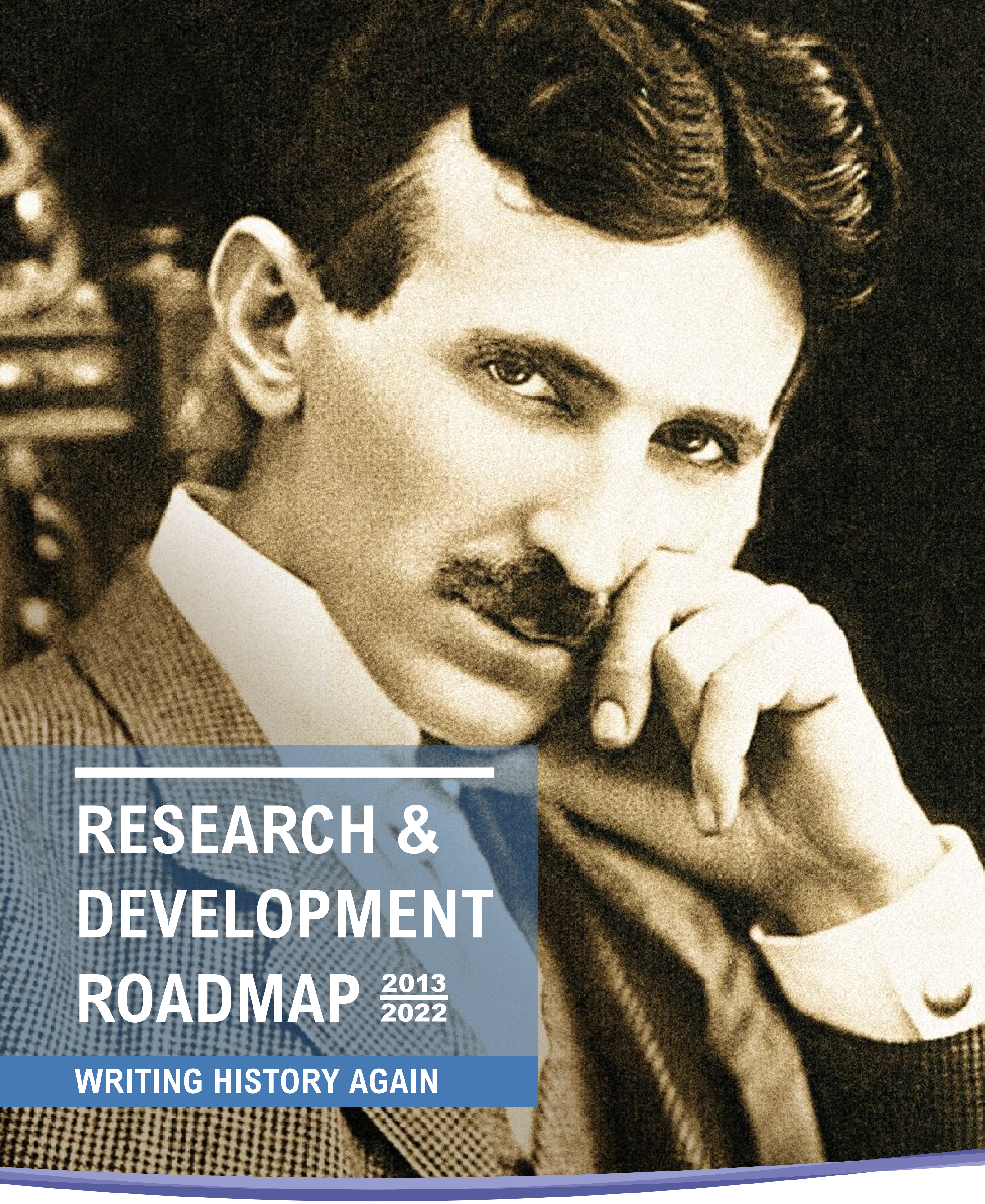

RESEARCH & DEVELOPMENT ROADMAP 2013 2022

WRITING HISTORY AGAIN

European Network of
Transmission System Operators
for Electricity

entsoe

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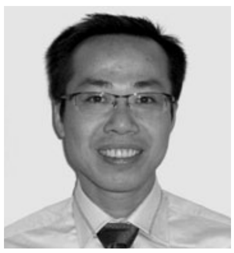

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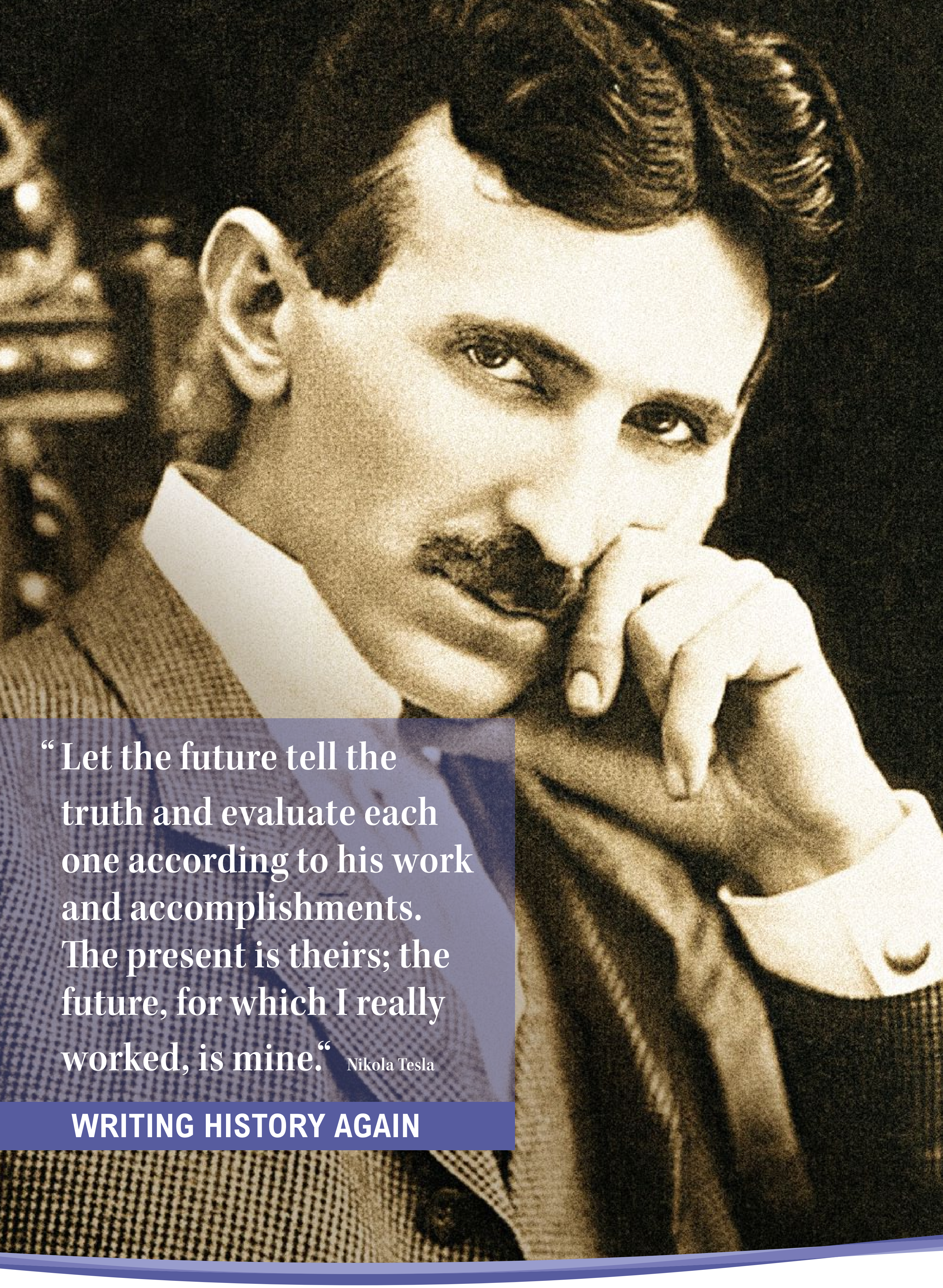
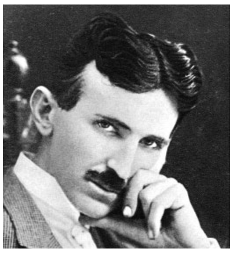


> “ Let the future tell the truth and evaluate each one according to his work and accomplishments. The present is theirs; the future, for which I really worked, is mine.“ Nikola Tesla

WRITING HISTORY AGAIN

CONTENTS



NIKOLA TESLA:
(10 July 1856 – 7 January 1943) was a Serbian-American inventor, electrical engineer, mechanical engineer, physicist, and futurist best known for his contributions to the design of the modern alternating current (AC) electrical supply system.

Tesla is also known for his high-voltage, high-frequency power experiments in New York and Colorado Springs which included patented devices and theoretical work used in the invention of radio communication, for his X-ray experiments, and for his ill-fated attempt at intercontinental wireless transmission in his unfinished Wardenclyffe Tower project.

APPENDICES 35

EXECUTIVE SUMMARY

EVOLVING ENERGY PARADIGM EXPOSES NEED FOR RESEARCH AND DEVELOPMENT (R&D)

Transmission System Operators (TSO) have many years of experience in operating and developing the transmission grid. In recent years however, the European energy system has seen significant changes. Public acceptance of new infrastructure and current R&D programs have not been able to keep pace. As Europe moves towards increased integration of renewable energy sources (RES) and an internal electricity market (IEM), a critical need has emerged for new expertise, approaches, methods and innovations. In order to maintain security of supply for the pan-European transmission system, an investment framework must be established that allows TSOs to carry out the R&D that is so urgently needed.

This Research and Development Roadmap outlines a methodology to achieve the European climate energy objectives as defined in the European Union's (EU) "20-20-20" targets and in the European Commission's Roadmap 2050. It lays the groundwork for the upcoming electricity highways and for the change to a low-carbon electricity system.

Transmission grids play a key role and must take decisive steps on the path towards achieving Europe's low-carbon energy objectives. By coordinating the efforts of the European Member States, powerful synergies will be developed to help propel Europe to the forefront of the global energy market. This includes implementation of a smart grid for Europe – essentially a modernized, highly efficient electricity network that effectively and efficiently integrates RES. Furthermore, these efforts will also pave the way for the IEM.

ROADMAP DESTINATIONS: SIX INNOVATION CLUSTERS

This R&D Roadmap formulates six distinct yet highly interdependent R&D clusters. These serve to focus and differentiate the many tasks required to address the challenges of Europe's rapidly shifting energy paradigm. Each cluster helps facilitate collaboration between European TSOs, industry and research institutes while collectively they provide a shared repository of ideas. These clusters are extremely cost-effective since they prevent similar R&D being duplicated by different TSOs and they exploit the many inherent synergies in Europe.

EVEN MODEST R&D INVESTMENTS BRING ENORMOUS BENEFITS

The size of the investments required for effective TSO R&D is relatively small yet the potential long term benefits of R&D work are enormous. For R&D to be truly effective, resources must be invested in both capital goods and the workforce. The total R&D budget is estimated to be € 1005 million for the next 10 years (2013 – 2022).

By performing pan-European R&D, transmission operators will be in position to progressively identify new functionality and technology needs for their network in a more coordinated fashion. Furthermore, R&D provides a means of mitigating the potential risks of failures in energy policies and infrastructure investment.

This Roadmap has impacts and benefits not only for TSOs but for all stakeholders including distribution system operators (DSOs), manufacturers, RES providers and society at large. No single TSO alone could conquer the many challenges facing the electricity industry. By closely collaborating and sharing R&D investments, TSOs, external partners and key stakeholders will be able to reach their key milestones and maximize results.

This Roadmap is an enabler for European energy policy: it ensures that electricity supply remains secure, sustainable and competitive. It also helps encourage the global leadership of European power technologies and Information Communication Technology (ICT), while stimulating education and boosting socio-economic benefits for grid-users and stakeholders. Through replication and scaling-up strategies, R&D outcomes can be adapted to the economies of scale and then deployed and commercialized universally.

ONLY ADEQUATELY FUNDED R&D RETURNS COST-EFFECTIVE AND ADVANCED SOLUTIONS

A long-term solution for financing TSO R&D (through energy tariffs or other means) is vital to foster investment in innovation. The current situation of relying on public financing has lead to chronic underfunding of R&D.

As regulated companies, TSOs have limited access to the financial benefits of technological innovation. The lack of explicit regulation has meant that R&D expenses are often treated as any other operating cost. In fact, the drive towards increasing cost-effectiveness tends to reduce R&D allotments on a yearly basis. Therefore, it is now crucial for European regulators and politicians to establish a regulatory framework that reverses this trend and maintains a stable environment for project-based funding.

INTRODUCTION

This Roadmap is aimed at decision-makers, stakeholders, policy and technical experts. It provides a general discussion of the various topics and issues. For readers interested in technical details, there are two appendices: Appendix A contains comprehensive descriptions of the core R&D activities (clusters and functional objectives) and Appendix B explains a methodology of defining the R&D activities.

BACKGROUND

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&D performed by the association and its member TSOs.

In 2010, ENTSO-E published its first R&D Plan 2010[1]. In December 2011, an updated version of the first edition of ENTSO-E's R&D Plan was released[2]. The first ENTSO-E R&D Plan initiated a dialogue between European TSOs, European regulatory authorities (ACER), EU Member States and the European Commission. It was also written to serve the needs of TSOs in the first European Electricity Grid Initiative (EEGI) Roadmap, which was approved at the same time as the creation of EEGI in June 2010.

ENTSO-E R&D: SCOPE AND DELIVERABLES

This R&D Roadmap evaluates Europe's energy policy goals (as defined in the so-called EU "20-20-20" targets and in the European Commission's Energy Roadmap 2050) and describes the challenges and opportunities they represent for TSOs. In addition to these energy targets, it focuses on the development of the pan-European transmission grid and completion of the IEM.

Its scope covers research, development and demonstration, and paves an important stone for system innovation. By fostering understanding for the importance of TSO R&D and its inherent benefits, this document strives to establish a supportive stakeholder environment.

Among ENTSO-E mandates, this document complements both Network Codes (NC) and the Ten-Year Network Development Plan (TYNDP) but does not limit its focus to technical or procedural aspects.

In 2012, ENTSO-E produces a new set of R&D deliverables consisting of three documents: R&D Roadmap, R&D Implementation Plan and R&D Activities and Indicative Timetable. The R&D Plan 2011 is being used as a reference for ongoing activities but it will be successively supplanted by the above-mentioned documents.

EEGI is one of the European Industrial Initiatives under the Strategic Energy Technology Plan (SET-Plan). The EEGI's mission is to create an adequate European grid (both transmission and distribution systems) to achieve the European energy policy goals.

1. **The R&D Roadmap** is issued every five years and details ten years of priority R&D activities required to meet twenty-year transmission system targets. It also contains background information on the current transmission system. It is written in accordance with the Strategic Research Agenda 2035 (SRA 2035)[3] published by the Smart Grids European Technology Platform.

2. **The R&D Implementation Plan** is issued every year and outlines R&D activities for the next three years as stipulated by the R&D roadmap. While the R&D Roadmap focuses on the R&D strategy, the R&D Implementation Plan deals with the realization of specific R&D projects. Since the Implementation Plan covers the short-term perspective, it can help develop upcoming Calls for Proposals through the European energy research and innovation program.

3. **The R&D Activities and Indicative Timetable** is part of the ENTSO-E Annual Work Program and refers to the ENTSO-E R&D Implementation Plan and/or highlights R&D activities for the following year.

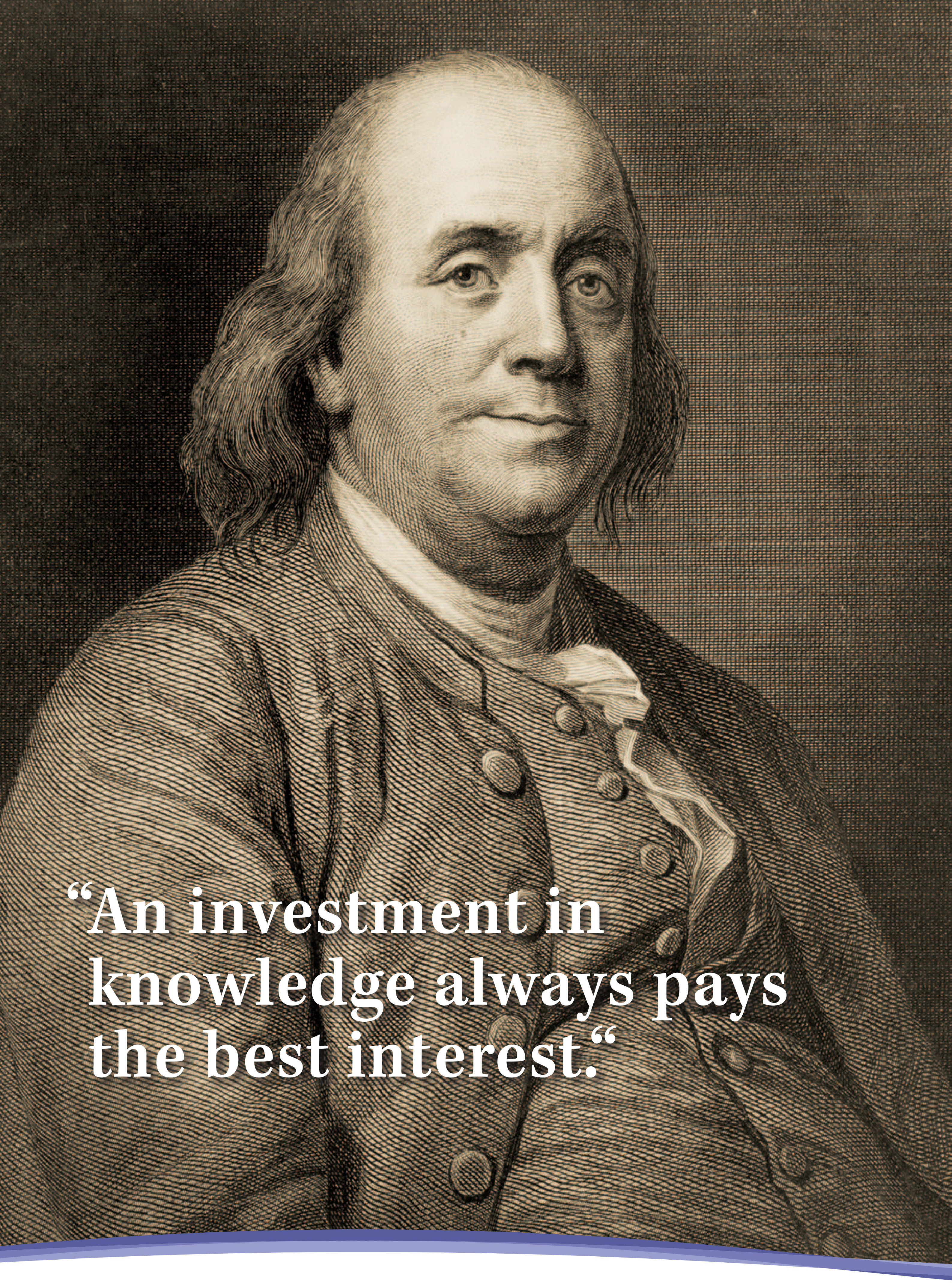
The present document represents only the R&D Roadmap. The R&D Implementation Plan and the ENTSO-E Annual Work Program are published separately.

Since the R&D Roadmap is valid for the next five years, its structure and approach differ from the previously published R&D Plan and major changes to the R&D strategy of ENTSO-E were shifted to this Roadmap.

1) R&D Plan 2010: https://www.entsoe.eu/rd/entso-e-rd-roadmap/

2) R&D Plan Update 2011: https://www.entsoe.eu/rd/entso-e-rd-roadmap/

3) Strategy Research Agenda 2035. http://www.smartgrids.eu/documents/sra2035.pdf

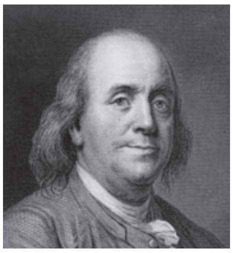

“An investment in
knowledge always pays
the best interest.“

THE NEED FOR TSO RESEARCH AND INNOVATION

The way forward over the next 20 years in the electricity sector is to invest in the innovations today that lead to tomorrow's electricity highways and a low-carbon electricity system.

In constructing the electricity highways as outlined in Energy Roadmap 2050[4], it is imperative to think beyond past scenarios while not being unrealistically futuristic. Laying the groundwork of tomorrow's energy supply will likely be quite daunting for some stakeholders. However, failing to agree upon a clear vision for the future would be much more perilous for all parties involved. Therefore, TSOs and their stakeholders have started the "e-Highway2050" project. The objective is to develop a top-down planning methodology for modular and robust expansion of the pan-European network from 2020 to 2050 in keeping with the targets of European energy policy[5]. Tomorrow's electricity system will not be based solely upon electricity highways. In order to achieve the energy policy goals and enable further integration of RES, huge investments are also necessary to expand existing networks and to develop smarter operation tools and integrate advanced technologies.

Europe must continue to strive towards a low-carbon future. European energy policies stipulate specific energy milestones for 2020 and 2050. The ability to flexibly handle variable generation from clean energy sources will necessitate an optimized mix of flexible generation, transmission capacity, energy storage and demand response. Innovative solutions are needed to achieve adequate reliability at minimum cost.



