of new application areas, IoT is also expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data, and an increase in the 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. In the future, Internet of Things may become a non-deterministic and open network in which auto-organized or intelligent entities like Web services, application of Service Oriented Architecture (SOA) components, objects standardized by the Organization for the Advancement of Structured Information Standards (OASIS), and (Web services, SOA components), virtual objects (avatars) will be interoperable and able to act independently (pursuing their own objectives or shared ones) depending on the context, circumstances or environments. ***Objectives:***

	Create awareness in the ENTSO-E organization on the benefit of applying the IoT technologies in combination with BigData applications. Recommend an ENTSO-E strategy on application of IoT in selected areas within the electricity sector. The expected outcome /value of the strategy shall be quantified /justified via descriptions of cases with a high amount of distributed sensors and the potential benefits with an increased efficiency by using the IoT. The aim of the strategy shall be to enhance decision-making in targeting the TSOs in the first round. ***Scope:*** To study IoT applications and services available. To recommend a strategy for ENTSO-E on selected areas applying IoT within the energy sector. ***Specific tasks:*** - Assess the potential benefits of intensify usage of IoT in TSOs activities - Develop an ENTSO-E whitepaper and/or a technical report on the benefits of applying IoT and related tools for the electricity sector. - Create study and white paper for applying IoT technologies through the public internet in a secure manner taking risks and privacy into account. - Develop needed tools for interfaces for intensified usage of IoT in planning , asset management and operational activities of TSOs
Expected outcomes	Applications beneficial for the stakeholders of ENTSO-E. A strategy for the ENTSO-E organization how to apply IoT in the future energy system.
Expected impacts	Increased network security level.
Contributors	Universities focusing the topics on IoT. Companies providing IoT services and tools. ITU-T study group SG17 – smart grid devices
Additional information	Interdependent with T18, T21. It also builds on JRC report on Smart Grid projects
Budget est.	30 M€
Timeline	2017 - 2023

T21	**Cybersecurity**
Contents	***Challenges:*** Computer security, including cybersecurity and information security, is the protection of IT systems from theft or damage to the hardware, the software, and to the information on them,

	as well as from disruption or misdirection of the services they provide. It includes controlling physical access to the hardware, as well as protecting against harm that may come via network access, data and code injection, and due to malpractice by operators, whether intentional, accidental, or due to them being tricked into deviating from secure procedures. The field is of growing importance due to the increasing reliance on computer systems in most industrial sectors and societies. Computer systems now include a very wide variety of "smart" devices, including smartphones, televisions and tiny devices as part of the Internet of Things (IoT) – and networks include not only the Internet and private data networks. ***Objectives:*** The objectives to be dealt with for this task among other, are the following: a. Security measures, monitoring, detection and reactions b. Reducing vulnerabilities c. IT Security by design for power system security d. Security architecture e. Hardware protection mechanisms f. Secure and robust controls and operating systems g. Secure coding and encryption h. Secure cross sector identification and authentication i. Network and information access control j. Response to breaches and warnings to actors within the sector k. Cross border coordination within the electricity sector ***Scope:*** Publish a strategy for the cyber security 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 the cyber security area 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 ENTSO-E strategy and design guideline for secure solution based on state of the art information security technologies and best theoretical and experienced practices combining information and power system security.

Expected impacts	Increased network security level
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. It also builds on: ITU-T strategy for IT and Banking sector EU digital single market – related aspects of the programme EU digitalization of the power system program initiatives EU cyber security project reports – strategy outcome
Budget est.	20 M€
Timeline	2022 - 2026

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APPENDIX 2 CONSULTATIONS OUTCOMES

The present Roadmap, elaborated by the Working Group R&I Planning of ENTSO-E RDIC Committee, is submitted prior to publication to a consultation process in 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 to particularly involved stakeholders (EERA, EDSO for SmartGrids, EASE, Technofi), through bilateral interaction and constructive joint analysis;
- external consultation with ETP Smart Grids and Member States through the Grid+storage project[18]
- public consultation via website procedure open to general public, also through proposed questions to focalise the comments.