BENJAMIN FRANKLIN (January 17, 1706 – April 17, 1790) was one of the Founding Fathers of the United States. A noted polymath, Franklin was a leading author, printer, political theorist, politician, postmaster, scientist, musician, inventor, satirist, civic activist, statesman, and diplomat. As a scientist, he was a major figure in the American Enlightenment and the history of physics for his discoveries and theories regarding electricity. He invented the lightning rod, bifocals, the Franklin stove, and a carriage odometer. He facilitated many civic organizations, including a fire department and a university.

4) Communication: Energy Roadmap 2050, 15.12.2011 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF

5) https://www.entsoe.eu/news/announcements/newssingleview/article/e-highway2050-project-selected-for-co-financing-by-the-ec/

FIVE MEGATRENDS IN THE ELECTRICITY SECTOR

1. Evolution of power generation from centralized plants to distributed renewable energy sources: Large power plants with high base loads and slow ramping capabilities will gradually be supplanted by renewable energy resources with variable generation. To maintain the balance of supply and demand, flexible power generation (e.g., hydro power plants and gas-based combustion engines) is still needed for large-scale integration of renewable power sources. Energy sources are expected to be clean but they will also have to be stable and efficient. This introduces a new paradigm for grid architecture and power technologies and also requires substantial balancing between control areas to ensure that supply meets demand.

2. The completion of the Internal Electricity Market for Europe will integrate wholesale markets across all timeframes (forwards, day-ahead, intraday and balancing) and establish a framework for advanced grid operating systems that enable storage, demand response and other distributed energy resources (DER).

3. End consumers may incur higher costs during the evolution towards cleaner energy creating a field of tension with the political and regulatory pressure for lower costs and higher operating efficiency. Innovative solutions will be developed to reduce such tensions by eventually reducing the cost of clean energy.

4. R&D will be facilitated on a pan-European basis: Europe has an outstanding opportunity to exploit synergies by working towards a unified vision of the energy matrix. By collaborating on R&D and sharing resources, innovative solutions will be found and operations optimized, thus stimulating investments.

5. Evolution towards the smart grid: As the existing infrastructure evolves towards the smart grid, there will be new opportunities for transmission systems and power generation. By exploiting innovative monitoring and control technologies, the smart grid eases the assimilation of distributed energy sources and allows consumers to participate directly in energy management.

KEY DRIVERS OF GRID MODERNIZATION

Europe's new electricity paradigm is driven by three main factors: EU energy policy deriving from the EU's "20-20-20" objectives and the recently adopted EU Energy Roadmap 2050, the IEM which is to be completed with a target date of 2014 as defined by the EU Council in February 2012 and the deployment and implementation of the smart grid.

EUROPEAN ENERGY POLICIES: ENERGY 2020 AND ROADMAP 2050

The Energy 2020[6] strategy sets targets to be reached by 2020. A report by the Joint Research Centre (JRC) on Technical Assessment of the Renewable Energy Action Plans published in 2011 indicates that RES are to provide up to 34%[7] of electricity and will go well beyond that level by 2035. Furthermore, the Energy Roadmap 2050 contemplates a reduction in greenhouse gas emissions of 80–95% below 1990 levels.

These requirements present a significant challenge for controlling and operating the pan-European transmission grid. Since most power generated from RES is inherently variable and difficult to predict accurately, energy storage and market simulation models will be required to manage demand response. Coping with variable generation issues also requires a new market design that enhances cross-border exchanges close to real time and monitors reserve capacities operated at the pan-European level. This is especially true because the significant changes to the power system (for instance increase of volatile RES, long distances) and lack of infrastructure investments drive the transmission grids closer to their physical limits. This presents new challenges for the operation and control of the power systems. In certain circumstances, power might have to be supplied under downgraded conditions (in terms of voltage and frequency) to circumnavigate major blackouts.

To achieve these energy and climate objectives, tremendous structural changes are needed in both transmission and power generation. Therefore, R&D efforts must be significantly stepped up to find the innovative solutions Europe urgently requires. At the moment, policy makers are mainly focused on integrating RES and improving energy efficiency, but in many cases they overlook the needs of the transmission network itself and, in particular, the needs of TSO R&D. This perception must be changed in order to confront these new challenges. As identified by its TYNDPs[8], TSOs are already developing transmission infrastructure for the next decade. However, R&D is urgently needed to develop solutions with a perspective beyond this 10-year window.

INTERNAL ELECTRICITY MARKET

By 2014, the completion of the IEM[9] will allow market participants to manage more efficiently their pan-European production and consumption decisions. In fact, wholesale markets will be integrated across borders and will function better. Once the IEM is in place and electricity producers and consumers contribute to maintaining the energy balance at pan-European level, a market framework will be established that fosters investment in new and more flexible means of power generation and of demand response.

The potential for power blackouts and investor hesitation can carry significant political ramifications. Governments may feel compelled to intervene to prevent market failure. Naturally, such a failure would repel investors as would other factors such as regulated pricing that fails to cover costs, inefficient subsidies for particular types of generation and fears that politicians and regulators might impede higher tariffs required to recover capital costs.

The Energy 2020 strategy sets targets to be reached by 2020

- A reduction in EU greenhouse gas emissions of at least 20 % below 1990 levels
- 20 % of EU energy consumption to come from renewable resources
- A 20 % reduction in primary energy use compared with projected levels; to be achieved by improving energy efficiency.

6) Energy 2020 A strategy for competitive, sustainable and secure energy, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:EN:PDF
7) JRC, Technical Assessment of the Renewable Energy Action Plans, 2011, http://ec.europa.eu/dgs/jrc/downloads/jrc_reference_report_2011_reap.pdf
8) https://www.entsoe.eu/resources/consultations/archive/tyndp/
9) http://register.consilium.europa.eu/pdf/en/11/st00/st00002-re01.en11.pdf

Pan-European integration of these markets will require a fundamental role for TSOs (e. g., in day-ahead and intraday market operations) and some aspects may even be solely managed by TSOs (e. g., capacity calculation and balancing markets).

ENTSO-E and its TSO members are actively developing network codes to pave essential milestones to the IEM. Cross-border trading has been constantly increasing also thanks to market integration promoted by TSOs. For instance, the Capacity Allocation and Congestion Management and other Network Codes currently being developed by ENTSO-E will make a decisive contribution to IEM completion. A highly developed infrastructure has already been implemented to seamlessly transport electricity across Europe in the greatest synchronous machine ever built. However, to understand complex market interactions, R&D is needed to develop large-scale market simulation tools involving renewables, demand-side response and storage systems.

IMPLEMENTING THE SMART GRID

As existing transmission systems – some of them decades old – continue to age, many sections will be increasingly challenged by greater demand and energy source volatility together with the need for security of supply and high efficiency[10]. The increasing integration of variable energy sources together with variable loads (such as electric vehicles) will demand a highly flexible system in terms of operations and management. Inevitably, much of the existing infrastructure will have to be replaced or modernized. However, it is important to ensure that the future transmission system is innovative and smart.

What is the smart grid? The smart grid sustains the supply of energy while exploiting all of the available resources to maximize the benefit for society. It is essentially an upgraded electricity network characterized by high flexibility and adaptability. This is made possible through network digitaliza-

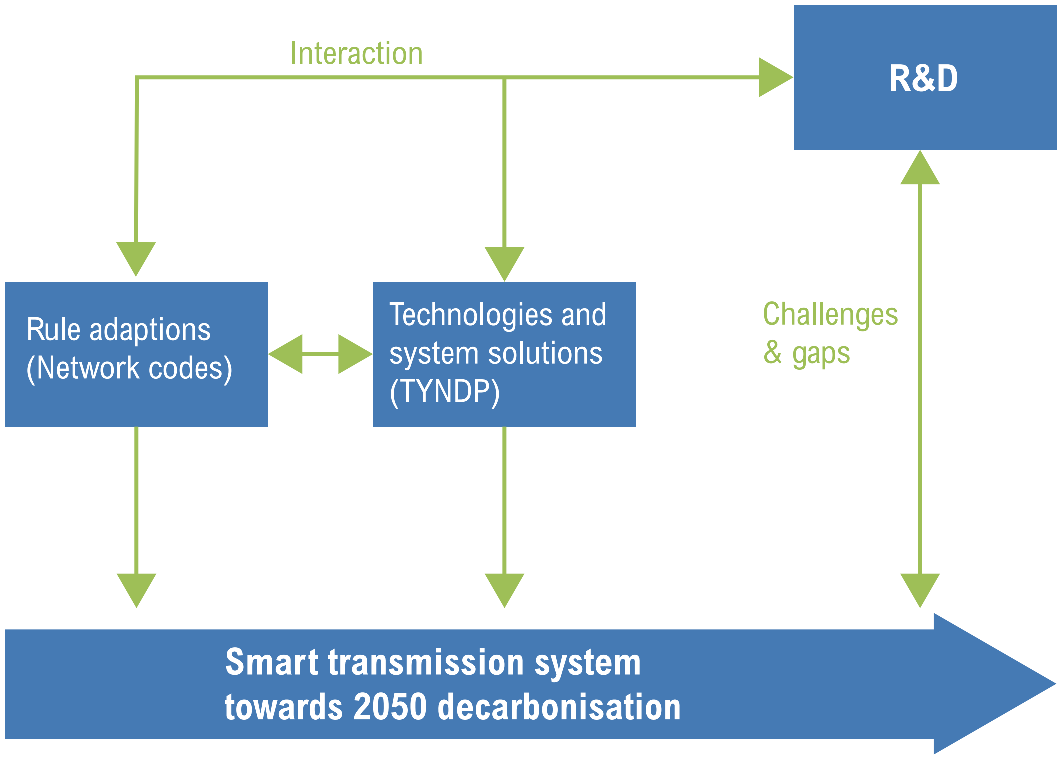


Figure 1: R&D Roadmap in relation to other ENTSO-E mandates

tion, such as two-way digital communications between the supplier and consumer and intelligent metering and monitoring systems[11].

The smart grid is central to ENTSO-E's vision for the European transmission system. Although sometimes misconstrued as being more relevant for distribution than transmission, the smart grid will be impossible without the involvement of TSOs. The smart grid enables TSOs to monitor their assets and react efficiently. TSOs are responsible for building new lines in response to market needs thus enabling demand response to bid on pan-European intraday and balancing markets.

Implementing the smart grid involves designing, planning, building, operating and maintaining the electricity grid of the future. It must fulfill European objectives for 2020 and beyond without compromising cost, quality, security or safety[12]. This entails deploying new technologies and optimizing the grid infrastructure to include RES. The key challenges facing TSOs are integrating new sources of energy and ensuring interoperability. TSOs must also implement smarter planning and operating methods and market design.

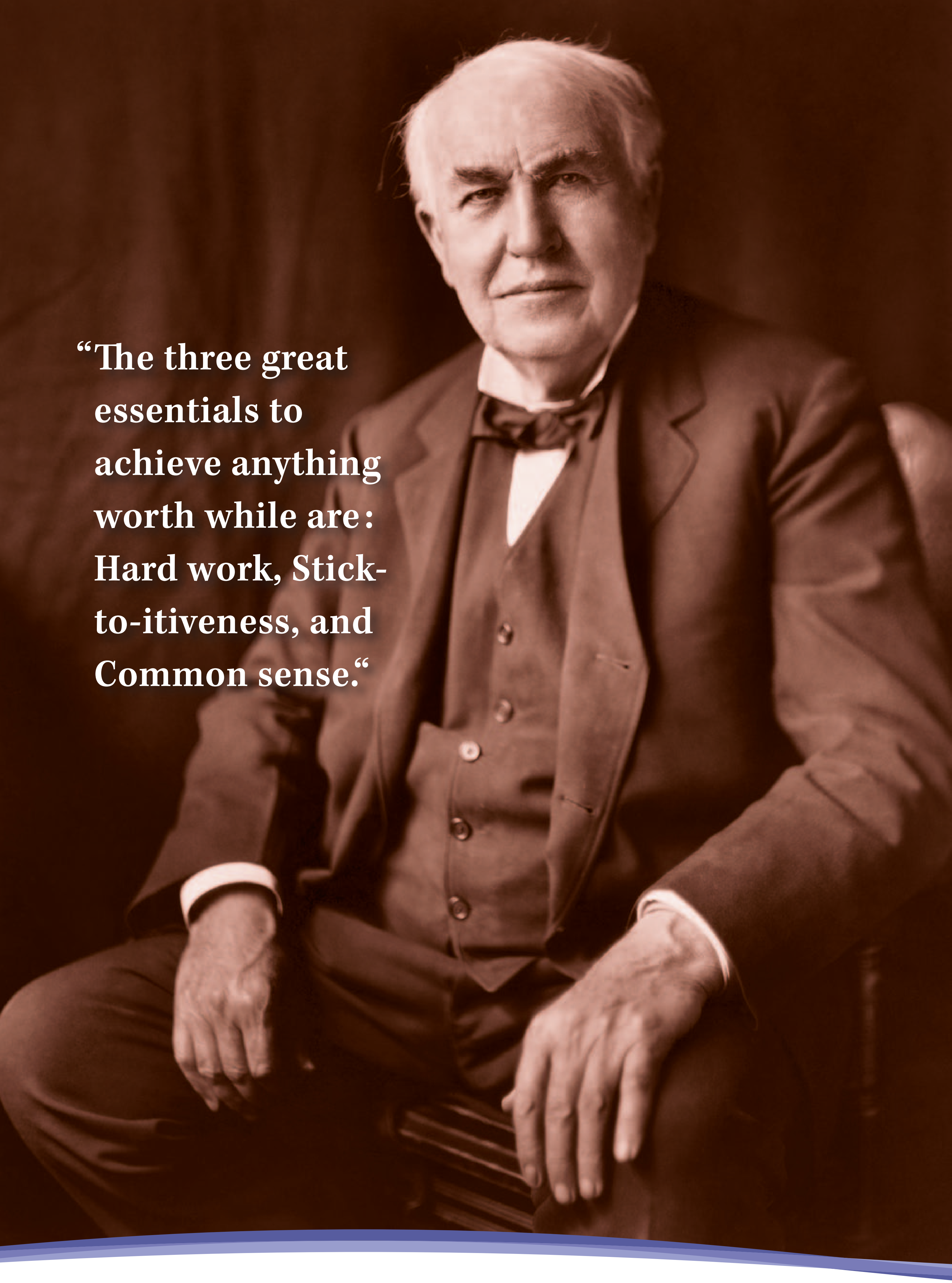
INTERACTION WITH OTHER EUROPEAN MANDATES

This Roadmap complements the European Network Codes (NC) and the Ten-Year Network Development Plan (TYNDP). While TYNDPs concentrate on hardware issues (technologies and system solutions) and NCs on "software" (rule adaptations), this Roadmap encompasses hardware as well as "software" issues over a 20-year window. TYNDPs discuss technology that is mature and currently available. The NCs foster harmonization and adoption of best practices in a pan-European perspective. Each one of these mandates makes an important contribution on the way to achieving Europe's energy policy goals.

10) IEA Technology Roadmap: Smart Grids, 2011

11) Grid + project, SRA 2035

12) CEER http://www.energy-regulators.eu/portal/page/portal/EER_HOME



“The three great essentials to achieve anything worth while are: Hard work, Stick-to-itiveness, and Common sense.“

THE VISION FOR R&D

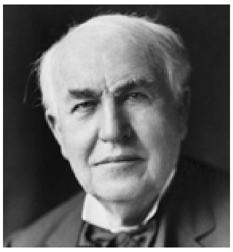
New technologies and energy sources will evolve more quickly than it is possible to implement the pan-European grid. Since electricity will increasingly originate from local and small-scale RES generation, there is a need for a strong, pan-European transmission backbone to link (large) generation and demand centers. By enabling ENTSO-E members to perform and collaborate on key R&D in advance, they will be able to implement a future-oriented infrastructure for all of Europe.

A business-as-usual approach is not an option. Merely continuing the present planning and operating methods will endanger security of supply and increase costs. TSOs must develop optimized delivery methods that encompass energy demands across Europe and that are not limited to local areas. R&D must also be performed on new transmission and storage technologies, and bi-directional digital communications. This will substantiate the need for standardization and allow better operation, planning, monitoring, controlling and interoperability of transmission networks.

All ENTSO-E members share a common vision for tackling these challenges. This entails becoming and remaining the focal point for all European technical, market and policy issues relating to TSOs and interfacing with power system users, EU institutions, regulators and national governments.

All of these considerations translate into three strategic R&D goals for the next 20 years:

1. To lay the technological groundwork for the future transmission system
2. To integrate RES into the market while ensuring sustainability and security of supply
3. To foster joint R&D and knowledge-sharing between TSOs so that funding programs can be formulated.



THOMAS EDISON
(February 11, 1847 – October 18, 1931) was an American inventor and businessman. He developed many devices that greatly influenced life around the world, including the phonograph, the motion picture camera, and a long-lasting, practical electric light bulb. Edison is the fourth most prolific inventor in history, holding 1,093 US patents in his name, as well as many patents in the United Kingdom, France, and Germany.

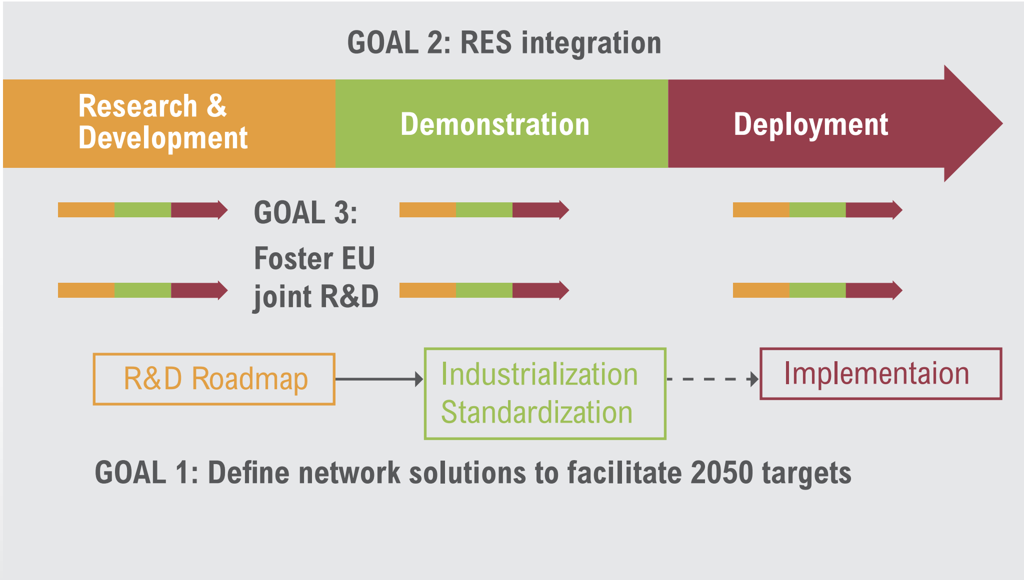


Figure 2: Strategic goals of the R&D Roadmap

SIX R&D ROADMAP TARGETS FOR 2050

The ENTSO-E members have utilized both bottom-up and top-down approaches to define six Roadmap targets for 2050:

1 To facilitate development of pan-European grid architecture that fulfils the low-carbon requirements of Energy Roadmap 2050 and enables effective power delivery throughout Europe

2 To demonstrate, understand and appraise the impact and potential benefits of state-of-the-art power technologies and offshore solutions

3 To design and validate novel ICT-based methodologies for network operation that meet today's and tomorrow's reliability targets

4 To develop the market designs for the IEM that are most beneficial for system operators, market participants and consumers

5 To determine and develop an optimal asset management strategy for equipment on a cost-effectiveness basis

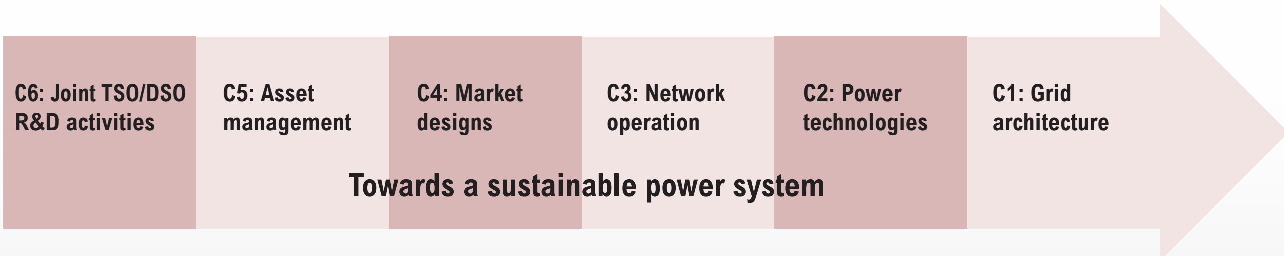
6 To strengthen collaborations between TSOs and DSOs in their efforts to integrate distributed energy resources

INNOVATION CLUSTERS

Based on the six R&D Roadmap targets for 2050, ENTSO-E has formulated the following six Innovation Clusters that focus on specific activities while still retaining links to the other clusters. Although each cluster is defined according to TSO functions they are all interdependent; hence R&D activities are performed in a coordinated fashion. These Innovation Clusters allow TSOs to collaborate on R&D with industry and research institutes to establish a common knowledge base accessible to all stakeholders. By preventing similar work from being duplicated by various TSOs, the Innovation Clusters are extremely cost-effective. Furthermore, they take advantage of the many synergies within Europe.