The Roadmap also builds on the wide public consultation carried out in 2015 on the Implementation Plan 2016-2018 and on the qualified opinion received from ACER, who is mandated – inter alia – to provide such opinions on R&I deliverables by ENTSO-E.

The main outcomes of these consultations, as well as the consequent reactions, are reported in the following tables, where the comments have been classified in three categories: methodology & planning process, research and development general topics, and Clusters/ Functional Objectives.

TO BE COMPLETED AFTER CONSULTATION PROCESS CARRIED OUT IN MAY 2016

METHODOLOGY & PLANNING PROCESS

Type and source of comment	Issue & rationale	ENTSO-E / RDIC reaction

[18] EC service contract with ENTSO-E, EDSO for Smart Grids, EASE, RSE, Technofi, Vito as project partners

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RESEARCH AND DEVELOPMENT GENERAL TOPICS

Type and source of comment	Issue & rationale	RDIC reaction

CLUSTERS AND FUNCTIONAL OBJECTIVES

Type and source of comment	Issue & rationale	RDIC reaction

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Appendix 3 - Assessing R&I projects results

Appendix 3.1 Application Report

Application report

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

Just as concrete examples, extracted from the full report (available on ENTSO-E website) it can be mentioned: the use of TWENTIES Project's 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 and ANEMOS Projects) and load simulation tools (MERGE Project) by REN.

Monitoring at cluster level

Through inter-TSOs cooperation work, support from European Commission and clear defined goals in the ENTSO-E R&I Roadmap and relevant Implementations Plans the projects carried out have been achieved significant results. About 20 projects with a beneficial outcome and strong involvement of TSOs have been financed or co-funded by the EC in the last 6 years. On top of that, there are plenty of started and already completed projects implemented at national level which results can be used through knowledge sharing activities. A set of significant projects are summarized and presented grouped by the ENTSO-E Roadmap's clusters.

Selection of these projects is made by measuring how achievements of each project contributes to the tasks addressed in the R&I Roadmap. If the project fulfill particular topic in R&I Roadmap and the task with which it contributes to this topic is completed above 75%, the project is described below.

CLUSTER 1: GRID ARCHITECTURE

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

"**Realisegrid**" is a project which targetting horizon year 2030. The result will be a set of methods, criteria, metrics, and tools to determine how the transmission infrastructure should be optimally developed to assist a reliable, competitive and sustainable electricity supply in the EU. "

"**REAL-SMART**" the outcome of the project is to convert wide-area measurements to information about 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 that aim at proving the benefits of novel technologies (most of them are available from manufacturers) coupled with innovative system management approaches to enable the transmission network to meet the demands of renewable energy keeping its present level of reliability performance.

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

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

"Concept for management of the future electricity system 2025" - the result is a model of Danish power system for 2025 with integrated 70% renewable energy source mainly installed in the LV or MV grid. This design gives the opportunity to examine the system behaviour and to balance the transmission grid and secure supply of ancillary services.

CLUSTER 2: POWER TECHNOLOGIES

"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). Also this project enables the planners to combine grid-market modeling with cost benefit analysis.

"TWENTIES" project –affects this cluster through its Demo 5 and 6, Dynamic line ratings, coordination of power technology devices and new power flow management system.

"220 kV SSSC device for power flow control" – the goal of the project is to maximize the utilization of current electricity system, taking into account renewable energy integration, developing technologies based on power electronics, explicitly application of FACTS (Flexible AC Transmission Systems) and HVDC (High Voltage DC) devices. Full scale 220 kV Static Synchronous Series Compensator demonstrator will be in operation in Spain.

"Cell controller pilot project" the project has developed a system for full automated operation and optimally utilization of increasing amount of decentralized production. The project demonstrate the import and export of active and reactive power flow, full voltage and frequency control and black start mode.

"ANEMOS PLUS" looks to progressive intelligent management software models based on stochastic approaches which are used to evaluate under real conditions the variability and control of wind power. These tools perform optimal reserves estimation for a system with high wind penetration, congestion management using localized wind power forecasts, optimal usage of hydro storage and scheduling of other available generation combined with wind farms, optimal trading of a wind power in electricity market.

"From wind power to heat pumps" – the project submits innovative approach for controlling of many intelligent heat pumps as 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 the wind generation is strong and after that using this stored heat energy to heat their houses.

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

"**NETZ:KRAFT**" – this projects 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 is developing an innovative toolbox prototype to assess and forecast the uncertainties in complex system operation resulting from renewable energy in-feeds and market activities. The result is the optimization of algorithms which give risk-based assessment supporting short-term trading, ensuring electricity demand and preventing power plant outages.

"AFTER" - main objectives are to define methodologies for vulnerability identification, global risk assessment and contingency planning considering interdependencies with Information Communication Technology systems (ITC). The risk based models and tools already developed in this project will be used for the definition and assessment of defense plan and analyses of restoration phase.

"GARPUR" develops state-of-the-art quantification platform for risk-based security analyses with risk indicators that compare the technical & economic benefits of the different reliability criteria for various TSO business and time frames. These new reliable management tools will support system operators in taking decisions in short-term operational planning & real time operations with advanced regulation and diagnostics technologies.

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

"Energy Data Feed" is establishing metering points that permit detection of irregularities and trigger next research steps to prevent instability and disturbance.

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

CLUSTER 4: MARKET DESGN

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

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

Achievements of **“ANEMOS Plus”** project have big impact in this cluster, as well as in power technology development.

“From wind power to heat pumps” project is looking at storage facilities that provide flexibility and optimization in electricity market.

CLUSTER 5: ASSET MANAGEMENT

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

CLUSTER 6: JOINT TSO-DSO R&I ACTIVITIES

“SAFEWIND”– in the project are developed progressive tools for wind power forecasting with focus on difficult weather situations and extremes, which have a crucial effect on the power system reliability. Deliverables of the project are innovative solutions assisting large-scale integration of wind energy, tools for prediction of loss of power, alarming systems for large forecast errors, forecast models and applications that use distributed measurements to improve wind power prognosis at DSO and TSO level.

“ANEMOS Plus” – the results of this project in this cluster favors TSO and DSO participants to quantify better service of additional reserves required to cover the volatility of wind generation. The stochastic methods for wind power forecasting for the short and long term developed under this project aid TSO and DSO in process like estimation reserves and congestion management.

“PROBA” project offers a methodology and prototype tool for TSO in order to estimate the risk indices related to accepting to connect new distributed generation (DG) units at the TSO/DSO boundary.

“Cell controller pilot” project has a big influence in this cluster – the project was established to promote and demonstrate the capability to use 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 impact on several clusters, because they depend on each other and are strongly connected. Some of these projects are implemented with EC co-funding, some of them are executed on national level with self-financing. The results of them are a good base for developing further goals and projects in research, development and demonstration, innovation for a reliable pan-European electricity grid.

Appendix 3.2 Impact Assessment: analysis of ongoing and just finished projects

Purpose of this analysis for ENTSO-E

This report provides a synthetic analysis of 50 research and innovation (R&I) projects in which one or several European TSOs are being or have been involved between 2007 and 2019.

The analysis refers to the Clusters and Functional Objectives of 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)
- Ongoing (end date after 2016)
- Just started (start date in 2015-2016)

Type 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

Type of next steps:

- Further research
- Further development
- Demonstration

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

Innovations towards improved grid planning approaches

2016: Modular plan of pan-European grid architectures at 2050

The e-Highway2050 project (2012-2015)[19] 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

[19] 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.

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electricity and pan-European market integration. The project results in a modular development plan for possible 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 to build 2050 energy scenarios, the methodology to build the equivalent grid model, the methodology for scenario quantification and the methodology to propose transmission investment needs per scenario.

2018: Towards a probabilistic planning approach

The GARPUR project (2013-2017)[20] is designing 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 as well as corrective control measures and their probability of failure. It covers the multiple decision making contexts and timescales (long term planning, mid-term & asset management, short-term planning to real-time operation). A full implementation of GARPUR is likely to need 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 real-time operation.

Innovations in transmission grid technologies

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

The 220 kV SSSC Device for Power Flow Control project (2009-2014)[21] aimed at designing, constructing, setting up in operation and testing a SSSC (Static Synchronous Series Compensator) device to prevent overload situations in the Spanish 220 kV transmission grid due to boosting renewable distributed penetration: the SSSC installation will consequently reduce the measures that the Spanish TSO REE has to make for solving 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 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

[20] 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.