DETAILED DESCRIPTIONS OF THE CLUSTERS AND THEIR FUNCTIONAL OBJECTIVES ARE GIVEN IN APPENDIX A.

Cluster	Name	Outcomes
1	**Grid architecture**	This cluster provides a set of scenarios and methods for developing network infrastructure that hosts massive amounts of renewable energy sources and growth in demand with acceptable network investments and operating costs beyond 2020. It is of utmost importance to develop coordinated pan-European planning to cope with the multiple dimensions of these tasks. Furthermore, technology and construction criteria must be defined for new grid sections while risks of making wrong decisions and investments must be reduced.
2	**Power technologies**	This cluster addresses the affordability and technical performance of components of emerging technologies that can significantly improve the operations of the interconnected transmission systems. This reduces the extra costs that arise from the management of variable power generation and volatility of demand inherent in renewable sources and demand management.
3	**Network operation**	This cluster studies ways of operating transmission systems that maintain high security of supply at reasonable costs. All TSOs have embraced and implemented a risk-based approach for making real-time and short-term decisions that affect both the security of supply and the functioning of the market.
4	**Market designs**	This cluster studies the ways and means to facilitate interactions between the European electricity markets and the pan-European grid. The aim is to achieve a more efficient and integrated market by optimizing the energy mix at the pan-European level while ensuring security of supply. Possible reviews of market designs must be analyzed in order to ensure that they facilitate the integration of the increasing share of variable renewable energy generation with demand-side management and storage.
5	**Asset management**	This cluster determines the most beneficial asset management strategy on a cost-effectiveness basis ("value for money"). New methods of performing cost/benefit analyses at the power system level must be developed that utilize advanced measurements of power system health. With ICT, better knowledge of the constraints faced by network components help optimize maintenance and replacement strategies in a grid where new and old assets coexist.
6	**Joint TSO/DSO R&D activities**	This cluster evaluates the smart grid initiatives by DSOs and their possible utilization for supporting the transmission grid with regulation and ancillary services provided at the interface with the distribution system.



ELEVEN R&D ROADMAP MILESTONES

ENTSO-E has identified eleven crucial milestones on the path towards Europe's green energy destinations. The sequence of these milestones and their relationships to the various clusters is shown in Figure 4.

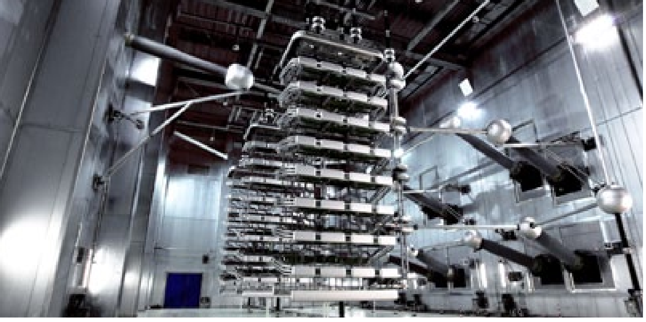
1 Integration of advanced power technologies: Through development and demonstration, novel power technologies are introduced that increase the observability, controllability and flexibility of the power grid.

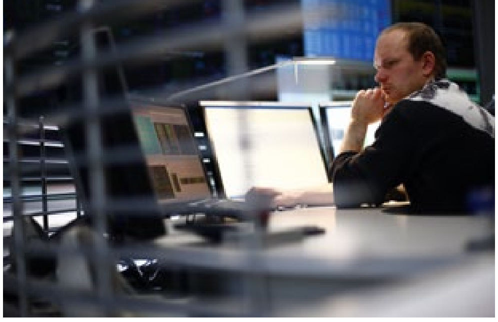
2 Optimal asset management: New approaches are developed and demonstrated for upgrading and enhancing technologies alongside conventional ones.

3 New market incentives and mechanisms: Regulatory mechanisms are implemented for an efficient pan-European electricity market with highly variable generation and consumption. Market incentives are introduced that help innovative technologies become competitive in the long run.

4 Active distribution grid: In coordination with TSOs, DSOs help to integrate distributed energy resources into the energy and balancing markets. New business models and market participants (e.g., aggregators) are set in place to increase predictability, observability and controllability of DER.

5 New system services and market designs: Grid services will be adapted to handle large amounts of variable generation from DER. New rules are developed and demonstrated for the energy, capacity and balancing markets. These services are provided by different actors connected at various levels of the power grid.





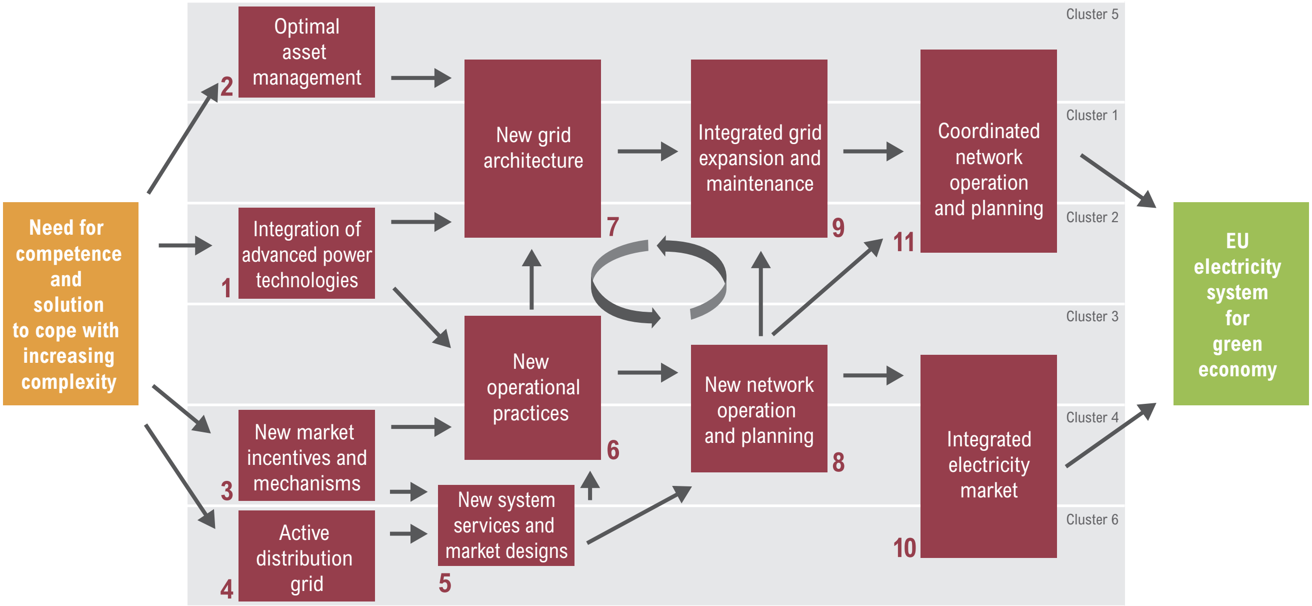


Figure 4: Eleven milestones of R&D Roadmap

6 New operating practices: New operating practices are introduced to cope with variable generation and consumption. This leverages the costs of maintaining security of supply against the gains for society.

7 New grid architecture: New methods and tools are developed to evaluate different grid expansion options that can cope with high variability in generation and demand.

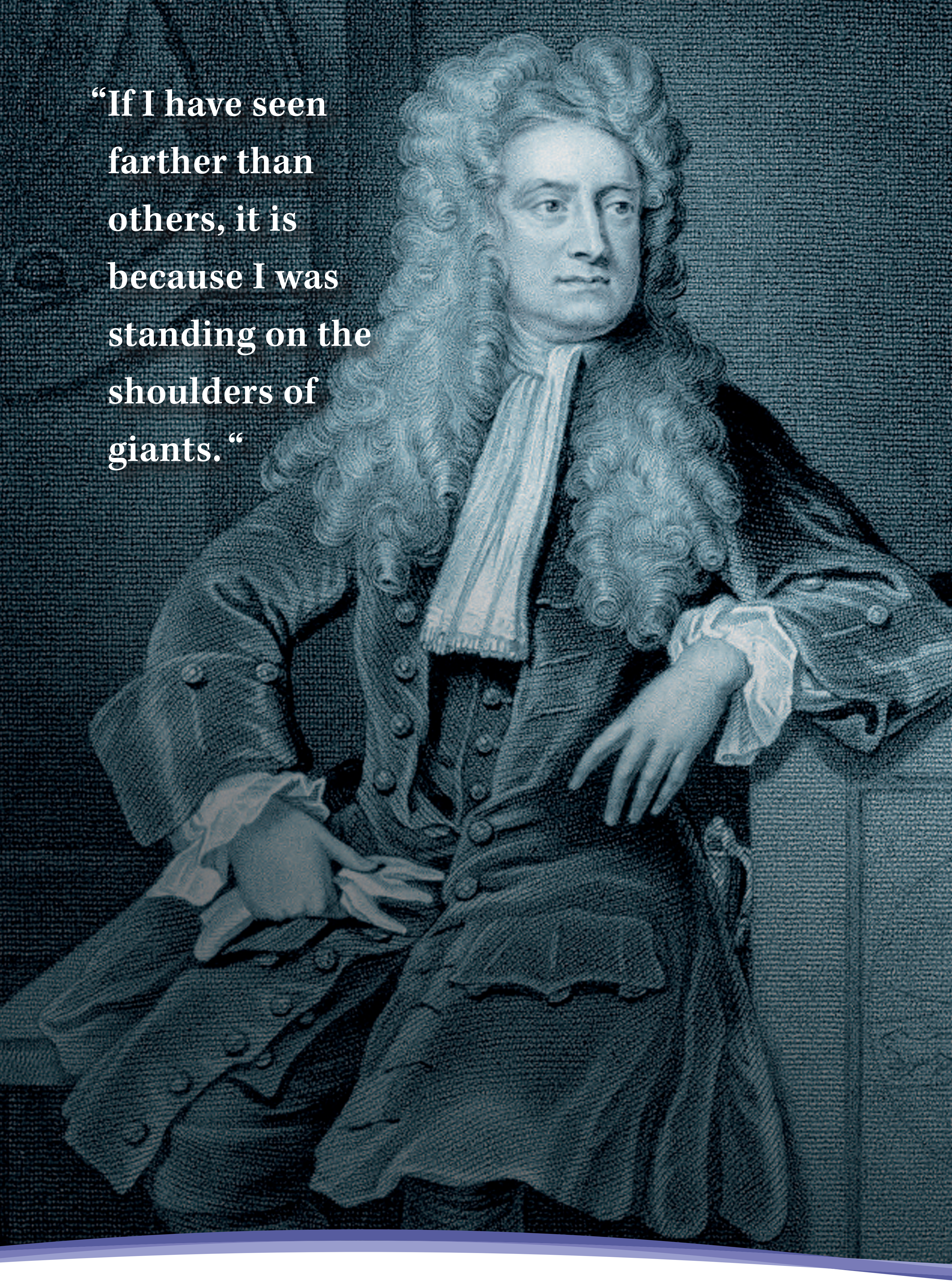
8 New network operation and planning: New methods and tools are implemented that help system planners and operators maintain security of supply over different time frames (long-term to real-time). New training tools are introduced that enable grid operators to coordinate response to market events.

9 Integrated grid expansion and maintenance: An integrated approach is established that allows the grid to be seamlessly expanded and maintained using old and new technologies throughout Europe. Both technical and economical efficiency constraints are taken into account.

10 Integrated electricity market: An integrated electricity market is established for Europe that allows power and balancing services to be traded efficiently across borders.

11 Coordinated network operation and planning: Planning, operation and maintenance of the pan-European grid is performed according to joint European interests (electricity highways, off-shore grid).

"If I have seen farther than others, it is because I was standing on the shoulders of giants."



R&D IMPACTS AND BENEFITS FOR EUROPE

This R&D Roadmap will have impacts and benefits for TSOs and stakeholders as well as for society at large. 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 liberating the electricity market. Furthermore, synergistic effects can be exploited in Europe to reduce costs and maximize 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.

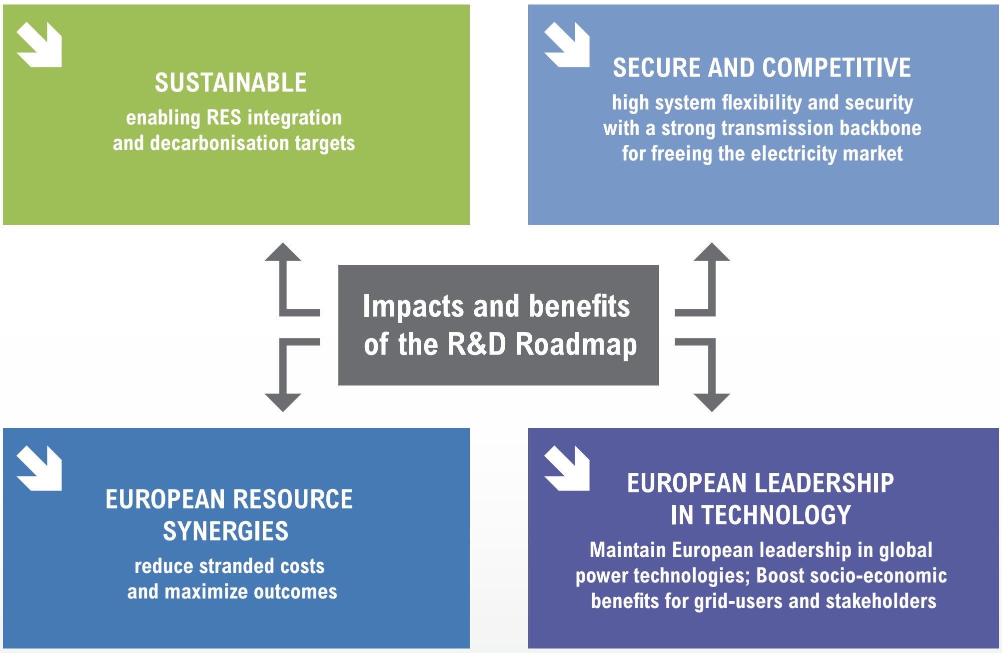


Figure 5: Overview of R&D benefits and impacts

SIR ISAAC NEWTON
(25 December 1642 – 20 March 1727) was an English physicist, mathematician, astronomer, natural philosopher, alchemist and theologian, who has been "considered by many to be the greatest and most influential scientist who ever lived." Newton built the first practical reflecting telescope and developed a theory of colour based on the observation that a prism decomposes white light into the many colours that form the visible spectrum. He also formulated an empirical law of cooling and studied the speed of sound.

SUSTAINABLE ENERGY

To achieve European climate and decarbonization targets, substantial volumes of energy must be generated from sustainable sources such as wind and solar energy. One of the challenges here is low acceptance of new transmission assets. For instance, significant onshore and offshore infrastructure must be constructed to connect RES. These impacts must be leveraged against the benefits of achieving sustainable energy and the decrease in Europe's carbon footprint.

Coordinated R&D by European TSOs will facilitate the deployment of RES while keeping capital and operating expenditures under control. Once RES becomes more effectively integrated into the power grid, it will be possible to assess their actual costs and move towards market-based deployment. European R&D also promotes scaling-up and replication of best practices (planning, market, operation) and a more efficient energy market, thus maximizing social welfare in Europe.

What are the benefits for European society?
End users will receive sustainable energy gained using the innovative power technologies and grid infrastructures discussed in this R&D Roadmap.

SECURITY OF SUPPLY AND MARKET COMPETITION

Green energy must remain affordable with high security of supply so that the European economy can continue to grow. However, electricity markets strive towards optimization and tend to push a system ever closer to its limits. Since most RES are intrinsically volatile, their integration into an ageing grid infrastructure is challenging. These challenges must be counteracted through R&D efforts to devise a new grid infrastructure that maintains security of supply and opens the electricity market to competition.

Without R&D, 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&D leads to smart and innovative solutions that benefit Europe as a whole. As foreseen by this R&D 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.

TECHNOLOGY LEADERSHIP AND WORKFORCE

R&D allows European TSOs to progressively identify their needs for new functionality and technology in a more coordinated fashion. It also encourages manufacturers to come up with solutions that are suitable for the pan-European grid. Moreover, collaborations with producers of power generation equipment, smart building technology and electric vehicles, promote cutting-edge solutions for the global marketplace.

Since knowledge is shared openly between TSOs, research institutes and manufacturers, innovations are accelerated (Appendix B). The high quality of the resulting solutions can be maintained by strictly enforcing timely delivery and reproducibility. Manufacturers with proprietary solutions for load and generation equipment will appreciate the feedback from TSOs so their solutions can be further optimized. A competitive marketplace for solutions also keeps costs for hardware and software solutions in check.

This R&D Roadmap promotes interoperability between manufacturers' solutions. Furthermore, ongoing standardization activities benefit from the R&D clusters and large-scale demonstrations.

What are the benefits for European society?
European universities and other academic institutions will have opportunities to develop new programs for students. The changing expertise and skillsets required to run tomorrow's grids will attract, develop and retain a talented workforce at European TSOs. By establishing world leadership in power technology, the European power manufacturing industry will be able to attract a global client base.

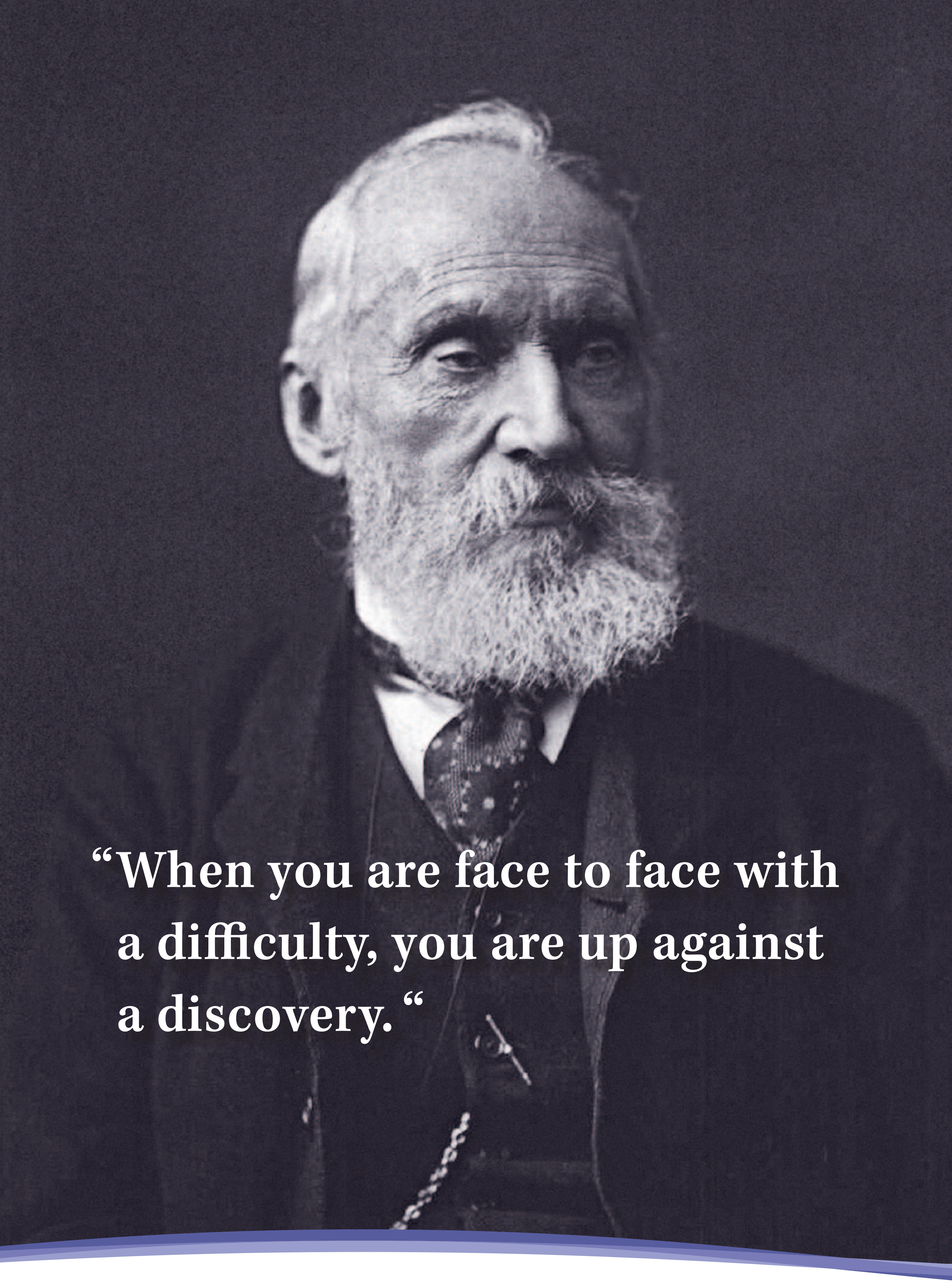
EXPLOITING EUROPEAN SYNERGIES

Even though each TSO operates its own system, it is nonetheless strongly interconnected to neighboring systems on the pan-European electricity grid. Hence, a problem or disturbance in one operating area can have significant consequences for other parts of Europe. This is one very important reason for coordinating cross-border activities on a pan-European level.