[21] 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.

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that the upscale of SSSC applications for larger power ratings and at higher voltage levels (300-400 kV) may be problematic in terms of protection for short circuit currents and design of the VSC converter that, instead of being of 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 been implemented yet around the world.

From 2015: Implementation of technologies increasing the grid capacities

The TWENTIES project (2010-2013)[22] gathered 6 demonstration projects to remove several barriers which prevent the electric system from welcoming more wind electricity, and wind electricity from contributing more to the electric system. The full scale demonstrations aimed at proving the benefits of novel technologies (most of them available from manufacturers) coupled with innovative system management approaches. In particular, the 5th demonstration aimed at demonstrating that adequate coordination mechanisms between DLR, Power Flow Controlling Devices and WAMS bring more flexibility to the electric system within affordable costs. This has led to the deployment and daily use in Belgium of 80 DLR devices.

2016: A database of cost and performances of power system technologies

Developed within the e-Highway2050 project (2012-2015), a database of cost and performance over the period 2015-2050 is given open access and is an asset for further collaborative R&I projects, for any use for grid planning studies, or more generally to any type of studies involving power technologies and their cost and performance trajectories over the period 2015-2050. It is being published on the GridInnovation-on-line platform[23].

2018: Innovative repowering of AC corridors

The **BEST PATHS project** (2014-2018)[24] develops novel network technologies to increase the pan-European transmission network capacity and electricity system flexibility. Five large-scale demonstrations are carried out to validate the technical feasibility, costs, impacts and benefits of the tested grid technologies. In particular, the 4th demonstration will deliver new knowhow 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 upgrading package which will help TSOs to deliver overhead lines that are more compact (and therefore more acceptable

[22] 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/.

[23] See www.gridinnovation-on-line.eu.

[24] 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.

on visual standpoints and less demanding in right-of-way), robust to face fluctuating power profiles, flexible in 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 enhances the existing system approach to AC overhead line repowering. It will also help TSOs and utilities to keep overhead lines reliable and resilient under the light of the developments in the European energy system, and 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, linking off-shore wind parks and on-shore 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)[25] will 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 grids but also brings together the future workforce in Europe which has to design, build and operate a commercial network. A first key technology is presented by Diode Rectifier offshore converter. This concept is ground breaking as it challenges the need for complex, bulky and expensive converters, reducing significantly investment and maintenance cost 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 which will be developed and demonstrated utilizing multi-vendor methods within the full scale Multi-Terminal Test Environment. The multi-vendor approach will allow DC grid protection to become a "plug-and-play" solution. The third technology pathway will first time demonstrate performance of existing HVDC circuit breaker prototypes to provide confidence and demonstrate technology readiness of this crucial network component. The **PROMOTION project** will take into account the results of the **BEST PATHS** and **TWENTIES** projects.

Innovations towards more secure and efficient management of the transmission system

From 2012: Wide Area Monitoring Systems

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

WAMS developed and upgraded within the ICOEUR project (2019-2012)[26] have been implemented and put in operation by several TSOs worldwide. In Europe, in particular, up to 2016 it has 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)[27] aimed at optimizing 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 key management functions were developed and demonstrated. The ANEMOS forecasting platform has been implemented by the system and market operator in Australia (AEMO): ANEMOS is the forecasting tool used for all renewable installations in Australia.

From 2015: A toolkit to security policy-makers

The SECONOMICS project (2012-2015)[28] delivered a toolkit to 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 and utilizing recent advances in modelling technology that seamlessly transverses 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. This has been already adopted by the standard body in the CVSS v3.0 issued in December 2014. CVSS is a general methodology that is 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)**[29] has delivered several pieces of software forming a new security assessment tool able to cope with increasingly uncertain operating conditions and take advantage of the growing flexibility of the grid. When considering online security analysis tools addressing dynamics of the system and uncertainties simultaneously, only a limited number of simulations can be run in real-time: this severely limits

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

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

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

[29] 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.

the analysis scope and forces system operators to operate in a conservative manner. The iTesla toolbox addresses this by carrying out extensive analysis 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. Beyond the end the project, RTE, the French TSO, is going to build full size (spatial and temporal) use cases that give 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 for preliminary tests an industrial version of the toolbox in an operational environment (control room) by 2018.

The Umbrella project (2012-2015)[30] has also delivered a toolbox prototype enabling 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. The two projects have cooperated to deliver common recommendations to ENTSO-E.

2018: Towards the digitalization of existing substations

Within the **Smart Substation project** (2012-2017)[31], a refurbishment of existing protection and control system for two large substations (10 Bays 225 kV, 12 Bays 90 kV) is carried out. The deployment of the smart substation will allow to test in real operations a local state estimator, weather-based dynamic rating for transformers and OHL, digital paralleling of voltage regulation, WAC Units and 61850 WAN for extended benefits across neighboring substations, automatic fault analysis and location. The deployed solution will allow network operators to better manage congestions thanks to local optimization and distributed intelligence and to host more renewables such as wind power. The deployment of the smart substation will also allow to test in real operations asset management functions. The deployment is on-going and the substation should be operational for validation by April 2016. The validation of the whole set of functionalities will last until February 2017. The construction of databases for long term analysis is performed by using the latest IT technologies (IoT, Big Data). A cost benefit analysis will validate the added value for the network operator.

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

[30] 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.

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

Funded by the Slovenian TSO ELES, the **SUMO project** (2011-2019)[32] 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, according with any 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 center by means of the visualization platform ODIN-VIS and the SCADA/EMS system. The main expected achievements are methods and software for evaluating and forecasting Dynamic Thermal Rating (DTR), fast methods to perform N-1 analyses, and implementation of an alarm system for extreme weather conditions affecting transmission lines. All these achievements are based on weather measurements and forecasts nearby the transmission line analyzed. 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 assimilating the real-time measurements from weather stations.

Innovations towards the integration of RES and DSR in the European electricity market

2016: Data sharing platform favoring energy efficiency services

The Estfeed data sharing platform (2012-2017)[33] is an open software platform for energy consumptions monitoring and management from customer perspective capable to interact with grids and to provide data feeds to service providers for an efficient use of energy. It is managed by ELERING, the Estonian TSO. It should facilitate the functioning of the energy market and give wider options to both consumers and businesses (including new types of stakeholders like ESCOs, aggregators, energy cooperatives). Sharing the data on the platform across different countries and regions will enable a better inter-TSO service. European-wide approach gives even more opportunities to market stakeholders to do their business and enables consumers to select between even more services and service providers.

2017: A numerical platform to test and compare short-term electricity market design options

The OPTIMATE project (2009-2012)[34] has delivered a prototype simulation tool able to simulate different market architecture options in a context of high RES penetration, based on an innovative approach consisting

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[32] The project is funded by ELES (SI).

[33] Co-funded by Norway Grants. The consortium includes Elering (EE).

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

in modelling in a sequential manner different short-term electricity markets and on an extensive database gathering information about technical and economic features of thermal plants, half-hourly forecasts of intermittent generation, network parameters… 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 end 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 have access to this tool to perform their own studies. For the time being, the OPTIMATE prototype is used by the Market4RES project (2014-2016)[35] which investigates the potential evolution of the Target Model (TM) for the integration of EU electricity markets that will 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)[36] 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 FRR will also be developed and tested within the participating countries, as well as a prototype Regional Balancing and Redispatching Platform allowing for cross-border exchanges of reserves. At the end of the project in 2020 these prototypes shall be close to implementation in TSO environment.

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

[36] 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 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 the energy system in Europe. 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, increasing decarbonisation and digitalisation of the energy sector or the Europeanisation of the energy market are only some of the challenges which need to be answered by policy makers as well as new and old stakeholders of the energy value chain.