R&D 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&D and therefore optimize 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 harmonization and standardization efforts which benefit TSOs and manufacturers alike. By reinforcing collaborations with DSOs and generation companies, grid operations and planning can be optimized by developing systematic R&D 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&D costs, improved services for electricity supply in all TSO control areas and even-out disparity. The joint pursuit of common goals serves to strengthen ties between European member states.



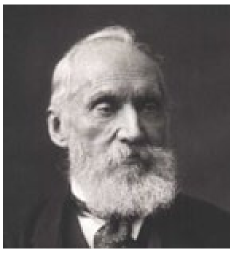
"When you are face to face with a difficulty, you are up against a discovery."

INVESTMENTS AND RESOURCES

The European energy reforms of the past decade have encouraged TSOs to adopt a business model oriented towards reducing capital and operating expenditures. As a result, there were few incentives for network investment and innovation. TSOs are, nonetheless, fully aware of the need for progress in order to reach the "20-20-20" energy objectives and beyond. At many TSOs however, R&D is insufficiently funded or simply not performed at all.

As regulated companies, TSOs have limited access to the financial benefits of technological innovation. The lack of explicit regulations means that R&D expenses are often treated as any other operating expense. In fact, the drive towards increasing cost-effectiveness tends to reduce R&D allotments on a yearly basis.

The result is that many European TSOs do not have sufficient funding and resources for R&D. The R&D required to construct the pan-European grid of tomorrow is chronically underfunded. Fair compensation is needed for services provided to the system, including innovation. Commensurate financial compensation for R&D must be implemented through appropriate regulatory frameworks (energy tariffs, national and European research funds).



WILLIAM THOMSON, 1ST BARON KELVIN
(26 June 1824 – 17 December 1907) was an Irish-born British mathematical physicist and engineer. At the University of Glasgow he did important work in the mathematical analysis of electricity and formulation of the first and second laws of thermodynamics, and did much to unify the emerging discipline of physics in its modern form.

Estimated R&D investments per cluster activity

The R&D estimate per cluster is a sum of estimated expenses to achieve and fulfil the defined tasks of its associated functional objectives (defined in Appendix A). The estimated expenses are based on the cluster analysis and the appraisal of completion. According to available information, about € 286 million are already committed and about € 719 million are expected in new resources to meet the Roadmap (this includes the additional R&D resources necessary for the new tasks defined in this Roadmap). Annual monitoring of R&D activities (https://www.entsoe.eu/rd/monitoring-of-the-rd-achievement/) will provide further information on committed resources.

Cluster	Name	R&D Investment in € million
1	Grid architecture	70
2	Power technologies	350
3	Network operation	125
4	Market designs	75
5	Asset management	135
6	Joint TSO/DSO R&D activities	250
	Total	**1005**

INVESTMENTS

For R&D to be effective, resources must be invested in capital goods and the workforce. It is impossible to meet the ambitious energy and climate targets without massive integration of renewable resources and smart grid implementation. Furthermore, aging and inflexible transmission systems must be modernized and new methodologies must be established.

TSOs are aware of the central role that transmission grids play in Europe's evolution towards low-carbon energy. They are fully committed to developing the smart grid of tomorrow that meets the needs of all grid users. Once R&D receives sufficient funding, solutions can be found for a future infrastructure that is secure, smart and cost-efficient.

The Roadmap contains information on the various R&D tasks and also adds a new R&D cluster for asset management. Hence, the budget calculated by this R&D Roadmap exceeds the previous R&D Plan. The table below summarizes the predicted costs per cluster activity, with a total budget of € 1005 million (see table above).

The investments required for R&D are modest when compared with the potential benefits and when viewed relative to investments required in other activities. The impact and benefits of effective R&D will be enormous over the long term. Compared to infrastructure investments of € 104 billion[13] as estimated in the Ten-Year Network Development Plan, investments in R&D are quite small – in fact, below 1%. This is much smaller than the € 1 trillion to be invested in the energy system from 2010 to 2020 as estimated by the European Commission[14]. R&D is a way to curb the risk of wrong infrastructure investment decisions.

FINANCING STRATEGIES

To foster investments in innovation, this R&D Roadmap proposes unambiguous strategies for financing R&D for the immediate future and over the long term. Once harmonized across Europe, R&D funding will also foster collaboration between TSOs.

COVERAGE THROUGH ELECTRICITY TARIFFS

As companies, TSOs are unique because they are partners rather than competitors. Since they do not compete for the same customer base, they can be actively encouraged to seek out synergies while tackling similar issues. In this regard, the Agency for the Cooperation of European Regulators (ACER) could play a decisive role in promoting appropriate pan-European remuneration mechanisms. Good examples of regulatory frameworks that provide R&D incentives can be found in the UK, Italy, Finland and Denmark.

Whereas tariff schemes in most European countries currently include a small component dedicated to recovering R&D costs, this is, apart from a few exceptions, far from sufficient to deal with the challenges ahead. There are two main reasons for incentivizing TSOs to do more research. Firstly, R&D is an inherently risky investment. Whereas other industries expect to recoup their R&D investment through selling new products – and possibly beating out competition – TSOs cannot easily do that. Secondly, developing experts takes time because both theoretical as well as practical skills and competences are needed.

The Third Internal Energy Market Package stipulates that tariffs should include a component that provides TSOs with sufficient incentives to perform R&D[15].

10) IEA Technology Roadmap: Smart Grids, 2011

11) Grid + project, SRA 2035

12) CEER http://www.energy-regulators.eu/portal/page/portal/EER_HOME

National Grid (UK) has received 0.5 % of regulated transmission turnover since April 2007 (e.g., £ 6.2 million for electricity in 2009/10) from the Innovation Funding Incentive. 80 % is covered by Ofgem and 20 % from National Grid. The Low Carbon Network Fund (LCNF) is a new framework that contributes £ 500 million over a 5-year period.

In Italy, an incentive regulation mechanism has been recently established for demonstrating the capabilities of the smart grid (mainly distribution-oriented).

In Denmark, a regulatory framework is in place stipulating that R&D costs are mandatory by law and are to be funded with a special PSO tariff (Public Service Obligation). The Finnish Energy Market Authority (EMA) plans to add a new innovation incentive in the next regulatory period. This will encourage the TSO to promote innovative technical and functional solutions. A maximum of 1 % of the reasonable return from the TSO will be treated as reasonable R&D expenditures in calculating the actual adjusted profit.

CURRENT AND PLANNED FUNDING SCHEMES

In March 2000, at the Lisbon European Council, Heads of State and Government set the Union the goal of becoming „the most competitive and dynamic knowledge based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion“. [16]

The EU supports investments in TSO R&D that boost innovation, economic growth and job creation. This fact is reflected by EU R&D budget increases following each of the framework programs (FP1 – FP7) and significant increases are planned for Horizon 2020. The Energy Roadmap 2050 also emphasizes that higher public and private investments in R&D and technological innovation are crucial to accelerate the implementation and commercialization of low-carbon solutions. Furthermore, Europe is contemplating spending 3 % of its GDP on R&D.

R&D expenses incurred prior to deployment are partly covered by the EEGI, but the cost of full-scale deployment on European networks is not. Since new tariff schemes are not expected for the majority of Member States in the medium term and possibly not until after 2014, a significant share of public funding will still be needed to cover investments on priority R&D projects. For this reason, the proposed funding scheme is divided into two phases:

16) http://ec.europa.eu/research/era/pdf/com3percent_en.pdf

PHASE 1: UNTIL 2014

Significant new incentives are not expected to be achieved through energy tariffs; substantial funding must be requested from European and national authorities and will likely be based largely on existing funding schemes. Priority projects must be identified and launched in this period. Therefore, projects with high expected benefits for system efficiency and security should be promoted in order to reach the “20-20-20” objectives.

PHASE 2: AFTER 2014

New mechanisms will be introduced such as tariff schemes that complement European and national funding. Public funds will be increasingly redirected to accelerate the development of innovative technology. The use of key performance indicators (KPIs) and a governance framework (Appendix B) will help reach the Roadmap destinations. KPIs are necessary to monitor the status of activities defined in the Roadmap while the governance framework defines and monitors effective processes for TSOs and other stakeholders in coordinating the R&D and its achievements.

COLLABORATIVE R&D

No single TSO alone will be able to conquer the many challenges facing the electricity industry. In order 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&D goals and maximize results. Knowledge can be quickly disseminated and shared among stakeholders and interested parties.

Full-scale demonstrations of R&D projects must be coordinated across Europe. This drastically reduces demonstration costs and stimulates further R&D. Consequently, implementation of this R&D Roadmap requires enhanced collaboration between European TSOs that goes beyond what is already performed within EU-supported research projects. **When it comes to planning and budgeting for R&D, TSOs share many interests with European policymakers.** It is mutually beneficial to maintain a diverse energy mix and increase the cost-effectiveness and strategic value of R&D. Both are to serve all Europeans who, in turn, expect their power to be safe, secure, affordable and green. Furthermore, European policymakers and TSOs alike look to exploit their innovations on world markets. These shared interests and objectives should encourage joint planning, prioritizing, and resource management.

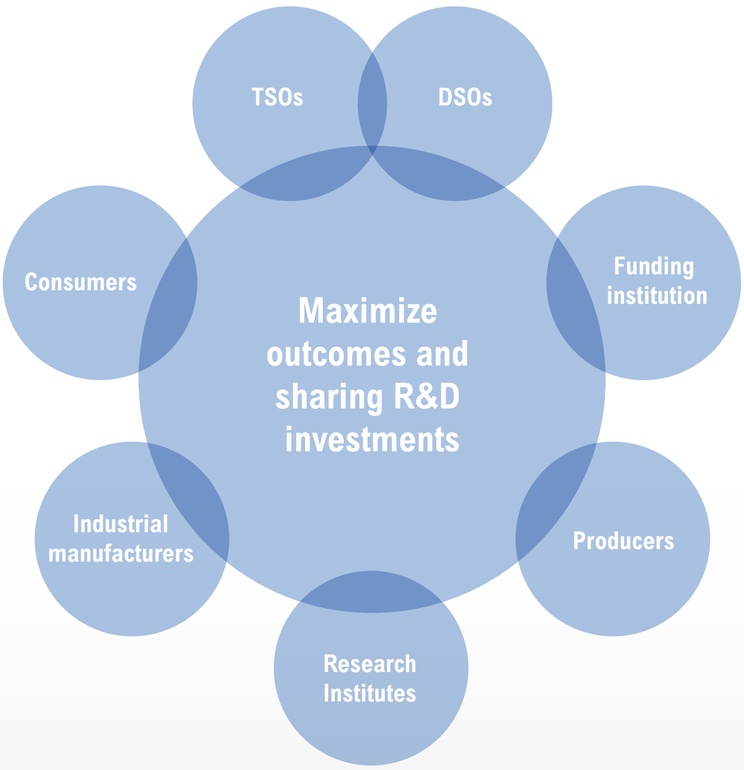
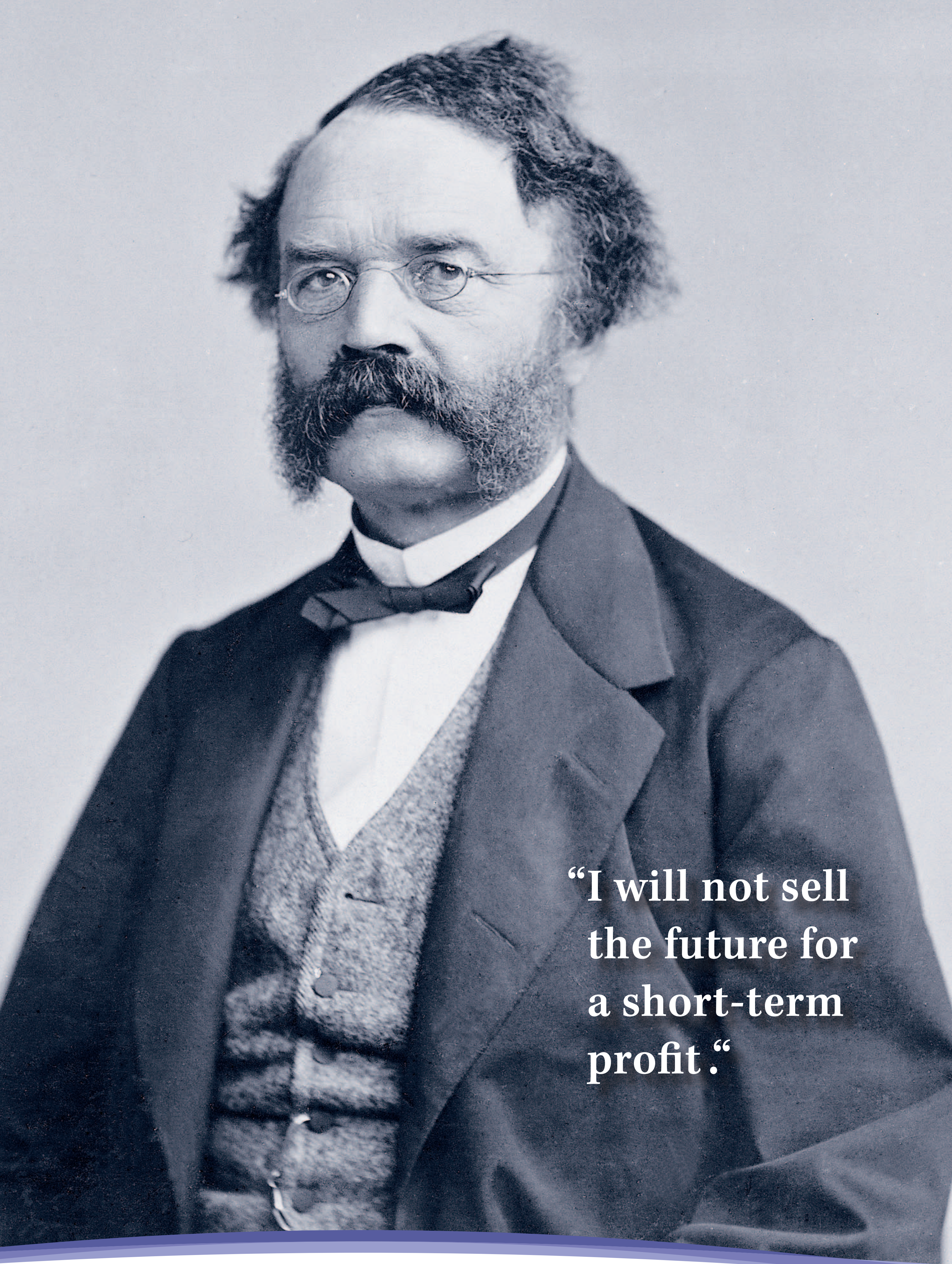


Figure 6: Collaborative R&D to maximize impacts (benefits), share investments and avoid duplication


“I will not sell the future for a short-term profit.“

CONCLUSIONS

The overarching objective of this Roadmap is to assert the urgency of enabling European TSOs to perform R&D and arrive at innovative solutions for the many challenges they currently face.

In order to achieve the European climate energy objectives defined through the "20-20-20" targets and the EU Energy Roadmap 2050, and to meet the new requirements of the Internal Electricity Market by 2014, Europe's TSOs must be ahead of the game – and this underscores the necessity of timely R&D. TSOs are aware of the central role they play and the need to accelerate the technological evolution process.

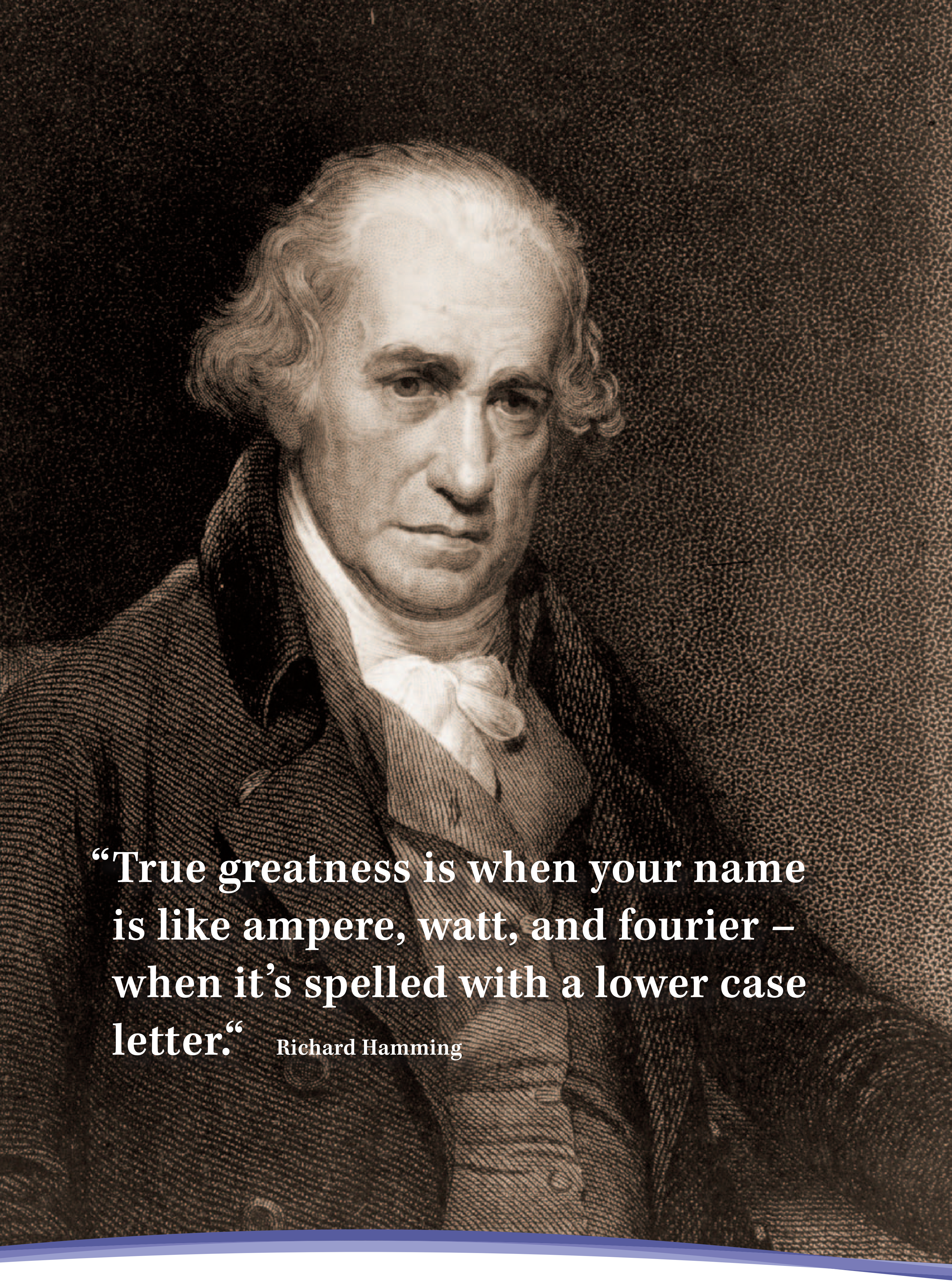
Now that the paradigm shift in electricity is already underway, a business-as-usual approach is simply not an option. European TSOs must now address energy demands from across Europe – they are no longer limited to the needs of their local control areas. Thus, new planning, market and regulatory concepts are required to maintain efficiency, cost-effectiveness and security of supply. R&D is also required to develop new energy transmission and storage technologies and enable bi-directional digital communications throughout the pan-European grid. Implementation of smart grid technology allows better planning, monitoring, controlling and interoperability of transmission systems.

Current estimates indicate that even though estimated R&D investments are quite modest, their impact and benefits will be enormous for market players, TSOs and European society. In return, these investments will yield cost-effective, innovative solutions that provide high-quality services to grid users at a low price. Collaborations between European TSOs prevent redundant R&D being performed while also ensuring optimum allocation of funds. By allowing TSOs to work together and bring their collective expertise to the table, enormous synergies will be unleashed in Europe.

European TSOs are regulated companies and as such they have restricted access to the benefits of technological innovation. In fact, recent European energy reforms have forced TSOs to reduce capital and operating expenditures. Since lack of explicit regulations means that R&D expenses are often treated as operating expenditures, this effectively eliminates incentives for network investment and innovation. Therefore, it is vital to implement commensurate financial compensation for R&D through regulatory frameworks (tariffs, national and European research funds).

When planning and budgeting for R&D, TSOs share many interests with policymakers, e.g., to ensure a diverse energy mix as well as to increase the cost-effectiveness and strategic value of R&D. By implementing this R&D Roadmap together with the Innovation Clusters and Functional Objectives described herein, Europe will achieve an electricity system that is low-carbon, cost-effective and reliable.

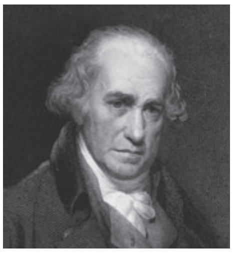
WERNER VON SIEMENS
(13 December 1816 – 6 December 1892) was a German inventor and industrialist. Siemens' name has been adopted as the SI unit of electrical conductance, the siemens.


“True greatness is when your name is like ampere, watt, and fourier – when it’s spelled with a lower case letter.“
Richard Hamming

APPENDICES

RICHARD HAMMING
(February 11, 1915 – January 7, 1998) was an American mathematician whose work had many implications for computer science and telecommunications.

He was a founder and president of the Association for Computing Machinery.



JAMES WATT
(19 January 1736 – 25 August 1819) was a Scottish inventor and mechanical engineer whose improvements to the Newcomen steam engine were fundamental to the changes brought by the Industrial Revolution in both his native Great Britain and the rest of the world.

He developed the concept of horsepower and the SI unit of power, the watt, was named after him.

APPENDIX A DESCRIPTION OF CLUSTERS AND FUNCTIONAL OBJECTIVES[17)]

CLUSTER 1: GRID ARCHITECTURE

CONTEXT

Until recently, the European transmission system has evolved towards a vertical structure with generation units feeding into the transmission grid, which in turn interfaces with the distribution system that supplies consumers. Cross-border interconnections were established to support the security of supply and long-term electricity trade between neighboring countries and control areas.

European policy has focused on decarbonizing the energy system, integrating massive amounts of RES and establishing a internal electricity market. To achieve this vision, enormous investments are required for the pan-European transmission grid. The TYNDP 2012 estimates that € 104 billion is required to build and refurbish the infrastructure required to host 250 GW of new generation capacity. This is equivalent to 25 % of the current generation total and will mainly originate from both onshore and offshore RES in the coming decade.[18)]

It is not only existing networks that require optimization, but novel and innovative planning methods are also required for the European network to implement high capacity corridors and properly integrate advanced technologies such as HVDC, FACTS, storage systems and more.

Other key tasks include developing the network to minimize environmental impact, improving energy efficiency and winning public acceptance of the new infrastructure. One further issue is the lack of an investment framework due to varying regulatory constraints in the different member states, an issue that must be resolved so that work on new transmission lines and infrastructure can be accelerated. This is closely related to market development and is discussed in more detail in Cluster 4.

Cluster 1 mainly focuses on how to overcome these challenges. Innovation and R&D are needed to develop efficient methods to enable optimal investments and guarantee that projects are implemented in a timely and economically sound manner.

17) The "Functional Projects" in previous R&D Plans have been renamed herein as "Functional Objectives". This became necessary in order to clearly differentiate between the high-level R&D strategy – research clusters and associated strategic research – and the specific R&D projects described in the R&D Implementation Plan.

18) TYNDP 2012, www.entsoe.eu 19) www.entsoe.eu

20) http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

OBJECTIVES

BARRIERS AND GAPS

In confronting the challenge to establish the new pan-European grid infrastructure, the following barriers and gaps have been identified in the present pan-European network (see table on page 37).

OBJECTIVES

The objective of this cluster is to provide a set of validated methods for developing network infrastructures. The new pan-European grid must host massively expanded RES while coping with demand growth and maintenance costs beyond 2020. This must be accomplished with an acceptable level of network investment. A pan-European planning framework must be delivered that establishes new criteria for building electricity infrastructure while reducing the risks inherent in decision-making and investments.

Specific objectives:

- To develop planning methodology for the pan-European electricity network scenarios from 2020 – 2050; this encompasses the new energy mix, new consumers (e. g., electric vehicles), consumption loads and energy storage. This R&D focuses on novel and unconventional technologies under consideration of network cost-benefit analysis. The base cases for these scenarios are defined in System Outlook and Adequacy Forecast, TYNDPs[19)], e-Highway2050, and Energy Roadmap 2050[20)]. Development of new technologies models will be included in the planning simulation software.
- To develop simulation software that allows TSOs to analyze pan-European grid expansion scenarios reflecting the goal of Europe's electricity supply being decarbonized by 2050; planning of pan-European networks in a joint and consistent way.
- To assess novel and known technologies for the cross-border connections needed to cope with EU requirements in a cost-effective manner.
- To evaluate the impact of offshore grids, HVDC networks in operation along with the existing

infrastructure as well as extra- and ultrahigh voltage AC solutions.
- To develop a method of assessing the social and environmental impact of grid development and recommend a suitable approach for pan-European network development.

EXPECTED OUTCOMES AND IMPACTS

Expected outcomes

- Validation of planning approaches for the pan-European grid; these integrate emerging technologies and support offshore grids.
- Identification of optimal transmission grid architectures able to cope with low-carbon electricity generation mixes and their pan-European power flows.
- Detailed study of benefits and impacts of deploying the above-mentioned pan-European architectures.
- More integrated and seamless planning approaches for European transmission grids.

Expected impacts

Achieving the above-mentioned objectives will bring about more cost-effective, environmentally friendly and robust planning methodologies for the pan-European transmission system, which are able to cope with massive integration of on- and offshore wind power, solar energy and other RES and DER.

The activities of Cluster 1 lay the foundations of the future pan-European transmission grid, which is a prerequisite for implementing the most appropriate and cost-effective technologies. It also establishes the best conditions for operating and controlling electricity, and allows for the creation of a single European electricity market.

STRUCTURE OF CLUSTER 1

The activities in Cluster 1 are divided into 3 different Functional Objectives.

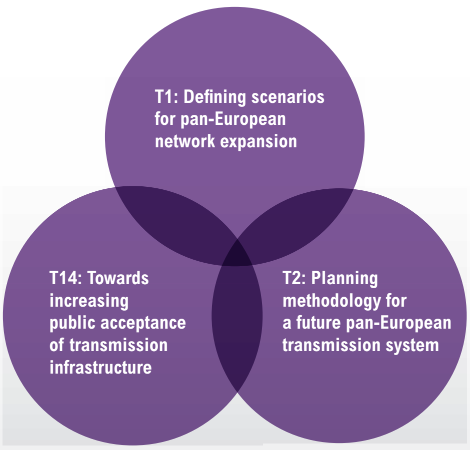


Figure 7: Structure of cluster 1: Grid Architecture.

Barriers impeding innovation	Knowledge gaps
So far, national regulatory schemes, energy mixes and selection criteria serve the construction of long term scenarios at the member state level. These scenarios are then patched together in a bottom-up approach in an attempt to maintain coherency at the pan-European level. A top-down approach must be designed and adopted to support long-term planning goals.	Currently there is no common framework for a pan-European planning methodology. The European energy policy presents a crucial challenge to the extra-high voltage (EHV) grid. Common criteria must be agreed upon for developing the methodology and building up the human resources needed for software development.
Enabling infrastructures to balance and optimize the existing power systems while overcoming potential geographical barriers that impede network development.	The need to assess new technologies that can determine optimal implementation plans while also optimizing the existing infrastructure. This is an evolutionary process.
To overcome the current public opposition to new construction of assets while minimizing their environmental impacts.	Social studies must be performed, assessed and scaled up so that new approaches can be developed that accelerate the construction of new infrastructure.
Currently, grids are built with known and proven technology. To meet the future challenges there is a need to develop the next generation grid architectures.	Assess the use of new materials and address logistic issues for faster building/refurbishment of towers, conductors, anti-icing surfaces, new materials etc.
The investments required to deploy the novel infrastructure technologies to meet EU targets are currently unknown.	Address technological and investment focus at European level of infant technologies such as off-shore HVDC VSC, storage technologies and demand response. Address its impact on the pan-European network and generate knowledge for its implementation in future pan-European scenarios.
Integration of massive RES increases transmission distances and power generation will become more volatile. This will also increase stress on existing networks.	Innovative grid extensions such as electricity highways are essential to transport power to consumption centers.

T1	Definition of scenarios for pan-European network expansion
CONTENT	**Challenges:** The long-term European energy vision (2050) requires a paradigm shift that must be assessed at the pan-European level. Uncertainties derived from the large amount of RES integration, inclusion of DER, new consumption demands, energy storage, and offshore generation creates a set of possible scenarios which, in turn, lays the foundations for novel infrastructure planning approaches at the pan-European level. **Objectives:** The purpose of developing the simulation methods is to establish pan-European grid expansion scenarios in line with the post-2020 targets. This must reflect the need for Europe's electricity supply to be largely carbon free by 2050. Such scenarios are the basis for the system architecture design software developed in T2 and will be aligned with the scenarios in the System Outlook and Adequacy Forecast, TYNDPs[21], e-Highway2050, and Energy Roadmap 2050[22]. **Scopes:** The methods are used for long-term planning (from 2020 to 2050) taking into account offshore grid development, DSM mechanisms, network constraint analysis and the future generation mix. Market rules developed in cluster 4 will also be considered. **Specific tasks:** • To define pan-European network expansion scenarios; identify maximum volume of RES and DER for pan-European network; analyze a combination of electricity and gas • To identify investments required to achieve the 2050 vision with different decarbonization scenarios of generation mix, storage and demand mix • To develop methods for integrating transmission systems with growing amounts of RES-based generation, considering optimal rates of storage needed at the pan-European level • To provide offshore grid design: optimization methods for grid capacity, technology and topology taking into account wind power characteristics, i. e., low capacity factor
Expected outcome	A concise and scientific approach is available to construct meaningful long term energy scenarios in Europe: it provides TSOs and all relevant stakeholders including policy makers with clear and reliable long-term goals to implement network development plans
Expected impact	Enabling of low-carbon economy by preparing investment strategies based on clear and trusted energy scenarios Pan-European energy scenario construction methodologies will be available for all stakeholders
Main contributors	TSO, Research institutes, Industries, Energy companies
Additional information	Typical optimization tools; other projects of interest: e-Highway2050
Budget estimation	€ 20 million
Timeline	2012 – 2016

21) www.entsoe.eu

22) http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

T2	Planning methodology for future pan-European transmission system
CONTENT	**Challenges:** New network infrastructures are needed to connect energy generation sites involving variable RES and DER with demand areas. The pan-European network has to be developed to accommodate the scenarios defined in T1. Top-down planning approaches at pan-European level must be developed involving a broad spectrum of novel technologies (generation, transmission, storage, demand management). **Objectives:** The objective is to develop simulation software to assess options of pan-European transmission system infrastructure. It facilitates system simulations at the pan-European level capable of comparing several design options based on various technical and economic criteria, taking into account emerging technologies such as HVDC VSC, multi-terminal and vendor-independent HVDC network, PST, FACTS, storage, high-capacity conductors, etc. **Scope:** This method is used for long- and medium-term planning to select the best technology for system development with clearly defined energy scenarios including the market rules developed in cluster 4. **Specific tasks:** • To investigate state-of-the-art planning software, technology portfolios and different regulatory frameworks • To define input data requirements and data interfaces (to / from cost-benefit simulators, power flow tools etc.), • To develop new algorithms and database functions for network simulation; enabling the integration of new emerging technologies such as HVDC, GIL, FACTS and storage • To model embedded HVDC/HVAC grids for planning simulation • To develop software tools for cost-benefit assessments of expansion options and validating impact on grid planning for coordinated design of architecture, power flow control devices, and other technologies • To provide coordinated grid design involving new network architectures, power flow control devices, storage and other technologies to achieve sustainable and efficient networks • To develop planning software to optimize location, coordination, control and integration of technologies within existing and future system architecture and operation. • To develop long-term planning methods to combine electricity market analyses, production capacities (all types including RES) and infrastructure in view of strengthening expected weak points on the grid • Proposal for network investment mechanisms at EU level
Expected outcome	TSOs will be able to jointly optimize network development and identify the most cost-effective technologies based on recognized optimization goals and constraints. Optimization of grid locations taking into account regulatory constraints to support cross-border system development. Optimization tools for planning and network development will be delivered at the pan-European level to prepare key investments based on economic models typical of future competitive electricity markets. Network reliability constraints will be considered since each investment in a network influences the reliability of supplied power at the local, regional, national and pan-European levels.
Expected impact	This long-term planning approach enables manufacturers and energy retailers to create provisional development plans. Investment signals will be sent to energy generation and load centers; this takes into account pan-European network investments and power technology constraints.
Main contributors	TSO, Research institutes,Technology providers
Additional information	This functional objective will be established using results obtained from other European projects, particularly e-Highway2050. This FO is highly interdependent with the other clusters (clusters 2–5)
Budget estimation	€ 20 million
Timeline	2014–2022

T14	Towards increasing public acceptance of transmission infrastructure
CONTENT	**Challenges:** There is a clear need to revisit current public consultation processes to both better appraise and understand the reasons for public reluctance to infrastructure investments and to develop new ways and means to address those concerns while increasing public awareness about future long-term energy challenges. • To meet the public and stakeholders' concerns and address them effectively • To understand how grid architectures and technology choices across Europe can be used to minimize negative environmental impacts **Objectives:** The objective is to improve public acceptance of transmission infrastructure while also reducing its environmental impact so that implementation can be accelerated. **Scope:** • New models of bird savers and mapping bird sensitive areas to maximise gains from fitting bird savers to existing lines. • Alternatives to SF_6 allowing for the compact design of electric power stations with efficient insulation properties • New design measures to minimize high-voltage equipment noise **Specific tasks:** • To investigate public perception of the power infrastructure; to improve the relationship between TSOs and the public with valuable feedback and signals in both directions • To contribute to developing and/or updating European guidelines on good practice in transparency and public engagement and permitting process • To produce guidelines for the construction of overhead power lines with reduced visual and environmental impact compared to existing construction guidelines and to ensure these guidelines are applicable across Europe • To analyze new technologies with reduced visibility of conductors, using coatings and nano-technologies • To propose new tower designs for overhead power lines with less visual impact, audible noise and EMF; in some cases also with reduced sag of overhead lines • To develop methodologies and software to evaluate bird collisions, human and animal exposure to EMF, audible noises, etc.; reduction of impact. • To provide methods for physical protection of the grid infrastructures against potential dangers: natural catastrophes, terrorism, cyber attacks etc.
Expected outcome	• Better mutual understanding between TSOs and the public. • Reduced negative environmental impacts of infrastructure (EMF, visual impact, during construction) • Acceleration of the permission and construction processes required to build new infrastructure and/or refurbish existing infrastructure • Faster repair of damaged infrastructure and sustainable demand / supply balance • Introduction of new materials (e.g., nanomaterials and composites) to develop new towers and "smart" conductors
Expected impact	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 economy
Main contributors	TSO, Technology providers, Research institutes, Industries, NGOs
Budget estimation	€ 30 million
Timeline	2012–2018

CLUSTER 2: POWER TECHNOLOGIES

CONTEXT

Current advances in technology offer transmission system operators many opportunities to implement new solutions to cope with future network development and operating challenges. On the one hand, innovative technologies must be wisely embedded into the existing infrastructure. On the other hand, the challenge is to integrate new and existing technology in a compatible and safe manner. Other aspects to be considered include the need to deploy ICT, storage technologies and develop expertise in hybrid AC/DC power systems and multi-terminal, vendor-independent HVDC VSC including HVDC breakers.

Advanced technologies can be grouped as follows:

- Power transfer capacity: HVDC and AC cable, AC/DC converter, multi-terminal and vendor-independent HVDC VSC, super-conducting, GIL and "low sag" conductors
- Power control devices: FACTS, phase-shifting transformers, HVDC back-to-back
- Monitoring devices and systems: PMU, WAMS, Smart Meter, RTTR, and combined DFR and PMU devices
- Control devices and systems: PDC, WACS, WAPS
- Storage: electrochemical storage, batteries from electric vehicles, etc.

These technologies have their own learning curves and innovation cycles. TSOs must question their investment costs, reliability, expected lifetime and service behavior under difficult operating conditions or when disturbances or major faults occur. Provided that their performance can be predicted using suitable simulation tools and network models, new technologies must be demonstrated in order to validate their performance and to specify real-life implementation procedures. This leads to final product specifications and product implementation plans as well as new network management rules.

This pre-commercial application phase requires extended cooperation between TSOs and manufacturers. Special attention must also be paid to new multi-terminal HVDC grid infrastructures for future onshore and offshore power grids, and extra research is still required for HVDC breakers.

OBJECTIVES

BARRIERS AND GAPS

Barriers impeding innovation	Knowledge gaps
Unproven technologies may be thought of as jeopardizing system operation.	Step-by-step testing of new technologies is needed to understand costs, benefits and drawbacks.
The benefits of new technologies must be validated under real-life conditions.	Large-scale demonstrations of new technologies are needed to measure system benefits.
Huge costs and risks involved with experimental new technologies (e.g., multi-vendor multi-terminal HVDC solutions: who will take such a risk?).	Full costs and benefits must be analyzed to prepare standardization and interoperability, thus allowing plug-and-play solutions for different vendors.
New technologies may impact system controllability, thus leading to more complex operations of the grid and implying more coordination between TSOs.	Validation through demonstrations including new operating tools, adequate operator training modules where tools for operators are developed in C3.
IPR (Intellectual Property Rights) issues arise very frequently when manufacturers are involved in joint projects and pilot projects.	An adequate IPR framework must be agreed upon.
TSOs may be slow to introduce new technologies due to a lack of knowledge about the TSO/DSO interface or the interfaces between TSOs and generation companies.	More effective coordination is required because power electronics is already proven for T&D infrastructures – however, applications are still rare and only performed under special surveillance – with the possible exception of HVDC and SVC.

OBJECTIVES

The main objective is to address the affordability and technical performance of emerging technologies that can significantly improve transmission systems. These technologies can help reduce extra costs associated with variable generation and load demand volatility linked to renewable resources and demand management (DR, DSM, etc.).

Specific objectives:

- To demonstrate and assess the performance and interoperability of new power technologies with the existing power system
- To evaluate and validate the impact of technologies in order to measure their added value for the electrical system as a whole, as well as deriving operating practices that affect all other aspects of the TSO business
- To investigate the impact of technology integration for cross-border connections that are cost-effective and offer increased security of supply in the pan-European power system
- To define final product specifications, requirements and implementation plans
- To embed technologies that increase RES integration and improve power system stability
- To provide field data for scaling-up and replication studies of innovative network configurations at the EU level

EXPECTED OUTCOMES AND IMPACTS

Expected outcomes

- Large scale demonstrations of adequate technology integration processes
- Once technologies are validated on the basis of detailed scaling-up and replication studies, TSOs can specify their future infrastructure needs.
- Manufacturers may validate technologies under real, large scale working conditions.

Expected impacts

The successful demonstration of emerging technologies will stimulate innovation and strengthen the technology leadership of European manufacturers and industries. Once technologies have been tried, tested and proven to be cost-effective and technically sound in Europe, they can be replicated in other parts of the world.

STRUCTURE OF CLUSTER 2

The activities in Cluster 2 are divided into 3 different Functional Objectives.

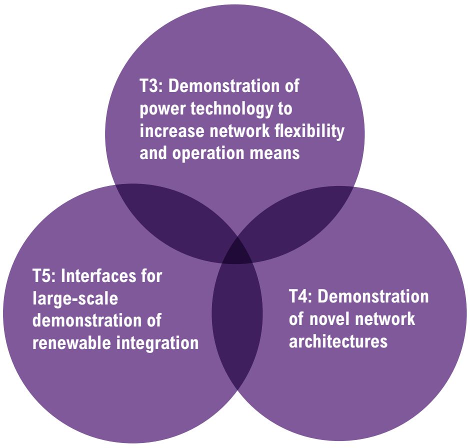


Figure 8: Structure of cluster 2: power technologies for future pan-EU transmission grid

T3	Demonstration of power technology to increase network flexibility and operation means
CONTENT	**Challenges:** The complexity of the pan-European network requires highly flexible development of transmission capacity and system operation to ensure security of supply. Furthermore, 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 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. Another key issue is to determine the best methods to share data gleaned from wide-area measurements between interconnected TSOs and to establish ancillary service responsibilities in faulted modes of operation. **Scope:** Power control devices FACTS, PST, high-temperature cables, new type of conductors (nano-technologies), HVDC VSC, storage and other technologies to be demonstrated and validated. **Specific tasks:** • To demonstrate the degree to which transfer capacity can be increased at the cross-border level and present 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 implement solutions for wide-area monitoring systems and demonstrate how to utilize such information in a coordinated manner during operations • 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 an optimal manner
Expected outcome	New methodologies will be validated for upgrading the existing grid in C1 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, this may increase interest in power flow control devices, thus favoring new parallel options for transmission line development.
Expected impact	A flexible network will be implemented that integrates RES and helps to cope with demand. The overall system reliability and quality of service will be improved.
Main contributors	TSOs, Technology providers, Research institutes
Additional information	Technology involved: • Equipment and methodologies to monitor conductor temperatures, i. e., nano-technologies- High-temperature power cables, lines and equipment • FACTS and PSTs
Budget estimation	€ 100 million
Timeline	2010 – 2018

T4	Demonstration of novel network architectures
CONTENT	**Challenges:** Future network architecture may have the following characteristics: • Current voltage levels maintained at 380 – 400, 220 kV / 150 kV with selective reinforcements at bottlenecks • Introduction of new AC voltage level of 750 kV • Introduction of selected HVDC links • Realization of a DC grid • Utilization of superconducting power cables (conductors) • Greater use of underlying 380 – 400 kV network in separate sub-networks Furthermore, an increasing number of high-voltage applications will utilize superconductor technology (e. g., fault current limiters). **Objectives:** The main objectives are: • To evaluate the impact of new technology and novel network infrastructure in large-scale experiments that address pan-European problems • To provide a reliable and stable backbone to support the internal European electricity markets **Scope:** This project assesses the impact of power electronics on system infrastructure (validation of on- and offshore options), which are to be quantified through demonstrations. **Specific tasks:** • To demonstrate on a large-scale new power technologies (incl. new materials) such as HVDC VSC, superconductivity, energy storage, fault current limiters and other promising technologies for joint management of on- and offshore networks • To validate various technology options to increase transmission capacity through selective reinforcement or implementation of an ultra-high voltage transmission system ("Super Grid") or DC backbone • To propose new schemes to extend synchronous areas in the pan-European grid and connect these with back-to-back HVDC to increase their utilization and reduce the complexity of balancing, planning and operation • To do research on the devices and concepts required to materialize multi-terminal DC grids which are to cope with current system needs and sources such as offshore generation • To coordinate offshore networks interconnected with various control areas; methods for coordinating load-frequency control, DC voltage control; other technologies required for DC (VSC) network • To implement HVDC solutions to enhance reliability – bi-polar or mono-polar DC schemes • To determinate standard DC voltage; since VSC technologies eliminate the need for transformers, investment and maintenance costs will be reduced significantly. Weight and space are cost drivers particularly for offshore installations
Expected outcome	TSOs can select different cost-effective technology options to increase transmission capacity while ensuring high-power system performance and efficiency. Experimental data gathered during experiments will be utilized in planning models, operational strategies and market simulators to validate network expansion and network flexibility costs within different pan-European scenarios. Large-scale demonstrations of power technologies provide feedback to manufacturers so that they can improve quality and performance.
Expected impact	Technical and economic feasibility of architectures accounted for by the electricity value chain players including regulators
Main contributors	TSOs, Technology providers, Research institutes
Budget estimation	€ 120 million
Timeline	2012 – 2018

<table>
<tr><th>T5</th><th>Interfaces for large-scale demonstration of renewable integration</th></tr>
<tr><td>CONTENT</td><td>Challenges:
In the current framework, RES present challenges to security of supply and economic interests. With increasing wind and PV gradients, reserves must be increased to maintain system stability. This will require high system margins on power reserves and standby production, or curtailment of wind or PV production. With higher margins on reserves, wind and PV integration leads to increased costs for balancing services and ultimately higher costs for security of supply as well as for end-users. Another approach is to implement frequency and voltage control with RES in the concept of the virtual power plant (VPP). This necessitates an affordable coordination and communications infrastructure.