To accompany the transition to this new European energy system, strong needs for Research and Innovation (R&I) have been identified in the transport and energy sectors. This need for R&I at the grid level is confirmed by the European Electricity Grid Initiative, which identified a requirement of € 170 million per year from 2010 in order to cope with future challenges and foster network and system adaptation. Several projects at the grid level were financed through EC Research Framework Programes: FP7 and Horizon 2020. Finally, the ENTSO-E Research and Development Roadmap 2013-2022 identified a needed € 1 billion R&I budget for the 2013-2022 period at the electricity transmission and distribution levels. In particular, TSOs are strategically positioned to ensure innovation for infrastructure, system and market. They 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. Their budget invested in R&I has stalled to only 0.3% of total revenues, the lowest ratio in the electricity sector and ten times as small as the objective of the Lisbon Treaty.

Barriers which can explain these limitations are multi-level. They encompass issues of company strategy, financial constraints, technological borders, environmental regulation, or 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 identification of necessary innovation by the different stakeholders. It might also account for issues regarding the financing and the implementation (coordination, market uptake, etc.) of research programmes. As regulated monopolies, TSOs are indeed in a particular position and face mixed incentives from profit maximisation, 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 needed to go back to the rationale behind incentives for innovation and TSO regulation in general. Preliminarily, it is to be emphasised that innovation by TSOs is not only a matter for TSOs themselves but also and more importantly for society as a whole. Indeed, the power system is a system where externalities between the different part of the supply (generation, transmission, distribution, consumers, suppliers and the other market actors) are so strong that their cooperation is at the same time very difficult to organise but very beneficial for the whole supply chain and end-users. Being central in the power system, innovating TSOs can then help the integration of the wave of innovation in the power system, which would enable society as a whole to collect more easily their benefits.

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Market players innovate because they expect benefits regarding the maintaining or increase of their market share or profitability, in the short or longer term. In order to do so, they take into account the demand for innovation, the technological opportunity of their research programmes, their ability to capture the profits created by their innovations and their opportunity cost linked with this innovation. Innovations with the most value for society should then 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 have a priori no competitive pressure from competitors which could drive them to invest in innovation and they often also do not capture the benefits from the innovation they do conduct. 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 ten years, incentive regulation has hence been applied by NRAs to TSOs and has proved an effective tool to incentivize and support 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 for 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 then 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 integrate enough the risk of disincentive for TSO innovation

Regulatory frameworks should aim at setting proper incentives to invest in long-term and transformational innovation. However, it appears that the current design of regulation does not always enable willing and anticipating TSOs to innovate in an efficient manner and in the right proportion. 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, they should provide safeguards for TSOs whose global financeability is at stake and comes as a direct cause for innovation postponement.

Those limitations of 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 as interdependent.

A first type of barriers identified by stakeholders concerns the institutional principles which frame the electricity systems and the corresponding regulators.

The institutional basis of NRAs' competencies and of TSO's missions is often grounded on fundamentals which have not evolved in all countries despite the surge in challenges at the system level and the regionalisation of electricity networks7. Immediately and easily quantifiable needs of the final user, in terms of cost and benefits (e.g., quality of supply), are sometimes still recognised as the main regulatory concern

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and TSOs, as already pointed at, conserve a traditional approach regarding their strategy and their willingness to invest in radical innovation. They do not integrate the other (and possibly new) objectives and challenges of the TSOs regarding the electricity system. As a result, the value of TSO activities and innovation for the system and society remains disregarded.

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 as relevant to their mission. Besides, regulatory frameworks are not always harmonised with regard to the current policy objectives and the incentives at the national and EU levels.

A crucial issue is also linked with the lack 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. Their awareness of TSO innovation is limited with regard to both ex ante and ex post scrutiny, as they do not have the capacity to assess R&I programmes in terms of cost and potential benefits.

A second type of barriers concerns the specific lack of adjustment of NRA frameworks to the new characteristics of TSO innovation. This results from the first barrier, as NRAs do not have the task nor the resources to enable such treatment.

The new economic characteristics of TSO innovation are thus not always considered in the regulatory frameworks. This concerns in particular the long-term nature of innovation which is not always taken into account, thus preventing the capture by the TSO of benefits in terms of cost reduction or output improvement over multiple regulatory periods. The specific risks (e.g., cost, delays, and results) are not integrated in the regulation. TSOs also face externalities, as the benefits linked with system and policy-oriented innovation often strongly diverge from TSOs' private benefits in terms of allowed revenue or innovation budget. These shortcomings limit the incentive of the TSO to carry out 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.