Objectives:
The goal is to determine the best method of deploying and demonstrating different concepts using ICT to integrate more RES.

Scope:
The main focus is to demonstrate ICT with innovative concepts that integrate RES.

Specific tasks:
• To validate the contribution of RES to voltage and frequency control, balancing using VPP
• To monitor and control the network to avoid large-scale intra-zone oscillations
• To validate integration scenarios where the network becomes more user-friendly and copes with variable generation from RES.
• To demonstrate with stakeholders various technologies to deploy the energy mix from conventional and renewable resources</td></tr>
<tr><td>Expected outcome</td><td>Effective rules will be validated for managing variable sources in liberalized energy 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 wind, solar and DER.</td></tr>
<tr><td>Expected impact</td><td>More RES will be integrated into the pan-European system without impacting its reliability.
RES will deliver new value streams to the electricity system.</td></tr>
<tr><td>Main contributors</td><td>TSOs, DSOs, Technology providers, Generation companies, ICT providers</td></tr>
<tr><td>Additional information</td><td>Technology involved:
• IT solutions to integration that are secure and scalable
• Power electronics
• HVDC technology</td></tr>
<tr><td>Budget estimation</td><td>€ 130 million</td></tr>
<tr><td>Timeline</td><td>2010 – 2018</td></tr>
</table>

CLUSTER 3: NETWORK OPERATION

CONTEXT

The primary objective of all TSOs is to ensure security of supply and system reliability, but the environment in which they have to do this is increasingly challenging. The evolving energy mix accentuates these challenges as Europe pushes strongly forward towards decarbonizing energy and becoming the global leader for green power.

In the coming decades, incremental changes in the operation and management of the electricity system will not suffice. With a large share of variable RES generation (50–80 %), operational planning and online operation of the power system is changing radically and will become much more demanding. Accelerating this trend is the progressive phasing out of conventional generation units responsible for covering base and peak loads as well as ancillary services. Free electricity trade and power flow across continental Europe will occur at previously unseen levels.

Instead of being determined on an annual basis, power system reserves will soon greatly depend on daily wind and sun forecasts. Some TSOs have already adapted their reserve management approach but one suspects that the current definition of primary, secondary and tertiary sources should be completely revamped.

On the other hand, devices such as PMUs provide TSOs with new information and hence opportunities for online monitoring. In this way, the power system can be operated on real-time measurements. As look-ahead technologies supplant historical data currently in use, power systems can be planned and operated much more efficiently. This requires new algorithms and methodologies to be able to handle and process the huge amount of information, as well as human-machine interfaces (HMI) to support decision-making in control centers.

The electricity grid paradigm has shifted to another level and dimension. From thousands of power plants connected to high-voltage systems a decade ago, the grid is now fed from millions of low- to high-voltage generation units and countless more are being added. The grid must be ready to integrate emerging technologies (see cluster 2) so that the roll-out process is based on a controlled scaling-up process.

The power reserves required to maintain a reliable and secure system is one example of the many concepts and processes that must be revisited – some of them in their entirety. There are many consequences such as the need for improved communications to allow DER to be controlled directly and / or indirectly and to monitor effective delivery of the requested services. This represents a challenge due to the reduction of corresponding reserves at the centralized level. New reserves will be needed, coming either from flexible 'conventional' generation units, or from centralized and decentralized RES, distributed generation, active demand and storage systems. This requires efficient observability as well as controlling and monitoring means.

TSOs must now address the new uncertainties and potential risks through new tasks such as operational planning based on capacity allocation and also real-time operations. Furthermore, TSOs have to review all of their traditional operating procedures and network tools. These challenges require new methods and tools, improved coordination between TSOs, DSOs and other stakeholders, new processes as well as training for operators and planners.

OBJECTIVES

BARRIERS AND GAPS

Barriers impeding innovation	Knowledge gaps
All stakeholders must be convinced of the necessity of the drastic changes required in TSO operations and planning. Even if analysis methods and tools exist, the underlying assumptions they rely upon leave too much uncertainty in the equation.	Methods and tools must be improved and demonstrated in a convincing manner. This covers the ways and means that such tools are shared among TSOs and how results are jointly built and shared.
Tools must be fed reliable data to be of use for planners and operators: capabilities and responsibilities must be addressed when delivering data to other parties.	Beyond methods and tools, the difficulty of gathering and managing the right data should not be underestimated. On the one hand, current data exchange barriers must be overcome where reasonable. On the other hand, some critical data (e. g., for probabilistic forecasts) is not currently available and requires R&D.
Resistance to work on breakthrough approaches for control & management, and resistance against testing them in a real environment.	System operator involvement in the R&D projects must be reinforced. Conceptual projects must at least contain a demonstration package that goes beyond studying what would be the consequences of new methods and tools from a researcher's perspective. Operators must participate, possibly using dispatch simulation systems when the consequences of involving real operations could be too risky
Trustworthy tools are critical for system operators – who are ultimately responsible for security of supply. Whereas some software providers claim to have adequate and reliable tools, intellectual property rights and proprietary modules often impede transparent access to source codes for building such trust.	TSOs must invite those software providers willing to be transparent to participate in projects so that trust established and existing tools can be leveraged.
Massive amounts of data with high sampling rate that must be converted to information appropriate for taking decisions	There is a need for methods and tools to collect and provide a synthesis of data to be used for supporting decisions during operational planning and real-time operations.

OBJECTIVES

The overall objective is to operate the transmission system and maintain high security and reliability at reasonable costs. All TSOs have embraced and implemented a risk-based approach for making real-time and short-term decisions that affect both the security of supply and the functioning of the market.

Specific objectives:

- To develop new simulation techniques, improve observability and controllability and hence increase the reliability of the pan-European network; the European power grid is currently operating under stress and close to its limits – both thermal and dynamic (frequency and voltage) – and must cope with increased RES generation and growth in demand.
- To develop new methodologies that improve – by design – the flexibility of the system; these must increase controllability while coping with possible stability issues. By reviewing the "N-1" or redundancy principles, system use can be optimized while available capacities are best exploited to suit market needs. New reliability criteria must be widely adopted by the TSO community and the resulting safety margins must be balanced against social welfare aspects.
- To develop interfaces and tools that help operators appraise network status and make decisions in real time (look-ahead functionality); this must increase the observability of the system and enable optimized decision-making across Europe.
- To improve and develop training methodologies for operators; this must improve coordination for dealing with issues on a pan-European scale.

EXPECTED OUTCOMES AND IMPACTS

Expected outcomes

- R&D projects deliver new knowledge about the current and future system functionality and limits (operational and complexity).
- R&D projects deliver new methodologies, operating principles and tools to be demonstrated at full scale.
- Large deployment will involve implementation projects by ENTSO-E members;
- Inputs to network code activities within ENTSO-E
- Reduced probability of high impact, low probability contingencies (Black Swan events, see box on page 48)

A Black Swan – as Nassin Nicholas Taleb explains it – is an event with the following three attributes. First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable.

New York Times, 22 April 2007, http://www.nytimes.com/2007/04/22/books/chapters/0422-1st-tale.html?_r=1

Expected impacts

- Increased flexibility will welcome more RES and DSM.
- Minimized welfare losses due to black-out or major disturbances

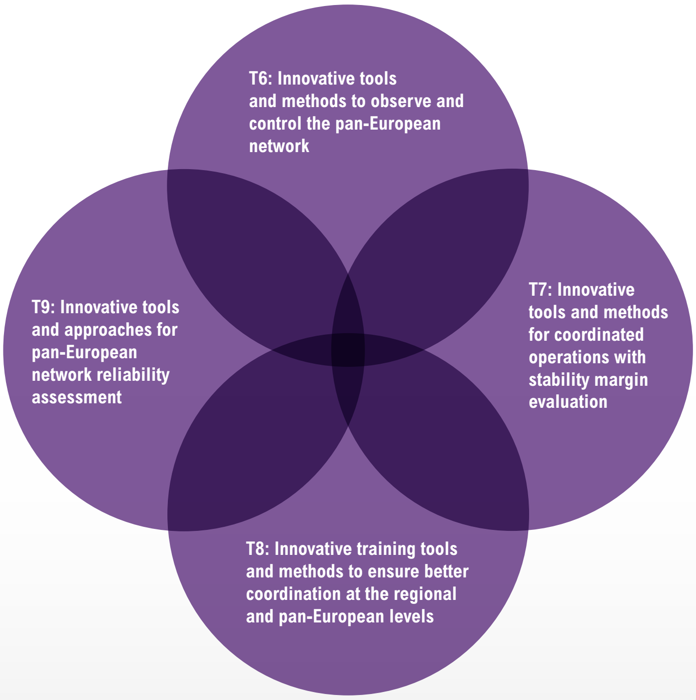


Figure 9: Structure of cluster 3: network operation

STRUCTURE OF CLUSTER 3

A multi-tiered approach is needed to achieve the network operation objectives. There are four functional objectives for this cluster to gain new expertise and harvest the benefits to enable further replication and large-scale deployment across Europe. These involve developing new methods and tools to:

1. Increase network observability at regional and pan-European levels to enable TSOs to perform appropriate control actions (T6)

2. Increase regional and pan-European coordination

a) System operation within the required stability limits (T7)

b) Handling contingencies at local, regional and pan-European levels to prevent as well as manage disturbances

c) By training operators to react to regional and pan-European disturbances (T8) in case b) should fail

3. Assess reliability at regional and pan-European levels (T9)

T6	Innovative tools and methods to observe and control the pan-European network
CONTENT	**Challenges:** Monitoring, control and protection systems are critical to increase transmission system observability and controllability but they cannot yet be applied within a pan-European interconnected system. Transmission systems are being operated under increasingly stressed conditions and are close to their stability limits. Massive integration of RES and DER, potential development of hybrid networks (AC / DC grid) and the increasing levels of interconnectivity require new monitoring methods. Currently, offline simulation tools or remote measurements devices are used and offer only limited flexibility. **Objectives:** To provide solutions which improve the ability to observe and control the pan-European system using information provided by local sensors (like PMU) and models, as well as information provided by forecasting tools. **Scope:** The main focus is to improve transmission system observability and controllability at the pan-European level. However, the methods and tools developed here must be able to interact with those developed for the distribution grids and their interfaces with the transmission grid (refer to FO TD1). **Specific tasks:** • To 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 • To develop a toolbox to increase awareness of pan-European operation/optimization vs. local and regional approaches • To develop local state models with a sufficient level of intelligence at the substation level and to use this valuable information with state estimators and dynamic simulation tools. These models will be aggregated for assessing the observability and controllability at the pan-European level • To increase observability and improve state estimation accuracy (both steady-state and dynamic) through adequate modeling (including not only modeling protection and system automatic schemes to some extent, but also by merging transmission and distribution models) • To exploit the information provided by forecasts of variable generation and flexible demand for observability and controllability purposes • To 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)
Expected outcome	Effective monitoring of the electricity system allows TSOs to make appropriate decisions regarding system operational planning and real-time operation. Validation of the increased role of corrective actions.
Expected impact	Facilitate massive integration of RES and increase interconnectivity while maintaining high levels of system reliability
Main contributors	TSOs, Technology providers, ICT and service providers, Research institutes, Generation companies
Additional information	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.
Budget estimation	€ 50 million
Timeline	2012 – 2020

T7	Innovative tools and methods for coordinated operation with stability margin evaluation
CONTENT	**Challenges:** During the last decade, the system moved from a very well-planned and almost predetermined operation to a more volatile mode with many more uncertainties in different parts of the electricity system value chain (generation, transmission, distribution, consumption, etc.). The expanding share of RES is affecting power system operations by raising the volatility of flows in the grid. This increases the complexity of managing balancing and congestion problems while still maintaining security of supply. Moreover, dynamic aspects must be monitored in real-time (or as closely as possible) and planning must be performed on a daily basis. Today, operators understand their system weaknesses and make decisions based on past experience. Increasingly rapid changes make the learning process more complex. Guidance is needed so that appropriate decisions can be made quickly. Once the worst-case scenario has been identified, an elaborate defense plan must be defined. Hence, operational procedures are becoming more complex than ever before. **Objectives:** New tools will be developed to facilitate the harmonization and coordination of operational procedures between TSOs so that electricity is delivered at the level of quality customers require. **Scope:** The main focus of this functional objective (FO) should be addressed in transmission systems at the pan-European, regional and national levels. **Specific tasks:** • To assess the effectiveness of control actions that deliver the right level of reliability while facing uncertainties from the large-scale deployment of RES and market integration • To develop approaches for optimal provisioning, dimensioning and sourcing of reserves together with local and/or regional distribution to maintain security of supply; to deliver dynamic management of system reserves at regional and pan-European levels • To implement stochastic approaches to critical optimization variables (larger dispersions around the deterministic values obtained from the current steady state simulation tools) to cope adequately with uncertainties • To facilitate converging policies for operational planning and to support the harmonization of operating rules across Europe • To propose data exchange procedures for adequate system simulation; to identify critical contingencies and to assess residual risks while taking into account effectiveness and availability of control actions and automatic protection schemes while identifying action paths to be implemented • To enable real-time detection of instabilities and prevent limit transgression in transmission systems; to develop new approaches to coordinate defense and restoration plans
Expected outcome	TSOs will be able to maintain system stability and high-quality supply of energy to consumers. The system will be operated in a coordinated and reliable manner through the use of new tools, methods and expertise, according to a new European reliability doctrine (see FO T9). It will also support the creation of coordinated defense and restoration plans based on a new set of principles and methods which account for uncertainties
Expected impact	Maintain security of supply at the level required by end users
Main contributors	TSOs, Research institutes
Additional information	The functional objectives are best achieved using the mixed logical-dynamical method wherein the most logical expressions are transformed into equivalent forms using discrete variables, or using the equilibrium constraints and solvers method for handling continuous and discrete variables (large-scale mixed integer linear problems or complementary constraints) simultaneously and robustly.
Budget estimation	€ 30 million
Timeline	2012 – 2017

T8 Improved training tools and methods to ensure better coordination at the regional and pan-European levels

CONTENT

Challenges:
The increasingly rapid evolution of transmission systems requires operators to be updated and trained on a regular basis. There's a need to enhance existing training tools and develop new training tools to simulate uncertainties, automatic control actions and the dynamic behavior of the changing transmission system. The development should focus on managing a broader scope of activities. Since an increasing level of coordination is required, coordinated trainings are necessary where personnel from different TSOs are trained to interact with each other – but also the interaction between DSOs and power plant operators is important.
Simulator and training facilities must evolve to cope with modeling the increasing complexity of operations in the presence of a large amount of RES.

Objectives:
Training facilities will be developed and validated at the prototype level with dispatchers. This involves novel man-machine interfaces where the state of neighboring systems is displayed using new visualization techniques and allows interactions between operators in either simulated or real scenarios.

Scope:
This functional objective (FO) addresses mainly system operators, system analysts and those in charge of control centers for the various members of ENTSO-E. To improve cooperation and coordination efforts, the interaction with external market participants – as DSOs and operators and those responsible at control centers for the various generation units – should be considered.

Specific tasks:

- To deliver and enhance real-time simulation of the entire interconnected European power system for training purposes
- To train dispatchers to reproduce and understand large-scale incidents
- To provide training as well as certification to operators on a validated European power system model and improve emergency response procedures
- To make the dispatching training simulation facility available to other operators such as power plant operators and distribution network operators; hence to improve the network interfaces between transmission/generation and transmission/distribution
- To develop and test common procedures for emergency scenarios
- To enable operator training by specifying the training simulator of the future, including the validation of critical algorithms
- To enable experimentation on what future training should include and who should be involved in order to learn and test the benefits of coordination mechanisms in stable and critical situations
- To establish, validate and deliver default data to fill all the gaps in such a way that simulations are realistic enough for the targeted use.

Expected outcome

Timely and coordinated common training tools and methods for operators (involving coordination procedures) minimizes system risks and impacts when large-scale disturbances occur within the pan-European system (including partial or whole system blackouts). They facilitate system restoration and an in-depth understanding of how the interconnected system behaves.
Training raises the expertise and skills of the network operating workforce: this in turn minimizes human risks in handling complex network operations

Expected impact

Global leadership position in system training

Main contributors

TSOs, IT providers, Training centers, Manufacturers, Research institutes

Additional information

- IT systems for training and simulations
- Software tools have already been developed (e.g. PEGASE project and individual TSO solutions)

Important to have universities participate so that new generation of power system engineers are educated

Budget estimation

€ 30 million

Timeline

2013–2017

T9	Innovative tools and approaches for pan-European network reliability assessment
CONTENT	**Challenges:** Operational planning is one of the most challenging tasks for TSOs. The current security criteria, the N-1 criteria, is a simple, robust, harmonized and transparent way of planning and operating transmission grids that was developed decades ago. The integration of renewable energy sources such as wind- and solar power has considerably changed and will continue to change the way transmission systems are planned and operated. In addition, the presence of both AC and DC links will make operation of the pan-European system even more challenging. In this perspective it is relevant to analyze if the N-1 criteria is still adequate for planning and operating transmission grids or if it has to be complemented to take into account the variability of RES and demand. **Objectives:** New principles designed to deliver the right level of reliability when managing the new pan-European system architecture must evolve without jeopardizing present-day reliability levels. The current N-1 criteria have been used for many years and therefore it is prudent to evaluate them against future reliability requirements. The consequences of the future security criteria must be analyzed comparing the resulting technical benefits (security of supply) against the social costs (welfare). **Scope:** This FO does not cover reserve management (T7), approaches for balancing or ancillary services. **Specific tasks:** • To evaluate the current performance of the (N-1) criteria security principles and the required level of reliability from the customer's perspective • To 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. • To 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 • To provide an appropriate approach to risk assessment for the evaluated criteria based on probabilistic analyses which takes into account correlations in the power system • To develop indicators for the evaluated criteria for network operators to help them make decisions for preventive and curative actions
Expected outcome	The outcome sets the grounds for future European principles that allow evolutions of system design and operations while taking advantage of the benefits of all new technologies. The tools allow TSOs to integrate new technologies in system planning procedures to maintain or increase today's system security and reliability levels.
Expected impact	An optimized use of the European transmission system which allows integration of RES without decreasing today's system security considering social welfare
Main contributors	TSOs, Research institutes
Additional information	Simulation and optimization tools and cost-benefit methodologies adapted to the pan-European system for both design and operations.
Budget estimation	€ 20 million
Timeline	2012 – 2018

CLUSTER 4: MARKET DESIGNS

CONTEXT

The unbundling and liberalization of the electricity markets in Europe have highlighted one specific characteristic of electricity markets: working rules and the resulting efficiency are very much affected by the technical performance of a given network – at the transmission and distribution levels. The business model of the industry has evolved progressively. TSOs, DSOs, regulators, power producers, suppliers, traders, industrial consumers and RES project developers are playing key roles in delivering an efficient electricity market. Thus, market facilitation involves a multidisciplinary approach to research activities, whereby network operators, manufacturers and economists must cooperate closely in addressing the many barriers that have been currently ascertained.