3. Recommendations for a preferable framework for innovation

A certain number of recommendations can be formulated to address the observed limitations and better align strategies and regulatory frameworks. These recommendations aim to solve 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 for society through both efficient and effective tools. More thoroughly, the proposed recommendations aim to:

- Reduce disincentives for efficient innovation. A "least-regret" solution should for example be to foster a better complementation between European R&I support schemes and regulatory treatments. In general, an incremental improvement of R&I support schemes, incentives for innovation and TSO regulations might enable a less costly adaptation.

- Ensure that TSOs, NRAs and policy makers recognise and integrate the value of radical innovation in their strategies and frameworks. While anticipatory transformation comes at a cost that all NRAs and TSOs cannot 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 efficiency and effectiveness of implemented innovation.

- Take into account the specificities of TSOs and the nature of their innovation. The long-term nature of their innovation and investments, the risk of contestability of their monopoly as well as the necessity for global financeability should be taken into account. The value of their investments and innovation measures 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 linked with a 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 to pursue and the remedies to implement. Experimental and reflexive modernisation should however enable to reduce these risks by ensuring dynamic improvement of frameworks and governance.

ACRONYMS AND GLOSSARY

AC	Alternate Current
ACER	Agency for Cooperation of Energy Regulators
C	Cluster
CAPEX	Capital expenditures
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Use
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
CORESO	Coordination of Electricity System Operators
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
DSM	Demand Side Management
DSO(s)	Distribution System Operator(s)
DSR	Demand Side Response
DTR	Dynamic Thermal Rating
EASE	European Association for Storage of Energy
EC	European Commission
EC-DG	European Commission – Directorate General
EDSO4SG	European DSO Association for Smart Grids
EEGI	European Electricity Grid Initiative

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EERA	European Energy Research Alliance
ELECTRA IRP	European Liaison on Electricity grid Committed Towards long-term
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
ENTSO-G	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
EWEA	The European Wind Energy Association
FACTS	Flexible Alternate Current Transmission Systems
FFR	Frequency Restoration Reserves
FO	Functional Objective, named with T standing for "transmission"
GDP	Gross Domestic Product
GHG	Green House 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 Organization for Standardization
IT	Information Technology
ITU	International Telecommunication Union

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ITU-T	ITU Telecommunication Standardization Sector; one of the three ITU sectors
JRC	Joint Research Center (European Commission)
JTC	Joint Technical Committee
KPI(s)	Key Performance Indicator(s)
LV	Low Voltage
MC	ENTSO-E Market Committee
MV	Medium Voltage
NC	Network code
NGOs	Non-Governmental Organizations
NRA	National Regulatory Authority
OHL	Overhead Line
OPEX	Operating expenditures
PCI	Projects of Common Interest
PMU	Phase-Measurement Units
PST	Phase-Shifting Transformer
PV	Photovoltaic
R&D ; R&D&I	Research & Development ; Research, Development and Innovation
R&I	Research and Innovation (N.B. for sake of readability, in this document R&I stands also for R&D and for R&D&I
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
SOS	Security of supply
SSSC	Static Synchronous Series Compensator
SWOT	Strength / Weaknesses / Opportunities / Threats

TM	Target Model
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
VPP	Virtual Power Plant
VSC	Voltage Sourced Converter
VT	Voltage Transformer
WACS	Wide Area Control Systems
WAMS	Wide Area Monitoring Systems
WAN	Wide Area Network
WAPS	Wide Area Protection Systems
WG MKS	Working Group Monitoring & Knowledge Sharing within RDIC Committee
WG RD Planning	Working Group R&D Planning within RDIC Committee
WP	Work Package

GLOSSARY

Implementation Plan	ENTSO-E deliverable R&I Implementation Plan, published yearly on as a follow-up tool of the ENTSO-E Roadmap
FP7	EU 7th Framework Programme for Research and Technological Development for 2007-2013, with total budget 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	Low Carbon Energy call for proposals is part of the Horizon 2020 'Secure, Clean and Efficient Energy' challenge for Work Program 2016-2017.
N-1	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.)

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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