Large-scale deployment in Europe of variable renewables with reduced predictability and the integration of demand-side management creates significant challenges for balancing control. This includes managing reserves and response to unplanned power plant outages. Ancillary services are increasingly necessary to compensate for uncertainties inherent in forecasting demand, wind and solar generation. This implies the need for more ancillary services as RES are increasingly integrated. In restructured electricity markets, the trend is towards decoupling the operational aspect of balancing control and the market settlement aspect of managing deviations in generation and consumption.

This also brings regulatory challenges. Adequate incentives are needed for investors and for grid operators to best exploit the benefits offered by these technologies. Improved and integrated balancing markets are mandatory as well as new ancillary services.

On the way towards the IEM, several coordination initiatives are being developed at the regional level. The approach to integrate the pan-European markets, assuming appropriate interconnection capacities between countries, should ideally augment price convergence between different areas through the efficient use of available means across all of Europe. However, without appropriate market mechanisms, price volatility will likely increase on a daily or even hourly basis. While price spikes indicate the need for flexible peak units, current signals to investors regarding the need for peak units are becoming more difficult to translate into investment decisions due to periods of very low prices. System adequacy will become increasingly difficult to manage, as the operating hours of conventional units decrease in favor of energy generated from RES.

One of the prerequisites for understanding the new market dynamics at a pan-European level is to model their dynamic interactions, taking into account the technical constraints identified in the transmission systems, and to find a way to overcome them.

Regardless of the capacity calculation method and allocation approach used, TSOs and regulators should use risk assessment methods to control the economic costs derived from counter-trading measures. Another issue is how to obtain more efficient interfacing between the physical network and market operation models by applying different techniques developed in ongoing R&D projects.

Several solutions are being researched and developed at the pan-European level, including load aggregation and virtual power plants. This impacts new connection rules, new market designs and new responsibilities for TSOs and DSOs as well other market players (e. g., balancing responsible parties, aggregators, etc.) and institutions (National Regulatory Authorities, ACER, etc).

Revisiting the business model of the industry as a whole helps to define regulations, incentives and other mechanisms that aim to decarbonize Europe while maintaining security of supply and energy efficiency.

Maintaining secure 24/7 operation of the grid will be very challenging simply because the pan-European transmission grid will involve so many different market participants.

Adequate correlation and harmonization between market rules and operational rules must be given. For instance, the schedule changes can impact upon the system frequency (see deterministic frequency deviations reports).

OBJECTIVES

BARRIERS AND GAPS

Barriers impeding innovation	Knowledge gaps
The integration of the European energy market is progressing but still not complete	Large-scale market simulation tools involving renewables, demand-side response and storage systems are needed to understand complex market interactions
Behavior of market participants is sometimes unpredictable – such situations can increase the risk of severe incidents on the pan-European transmission grid	• Cross-border interaction, including more efficient congestion management, must be optimized • New market design required for balancing and for ancillary services across Europe (opportunities and benefits)
Decisions to build new power plants are strongly linked to political and regulatory framework – business cases can change rapidly and disturb market models	Visions are needed for future markets (e. g., capacity markets) and future market spread including structural constraints between those markets
Huge increase of variable RES production causes more uncertainties for the market and also for transmission system operations	• New market models for integrating RES must be implemented • Energy-efficient networks with optimal exploitation of DER, demand-side management and electricity storage
Many different regulation regimes exist in Europe and make comparison between various market situations very complex	New grid tariff designs and investment incentive regimes must be assessed
Lack of sufficient interconnections between countries	• Find new ways and means of increasing interconnections between different systems (as per TYNDP) • The interdependencies between market mechanisms and infrastructure development must be better understood

OBJECTIVES

This cluster studies ways and means of facilitating interactions between the European electricity markets and the pan-European transmission system. The aim is to achieve a more efficient market with an optimized energy mix and security of supply. Potential reviews of market designs must be analyzed to ensure they can cope with the variability of renewable energy generation as well as with demand-side management and energy storage.

Specific objectives:

- Large-scale market simulation tools involving renewables, demand-side response and storage systems at the transmission level
- Cross-border interactions, including more efficient congestion management
- Designing new markets for balancing and ancillary services at the transmission level and with a European dimension

EXPECTED OUTCOMES AND IMPACTS

Expected outcomes:

- Improved understanding of market participant behavior and market interdependencies
- New market approaches will be determined and best practices found

Expected impacts:

The completion of the European energy market will:

- Contribute to integrating volatile energy generation from RES
- Help to identify the "setscrews" for the market
- Result in recommendations for novel regulatory schemes that optimize new value streams (ancillary services, balancing, storage, etc.)

STRUCTURE OF CLUSTER 4

Market designs are mandatory as an economical means to calculate fair payment for usage of transmission capacity. They are also essential to fully integrate and exploit the benefits of RES and to manage energy demand and storage. FO T10 focuses on developing frameworks and market tools for ancillary and balancing applications including active demand management. However, more than this must be done to maintain security of supply and efficiency when integrating very large volumes of RES. This is addressed in FO T12. Finally, fair calculation of capacity allocation and congestion management is handled in T11.

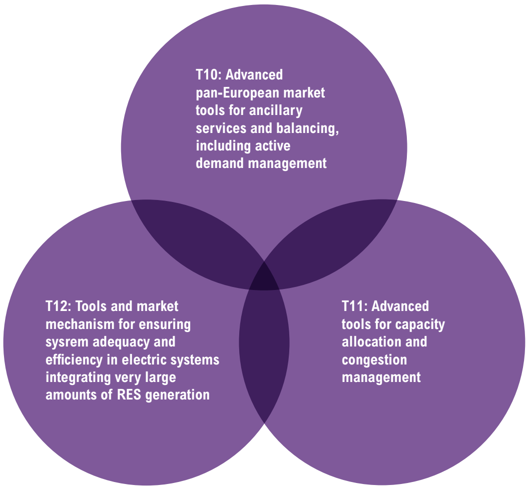


Figure 10: Structure of Cluster 4: Market Designs

T10[23)	Advanced pan-European market tools for ancillary services and balancing, including active demand management
CONTENT	**Challenges:** Current EU targets for integration of RES – in particular wind and solar energy – present significant challenges for balancing control and management of power and energy reserves within existing transmission grids. Balancing control can be seen as two fairly independent tasks: maintaining the grid frequency within definite limits and real-time management of network congestion arising from unplanned deviations. Novel market simulation tools are needed to properly design pan-European value streams. **Objectives:** New market tools are to be delivered that go beyond those currently used in member states. These are to stimulate RES involvement, active demand and storage systems, contribute to system balancing and provide ancillary services. **Scope:** Optimal utilization of ancillary and balancing services at pan-European level well integrated in market mechanisms enabling also regional approaches. **Specific tasks:** • To model aggregated RES / DER, flexible conventional generation, demand and storage systems to be used for market design, market mechanisms and simulation tools for planning and operation purposes • To design market mechanisms for incentivizing both maximization of the provision of ancillary services (including aggregated RES, cogeneration and high-efficiency production, demand, storage etc.) and the minimization of the use of ancillary services; the aim is to harmonize the requirements of provider licenses with supervision, control and recording of services provided • To develop a new tool for detailed analyses of various balancing market designs to identify best practices and to perform large-scale experiments with metered customers that demonstrate the costs and benefits of demand-side management required at the pan-European level • To design and develop mechanisms and platforms for cross-border balancing and power reserve services, moving towards possible future development of regional / pan-regional platforms and even markets based on economic and technical analyses, all while operating within the required security margins • To develop a set of data exchange templates and ICT infrastructures to enable ancillary and balancing services at the EU level
Expected outcome	Business models and frameworks will be delivered for the pan-European grid that improve the real-time market for balancing services. This will be achieved by implementing technologies that make the pan-European grid more flexible and reliable to cope with security of supply.
Expected impact	Cost-benefit analyses will be available for each market player in various business cases in support of further system optimization
Main contributors	TSOs, DSOs, Energy service companies, Power utilities, ICT and automation providers, Research institutes, Regulatory authorities
Additional information	• Optimization techniques and market simulation tools constrained by transmission issues • Telecommunications, metering and monitoring • Control and management algorithms • Software tools for forecasting Work done in this FO is interdependent on T1, T2
Budget estimation	€ 30 million
Timeline	2012 – 2018

23) T13 in the R&D Plan update 2011 is merged in this FO

T11	Advanced tools for capacity allocation and congestion management
CONTENT	**Challenges:** Pan-European power flows within a free energy market plus massive integration of variable RES are resulting in local and regional bottlenecks. A fair charging mechanism for capacity use is needed. Regardless of the methods used to calculate capacities and allocation, risk assessment methods must be used that control economic costs derived from counter-trading measures and to assess the trade off in economic surplus between the costs of redispatch, counter trade and benefits of the resulting increase in capacity. The transmission reliability margin – a security margin – copes with uncertainties by computing transfer capacity values. The main challenges that remain to be resolved are how to manage 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 makes it possible to manage congestion within the pan-European grids without affecting system reliability. The tools to be delivered should be synchronized with current market coupling initiatives. **Scope:** This FO consists of several steps that integrate the various elementary research results generated by the activities in Cluster 4: • At a theoretical level, to compare current tools and the results developed at the national level involving power systems engineering, operations research and economics • To validate that a flow-based market coupling approach can be applied across a wide region with interdependent flows; coexisting with ATC market coupling approaches in other adjacent regions without interdependent flows • To introduce simulation options that account for interactions between the various regulatory frameworks • To introduce data on transmission and generation that are vital to achieve meaningful results **Specific tasks:** • To investigate interactions between system operations and dynamic capacity and reserve allocation methods at the regional and pan-European levels to cope with uncertainties from RES, load and system disturbances • To model strategies in view of improved congestion management and to analyze the possibility of more efficient options, if any exist, for the pan-European electricity market • To expand flow-based market coupling in areas with interdependent flows, based on successful experience • To develop an algorithm for computing potential extra capacities in real time or as closely as possible; taking into account security criteria and without the need for counter-trading issues • To performing risk-benefit analyses and develop an interface using the Congestion Management Module (CMM)
Expected outcome	Delivery of new congestion management rules that do not impact system reliability by implementing flow-based market coupling and improving the methods for calculating capacity and assessing risk. Specific network management procedures will be developed to cope with uncertainties in transfer capacity values and achieve the most cost-effective balance between profit and security of the system.
Expected impact	Transparent and flexible operation of the pan-European electricity market
Main contributors	TSOs, Generation companies, Research institutes, Service providers, Regulatory authorities
Additional information	Technology involved: Simulation techniques
Budget estimation	€ 25 million
Timeline	2012 – 2018

T12	Tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation
CONTENT	**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 in the d-2 and d-1 scheduling processes. Therefore, consideration should be given to the development of improved market models and simulation tools which would allow adequate system capacity to host a large share of RES generation. **Objectives:** Together with the infrastructure development mentioned in T5, market models and simulation tools may, for instance, improve generation shifts. They may also provide recommendations on specific rules for integrating renewables in power, balancing and system services and therefore allow massive integration of RES. The objective of the models and simulation tools is 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. **Scope:** This FO is based on what has been achieved in the Optimate, EWIS, Twenties, TradeWind and other projects related to the research and 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. **Specific tasks:** • To design market mechanisms that allow participation of RES (active and reactive power control), storage devices and conventional generation shift to ensure system adequacy and efficiency • To design investment incentive regimes that promote conventional and RES generation flexibility, new transmission capacity and to foster storage systems • To design grid tariff mechanisms for active demand-side management to correlate the load curve and RES integration
Expected outcome	A simulation toolbox will be delivered that quantifies the economic impact of multiple renewable integration routes through large-scale experiments. This tests the market integration of renewable generation while accounting for the results of the TWENTIES project. As a result, it will be possible to make long-term forecasts of costs and benefits for the market and individual customers.
Expected impact	Increased integration of RES and maximized welfare through correct market signals at acceptable reliability levels
Main contributors	TSOs, Research institutes, Generation companies, DSOs, Power exchanges, Regulatory authorities
Budget estimation	€ 20 million
Timeline	2010 – 2014

CLUSTER 5: ASSET MANAGEMENT

CONTEXT

Asset management aims at maintaining robust and cost-effective network infrastructures with reliable performances. Thus, it helps to decide when old components are to be kept or when, due to reasons of reliability, serviceability and /or availability, new equipment is required for part of or even the entire network. These decisions directly impact the network OPEX and CAPEX as negotiated with regulators. So far, these decisions are guided by several pieces of data:

- Ex-ante reliability figures provided by manufacturers
- Ex-post knowledge of real-life equipment reliability

Recorded knowledge of normalized constraints under which equipment has been operated. While taking worker's safety into account, existing networks are continuously challenged to choose from the following options:

- Implementing maintenance procedures to extend lifetime
- Upgrading equipment to increase lifetime or replace failing subsystems
- Partial replacement of infrastructure

This challenge becomes even more daunting when TSOs face public reluctance (see yellow box on page 60) to accept new overhead lines. Novel technology options will therefore come into the picture such as, for instance, long underground HVAC cables, HVDC cables, AC/DC converters, FACTS, PSTs as well as complex protection, control and supervision systems. These new technologies also present asset management issues such as: is it possible to perform live "line-work" on DC devices to avoid outages?

The coexistence of new and old assets will therefore connect with the overarching goals for interconnected TSOs. That is to say, how can extra capacity be gained for the existing network while working within acceptable reliability constraints at affordable costs?

The present cluster aims at revisiting the current approaches in light of the above trends while facing a paradigm shift in asset design. Here the question is: can working specifications for equipment be dedicated to specific areas of the network to maximize asset lifetime while keeping reliability levels within acceptable values and increasing network capacity according to local asset management (which includes old, revamped and new assets)?

OBJECTIVES

BARRIERS AND GAPS

Barriers impeding innovation	Knowledge gaps
The use of conventional components will change due to more variable power flows generated by variable generations.	The technology lifespan has already been quite extensively studied for conventional equipment (power line conductors, insulators, breakers). The aging process of some materials (e.g., insulators in oil) is still not fully understood and more research is needed to understand the impact of variable power flows.
The lifetime behavior of new components using ever more power electronics must be better understood since they are increasingly deployed in the network.	Aging of FACTS and HVDC components under variable power flows.
Over the past decade, substation automation gear has utilized digital technology. For the first generation systems, the lifespan issues become critical. Due to the lack of standardization for this first generation of gear, they are generally based on proprietary solutions. Introduction of the IEC 61850 standard is one part of the solution.	Special attention must be paid to embedded software and communication systems becoming obsolete. New bugs in "obsolete" software could be generated due to new operating conditions: it might be very difficult to fix bugs in older source code (lost knowledge, lack of compilers…).
The maintenance strategies are generally based on periodic inspections and standardized preventive maintenance actions. These strategies are easy to implement and organize but certainly not optimal for reducing costs and improving grid flexibility.	ICT solutions in substations should allow information to be collected on component health and life state. The issue is to process and exploit large amounts of raw information to improve asset management. Solutions must be designed, developed and tested to address these issues, beginning with a few critical components.
A new possibility is to use automated systems such as robots to detect and monitor problems or even to intervene in hostile environments. Autonomous robots equipped with video and thermo-graphic sensors have been tested for substation monitoring.	Demonstrations of a robotized approach are required before they can be commercialized.

Low social acceptance: negative impact on landscape, Not In My Backyard "NIMBY" syndrome and now fear of hypothetical electromagnetic effects; "NOCEBO" people become sick through strong belief that nearby overhead power lines have a negative impact of their health. There is no scientific evidence of such impact.

OBJECTIVES

The overarching goal of this cluster is to maximize the value for money of component assembly, thanks to both improved monitoring of health (under managed working conditions) and to improved preventative maintenance decisions suited to local network conditions.

Moving away from "normalized" implementation of power components while achieving the overarching goals requires the pursuit of several objectives:

- Validation of new monitoring concepts for primary and secondary components in view of scheduling maintenance that maximizes network flexibility
- Utilization of conditional maintenance in view of further increasing network flexibility
- Anticipation of novel maintenance methodologies for new power technologies (HVDC links, AC/C converters, underground cables)
- Better understanding of how network working conditions impacts the aging of critical components, using ex-post analysis of assets that have been removed from the grid

EXPECTED OUTCOMES AND IMPACTS

Expected Outcomes

- New approaches to extend the lifetime of existing power components thanks to improved real-time monitoring of their health
- New maintenance approaches to manage critical assets based on local optimization that are shown to reduce operational costs while increasing network flexibility and ensuring adequate power quality
- Optimized maintenance approaches for new network components and increase the availability of transmission networks, as well as reduction of maintenance actions and duration needed for new or maintenance work
- New specifications for manufacturers of sensors and IT systems able to further support health monitoring, conditional maintenance and overall improved asset management
- Recommendations for scaling-up and replicating of coordinated asset management techniques
- Interoperability and standardization guidelines of component health monitoring systems constructed jointly with manufacturers
- Operator training recommendations are proposed to support novel asset management approaches

Expected impacts

- Easier integration of renewable generation due to a greater grid flexibility provided by an optimal asset management
- Greater grid capacity for the electricity market leading to a more efficient market. For the same level of quality and security of supply, a smarter asset management offers more grid capacity
- Reduced costs of the asset maintenance activities with increased performance of existing assets
- Smooth integration of new technologies with optimum OPEX

STRUCTURE OF CLUSTER 5

This cluster is built on three functional objectives. T15 focuses on the component level where methodologies are developed to determine and to maximize the lifetime of critical power components for existing and future networks. In-depth knowledge about the way each component performs is essential to develop methods and tools to optimize the asset lifetime at system level, and this is derived from the quantitative cost/benefit analyses in T16. Finally, T17 demonstrates the potential at the EU level for new asset management approaches.

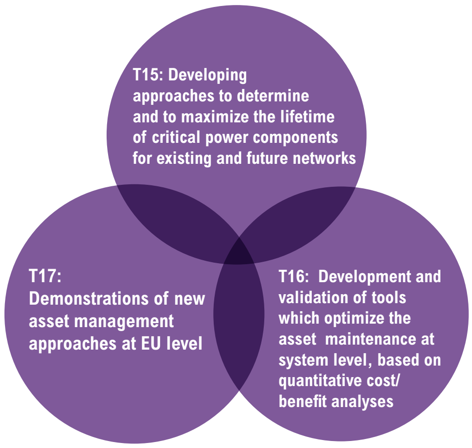


Figure 11: Structure of cluster 5 asset management

T15	Developing approaches to determine and to maximize the lifetime of critical power components for existing and future networks
CONTENT	**Challenges:** So far, asset management relies on an average life-span of equipment as a function of a few critical working parameters (e.g., working temperature, number of switching, etc). A challenge is to revisit the lifetime prediction modeling based on extended parameters that can be easily monitored (based on a trade-off between the extra cost for monitoring and the expected lifetime expansion). The other challenge is to account for the reliability of the new monitoring system itself. **Objectives:** Various approaches of calculating and maximizing the lifetime of critical power components for the existing and future networks are to be developed and validated. **Scope:** • To cover a significant part of critical network componentry • To include field data of several TSOs from different climates and operating voltagesTo involve manufacturers in the technology choices in view of preparing future demonstrations **Specific tasks:** The following tasks are tentatively planned for each component: • To identify the 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 statuses that are comparable across TSOs, with in-depth analysis and shared experiences • To develop a methodology to determine and expand the life span of components including conventional components (conductor, insulator, tower, breaker, etc.) and new components such as power electronic devices and digital devices • To propose dedicated, intelligent monitoring and analysis of results from equipment operation • If necessary, specify new measurement devices and associated ICT system • To assess the environmental impact (noise, leakage, etc.) and safety for workers or nearby inhabitants (especially in case of failure), taking into account aging processes and technical obsolescence • 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 assess the benefits of partially renewing small components (joints, etc.) or adding new protective layers (paint coating) to extend life span. A methodology is to be developed that assesses the capability of each component to be partially repaired or where the coating is to be replaced • To develop new ways of detecting component failure based on failure models
Expected outcome	• For each component, an approach for local health monitoring is proposed based on a wide coverage of climate and working conditions • The life span prediction model is based on past real-life data of existing equipment • Lifetime prediction models for new components are determined jointly with manufacturers • More TSOs can contribute to strengthen the proposed approaches • More manufacturers can contribute with their own technology • Feedback from TSOs to technology manufacturers for future health monitoring systems • Delayed network investments to ensure the same capacity
Expected impact	• Increased network flexibility for grid users at optimized OPEX which allows a larger share of RES and increased security of supply • Standards for health monitoring equipment for power technologies at the pan-European level
Main contributors	TSOs, Technology providers, manufacturers, IT providers, Research institutes
Additional information	The associated IT system at the substation and enterprise levels must be defined and costs evaluated. Standards could help implement efficient asset management methodologies for the same type of equipment from different manufacturers. At least 5 critical technologies will be investigated in parallel during the first 5 years.
Budget estimation	€ 30 million
Timeline	2014–2018

T16	Development and validation of tools which optimize asset maintenance at the system level, based on quantitative cost/benefit analysis
CONTENT	**Challenges:** Asset management based on optimization at the system level is complex. Since all decision-making processes must be taken into account, this requires a well-defined level of system reliability. The main R&D challenge is to specify and develop a realistic and workable approach, using relevant approximation and heuristics. **Objectives:** Development and validation of tools which optimize the asset lifetime at system level, based on quantitative cost/benefit analyses **Scope:** Specify approaches and tools to prepare optimal decisions for asset management: covering the health monitoring of several technologies for a given network. These approaches must answer the following questions: • Which equipment has to be replaced, repaired or upgraded and when (e.g., preventatively)? • How many spare parts are needed, how much maintenance personnel is required and where should maintenance personnel and spare parts warehouses be situated to minimize undeliverable energy? **Specific tasks:** • To define methods and tools to optimize asset management at the system level. The proposed methodology provides an assessment of the costs and benefits of different asset management strategies. The methodology proposes a risk-based approach at the system level, including interactions between equipment, impacts on security and quality of supply and also environmental and safety constraints. The organization of maintenance work, availability of spare parts (supply chain, quantity of spare parts and location) are part of the global optimization challenge • Provide tools for dynamic management of outage planning & maintenance schedules.
Expected outcome	• By combining results from T15 and T16, participating TSOs are able to test their approach on the same subset of equipment in different ENTSO-E control zones • OPEX reduction will be quantified for this subset; other components can be defined for T15, whereas T16 is extended to cover them • Scaling and replication activities will be specified for T17 • Manufacturers will do more for ensuring interoperability and will define standards for monitoring equipment health • TSOs will further optimize asset management of the transmission system, including replacement, supervision and maintenance policies. A number of maintenance actions will evolve and their priority level, total cost and benefits to grid performance will be recorded.
Expected impact	Maintain system reliability at lower costs whatever the RES share in the power mix
Main contributors	TSOs, ICT providers, Research institutes
Additional information	The methodology and tools must be flexible and adaptable for each European TSO with different types of constraints and rules. Approximation and heuristics could be different from one TSO to another. Two large projects embedded with ICT, involving several TSOs (€ 15 million each, 3–5 years)
Budget estimation	€ 30 million
Timeline	2014–2018

T17	Demonstrations of new asset management approaches at EU level
CONTENT	**Challenges:** The challenge is to demonstrate how integrated asset management approaches can be implemented, scaled up and replicated at managed costs and that the expected benefits are realized. The demonstration could be done using a few types of equipment at substation level. Next, the scaling-up and replication of the results must be performed in several control zones. Expected benefits at the system level can be quantified within given approximations. **Objectives:** The scaling-up of new asset management approaches and its potential for replication at the EU level are to be demonstrated. **Scope:** • Demonstrations in several control zones with several manufacturers • A typical set of critical power technologies • Experimental results to prepare for scaling-up and replication **Specific tasks:** • To utilize embedded ICT to monitor individual assets and to define a method of supervision based on this information at the system level for several TSOs in parallel • To implement robotics for problem detection as well as to intervene in hostile environments and avoid the need for human maintenance. These include UAV to inspect overhead lines and robots that move while “grabbing” the conductors • To implement maintenance activities with the network “on”, especially for DC equipment • To propose scaling-up and replication rules for new asset management approaches at the pan-European level
Expected outcome	Validation of the proposed solutions for asset management, with the assessment of their future replication and scaling up at the pan-European level • TSO maintenance rules revisited with standards and interoperability of health monitoring system, and decision-making tools for asset management at TSOs level • TSOs can specify technical specifications to manufacturers for deployment • TSOs achieve increased network flexibility and capacity, reduced OPEX and delayed capital investment
Expected impact	Maintain system reliability at lower costs whatever the RES share in the power mix
Main contributors	TSOs, ICT providers, Research institutes
Additional information	• Several years of operations are needed to quantify costs and benefits • Five control zones X € 15 million demonstration per control zone
Budget estimation	€ 75 million
Timeline	2017 – 2022

CLUSTER 6: JOINT TSO / DSO R&D ACTIVITIES

CONTEXT

Even though the transmission system is physically linked with the distribution system to transfer electric power and energy, real-time communications are scarce and no information is shared on normal and /or contingency situations. Furthermore, distribution system states and conditions (i. e., load, capacity, and voltage) are often not monitored. This still functions well with unidirectional power flow from the transmission system and only slight integration of distributed energy resources (DER).

However, with increasing amounts of DER being connected at the distribution level, new electricity loads and growth in demand, the lack of a communications interface and little to no system status information creates problems for system operators. For instance, massive amounts of PV are connected at low to medium voltages in many countries. DER have an important impact on system stability. For this reason, TSOs and DSOs must cooperate closely and increase their communications.

New types of consumption such as electric heat pumps and electric vehicles will also enter the markets for energy and ancillary services and will not follow a predefined profile such as conventional consumption. New methods are needed to design the best TSO/DSO interface and identify what the network requires in order to cope with increasingly volatile generation and consumption. Enhanced monitoring tools at the generation interface (also at the distribution level) can also facilitate transmission grid operation.

Innovative concepts such as the smart grid together with joint R&D TSO and DSO activities will be essential to achieve the European energy target for 2020 and goals to integrate RES into the energy system by 2050.

The deployment of innovative technologies on one hand changes the architecture of transmission (HVDC) that affects the distribution grid. On the other hand, active components in the distribution grids (e.g., power electronic converters) can provide services to the transmission system such as virtual power plants (VPP), 'aggregators' or service providers (e. g., EVs) organized at the distribution system level.

Different from the other clusters which focus largely on the transmission level, this cluster identifies from the TSO perspective additional benefits and potential services that future distribution systems can provide.

OBJECTIVES

BARRIERS AND GAPS

Barriers impeding innovation	Knowledge gaps
It is challenging to integrate ICT technologies into the existing system. Existing grids should be used in a more intelligent and efficient manner.	Lack of real-time communication between distribution and transmission levels
Weak integration of energy systems. Stronger integration of electricity / gas, electricity / heat systems is an obvious option in several member states	More flexibility is needed
Many imbalances can be solved at the distribution level before they are transmitted to the transmission grid and ancillary services. However, imbalances must be resolved where it is most economical. Local balancing should only be applied for congested lines or transformers.	New market designs and products are needed The option of local balancing on the whole system (including centralized production) vs. network reinforcement should be investigated
Autonomous self-controlling and healing grids (dynamic topology, power re-routing).	Autonomous, distributed control systems and introduction of corrective actions

OBJECTIVES

The overall aim is to evaluate the smart grid initiatives by DSOs and their possible utilization for supporting the transmission grid with regulation and ancillary services provided at the interface with the lower voltage grid.

Specific objectives:

- To develop forecasting tools (both short- and long-term) and design a communications infrastructure in line with the relevant measures from the TSO perspective, allowing better coordination of system operations
- To investigate the behavior of customer segments at the distribution system level and integrate them so they can actively participate in system management and development of models (e.g., aggregators). This makes the system more flexible and adds value for consumers so they are on equal terms with other actors (e.g., gas turbines)
- To develop and identify a set of relevant ancillary services shared by the DSO and the TSO that allow deployment of emerging technologies (integration of electric vehicles, micro-generation). This must account for delivery of the expected quality of service. Services related to energy and power may be regulated or provided by commercial actors (i.e., those responsible for balancing). DSOs can only provide services related to reactive power, voltage control etc. However, DSOs can also buy energy and ancillary services to resolve local congestion problems.
- To improve the current TSO/DSO interface with respect to defense and restoration plans
- To provide a common framework for interoperability (communication protocols, information models, semantic models, connection requirements, etc.) in the field of Smart Grids as requested by European Commission on 1st of March 2011, by Mandate M/490
- To define a framework that allows scaling-up and replication in different topological scenarios

EXPECTED OUTCOMES AND IMPACTS

Expected outcomes

- Better coordination between transmission and distribution systems by exchanging information and data in real time
- Faster and well controlled network restoration due to participation of DSOs in process
- Specific products for providing ancillary services and demand-side management (DSM) will incentivize development of DER
- Validated tools that can be used at the pan-European level to encourage increased network observability

Expected Impacts

- Realization of methodologies and tools for scaling-up and replicating solutions, maximization of impacts for future use of developed solutions at the pan-European level
- Convergence between various international and European standards increases competitiveness

STRUCTURE OF CLUSTER 6

This cluster covers the functional objectives that the TSOs and DSOs have in common. It is divided into 5 functional objectives.

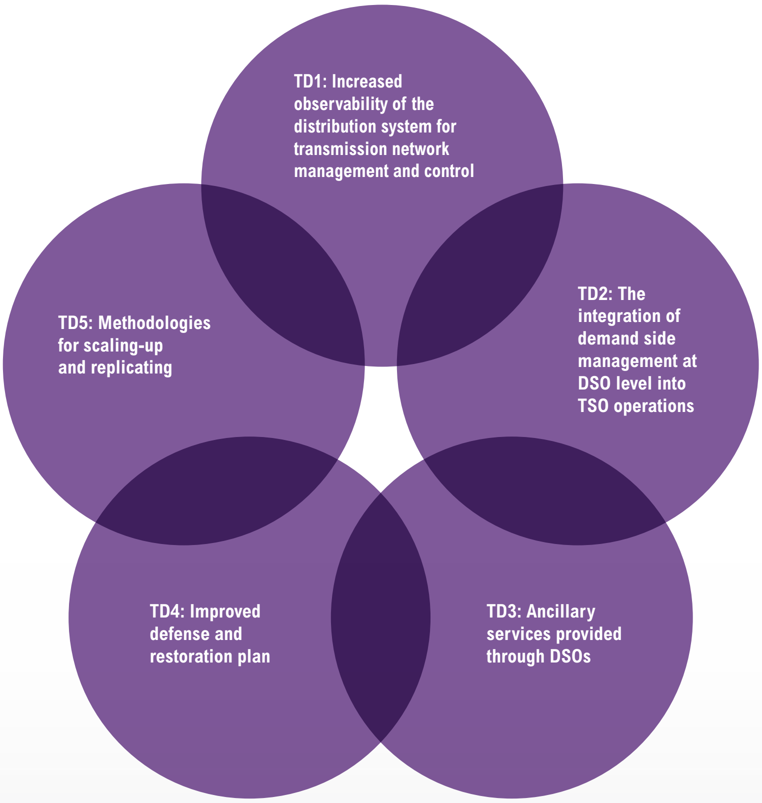


Figure 12: Structure of Cluster 6: Joint TSO/DSO

TD1	Increased observability of the distribution system for transmission network management and control
CONTENT	**Challenges:** A challenge for every network operator is to aggregate data that is coherent at all voltage levels and between operational areas. There is a need to accurately model the load and DER. This data aggregation should cover different time horizons, ranging from short-term (real-time operational planning) up to long-term (network planning). Forecasting engines are needed to manage reserves in a timely and secure manner. Furthermore, the presence of PV, wind or CHP units at the distribution level requires TSOs to foresee the real-time requirements of the distribution system to maintain operational security. As new network codes are written to integrate DER into the network, some degree of control over DER is required. This may ask for DER control centers to monitor, forecast and operate DER according to the needs of DSOs and TSOs. This provides more capabilities such as power flow control, load management, autonomous operation and control at the cell level, among others. **Objectives:** The main objective is to increase observability of the distribution system for transmission network management and controllability owing to better forecasting and data flow. **Scope:** Integration of DER in power control: active and reactive power control capability, technical aggregation, observability of DER for TSO and DSO **Specific tasks:** • To improve short-term (15', 1h, 3h) and long-term (5-day) forecast engines for PV, wind, CHP and loads. • To develop new modeling methods and tools for steady-state (static parameters) and dynamic analyses (capacities up to 1 MW) • To deliver methods and tools for planning new DER connections at the TSO/DSO boundary (response to new connection requirements) • To develop new methodologies for data processing at various system levels (DSO, TSO) • To design new architecture, control systems and communications (including GIS assistance) that allow multiple new generators to be connected and share information with TSOs • New integrated functions (scaling-up techniques) and solutions for technical aggregation of DER data acquisition capabilities for improved DER production observability
Expected outcome	• More accurate production and load analysis for each network operator thus minimizing the impact of DER on the network and increasing the level of observability. • Deployment of DER control centers, responding both to TSO and DSO constraints • Improved load forecasts that deliver better network security margins (i.e., more reliable determination of reserve requirements in a timely and secure manner) and make network operations more efficient
Expected impact	Validated tools that can be used at a pan-European level to encourage increased observability
Main contributors	TSOs, DSOs, Research institutes, Manufacturers, Generation companies, Aggregators
Additional information	Demonstration phases are foreseen that prepare scalability and replication in non-participating member states
Budget estimation	€ 45 million
Timeline	2011 – 2018

TD2	The integration of demand side management at DSO level into TSO operations
CONTENT	**Challenges:** The potential benefits of load control, such as peak shaving and energy savings, must involve large-scale participation of end consumers in order to assess their impact on TSO planning and operations. New technologies such as smart meters and energy boxes must be included to add value to traditional demand response and raise awareness about consumption patterns and foster active customer participation in the energy market. **Objectives:** The main objective is to develop processes for commercial actors (e. g., VPP, aggregators, retail companies) to generate localized offers that could be activated by the relevant DSO, TSO, or market operators. **Scope:** In contrast to T10, DSM is performed at DSO level. **Specific tasks:** To achieve these goals, demonstration specifications are required for demand-side management: • To define demand requirements and data required by TSOs for the pan-European planning tool • To demonstrate active customer 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 %) • To model customer / load behavior and segmentation and quantify the degree of flexibility provided by distribution networks, e. g., through reconfiguration or other methods
Expected outcome	The existence of load control provided by distributed resources allows TSO to plan and operate the network in an efficient and economical way.
Expected impact	Increased level of flexibility for TSO planning and operations allows increased integration of RES while maintaining security of supply at the pan-European level.
Main contributors	TSOs, DSOs, Manufacturers, Customers, Service providers
Budget estimation	€ 70 million
Timeline	2012 – 2018

TD3	Ancillary services provided through DSOs
CONTENT	**Challenges:** Distribution companies formerly contributed to ancillary services in transmission systems through reactive compensation on the MV side of the HV/MV transformer. Load-tripping schemes limit drops in frequency in the event of a loss of generation, etc. The evolution of the electricity sector and the expected arrival of aggregators will strongly affect the roles of the TSOs and DSOs. In that regard, TSOs and DSOs must address the legal, contractual and market aspects. **Objectives:** This FO creates new incentive mechanisms and addresses technical aspects to allow new ancillary services for TSOs from DER and load control provided through DSOs. **Scope:** New procedures and strategies will be developed to provide ancillary services by DSOs to TSOs using DER and load control. **Specific tasks:** • 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. • 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 • New actors and market models that enable DER 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
Expected outcome	• The increased level of DER in distribution networks brings more active contribution from DSOs and service providers in terms of issues like active and reactive power reserves, voltage and frequency control and network restoration. Thus, the inherent flexibility in the loads contributes effectively to ancillary services and can be traded on the market. • Replacement of load tripping through new provided services
Expected impact	New recommendations on grid code evolutions, based on ancillary services that can be provided at DSO level
Main contributors	TSOs, DSOs, ICT providers, Manufacturers, Service providers, Generation companies, Aggregators
Budget estimation	€ 50 million
Timeline	2014 – 2018

TD4	Improved defense and restoration plan
CONTENT	**Challenges:** There are almost no common and binding procedures at the pan-European level for managing defense and restoration with contributions from RES (wind farms in particular) and DER within distribution systems during emergencies. Regulatory and technical issues as well as social and economic aspects must be considered when designing a restoration plan at the pan-European level. The distribution networks can participate in defense plans 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). The distribution networks could also participate in small disturbance management that require new methodologies and techniques. Research is needed to develop, among other new methodologies, new power system restoration planning methodologies that may incorporate interactive graphics and optimization algorithms. To harmonize an emergency strategy in connection with RES and DER management during emergency situations, simulation tools to detect weak points in the pan-European system are needed together with operational guidelines with acceptable reconnection scenarios. **Objectives:** The main objective is to involve DSOs in an improved defense and restoration plan for the entire pan-European system. **Scope:** Since FO T7 develops new methods and tools for identifying and assessing the vulnerabilities of the pan-European grid by considering both the power and ICT systems together, this FO should develop solutions involving components at the distribution level. **Specific tasks:** • To develop simulation tools and methods that detect weaknesses in the system with respect to reconnecting DER and storage systems • To develop simulation tools and methods of assessing the risk of breakdowns during reconnection • To develop simulation tools for interactive system restoration including advanced forecast tools developed in TD1 for wind, solar PV and other variable RES. • To address regulatory and technical challenges that implement restoration plans at the pan-European level • To 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 efficacy and cost-effectiveness when compared to the traditional or usual black-start approach. • To investigate the impact of micro-grids and islanding capabilities taking into account efficacy and cost-effectiveness. • To train operators about the evolution of national regulatory schemes in order to foster coordination efforts
Expected outcome	• 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 impact	Regulatory and technical solutions to implement restoration plans at the pan- European level to lessen the impact of power shortages for end users
Main contributors	TSOs, DSOs, ICT providers, Manufacturers, Generation companies
Budget estimation	€ 45 million
Timeline	2011 – 2018

TD5 Methodologies for scaling-up and replicating

CONTENT

Challenges:
The EEGI roadmap provides a set of Functional Objectives to initiate smart grid R&D projects. These require public support so the future technical risks of innovative solution deployment will be covered in a manner that is satisfactory both for regulators and free-market players. However, the following challenges still exist:

- The economic risk of deployment is not under control, even though technical risks seem to be under control (lack of economic scaling)
- The regulatory environment, which may be favorable in one control zone (economic scaling is managed), is no longer favorable in another control zone (lack of replication potential)
- The exchange of data, knowledge, results and tools requires a proper framework and guidelines to ensure that they are scalable and can be replicated. In this respect, interoperability between various standard protocols (IEC 61968 DMS; IEC 61850-7-420 DER, IEC 61970 EMS, IEC TS 62351 Security) requires further study, probably supported by field experiments

There is thus a need for scientific approaches to address "ex-ante" fears in order to propose, before deployment, solutions for the following issues:

- Scalability of an innovative network solution is project-dependent; the use of experimental results from R&D with the help of numerical modeling techniques makes it possible to demonstrate that economic scaling is under control within acceptable uncertainties.
- Replication potential of scalable innovative network solutions depends on the control area and its specific boundary conditions; the use of experimental results from R&D with the help of numerical techniques and empirical data on boundary conditions makes it possible to demonstrate that the potential for replication is appraised within acceptable uncertainties.

Objectives:
The purpose is to study and validate a set of shared common tools and a methodology amongst network operators in Europe; it addresses interoperability and standardization as well as scaling-up and replication issues with answers that can be trusted by all the involved stakeholders, including regulators.

Scope:
This FO proposes generic scaling-up and replication approaches.

Specific tasks:

- To investigate the acceptable levels of risk and uncertainty in studies in order to adequately assess the scaling-up and replication potentials of solutions and their requirements
- To document the methodology for future project participants so that they can assess the experimental data requirements necessary to design a smart grid demonstration
- To develop information models for the smart grid security, taking into account business interactions and the physical processes of delivering electricity, and also the disruption of business communications, or of the delivery of electricity
- To analyze data exchange protocols that reinforce interoperability constraints at the pan-European level with an adequate level of security
- To study appropriate confidentiality constraints in the developed toolbox to ensure appropriate sharing of results while at the same time preserving stakeholder interests.
- To define open standard data models that ensure interoperability between different data exchange protocols for smart grid applications and to increase competitiveness

Expected outcome	• Barriers to scaling-up and replication are identified and solutions are provided to remove them • Options to make the studied functionalities evolve in view of future scaling and replication are proposed
Expected impact	The intricacies of the European grids make scaling-up and replication extremely complex. By jointly addressing scientific and technical issues, the following is possible: • Reduced development costs for manufacturers • Accelerated validation phase of innovative technologies and solutions • Maximized impact of future use at EU level Furthermore, convergence on interoperability of different standards at EU level ensures: • Increased competitiveness • Customized solutions adapted to local requirements • Application of homogeneous IT-supporting systems
Main contributors	TSOs, DSOs, Simulation tool developers at academic and industrial level, Power technology manufacturers, Academics involved in regulatory environment simulations, Professional associations representing generation and retail activities, ICT providers, Service providers
Additional information	It is expected that one or two large R&D projects will lead to the creation of an operational tool box for use by network operators and power industry manufacturers; this is based on the many existing demonstration results but several R&D projects are needed in order to address data modeling and interoperability capabilities.
Budget estimation	€ 40 million
Timeline	2011 – 2018

APPENDIX B
METHODOLOGY OF DEFINING THE R&D ROADMAP AND ACTIVITIES

SWOT ANALYSIS

The shift to a new paradigm in electricity has enormous consequences for European TSOs. It is therefore imperative to expand expertise and develop innovative solutions to deal with the challenges of tomorrow's pan-European transmission grid. But first, the current status of Europe's TSOs must be assessed and the necessary R&D prioritized. To accomplish this, a SWOT (strengths, weaknesses, opportunities and threats) analysis has been performed and the results are shown below.

STRENGTHS

- TSOs have extensive expertise in planning and operating the current electricity system.
- Several collaborative R&D projects funded through the European framework program have provided TSOs with their first experiences doing R&D together and the benefits are already apparent.
- Through the efforts of daily network operation and regional initiatives (Coreso, TSC, etc.) and ENTSO-E, European TSOs realize the positive effects of increased levels of coordination and cooperation.
- ENTSO-E and its members are enablers of energy policy goals (high involvement in EEGI as stipulated by SET Plan) and comply with regulator requests.

WEAKNESSES

- TSOs lack direct (in-field) experience with many novel and unconventional technologies that are critical for the future grid.
- TSOs lack resources (monetary and human) to develop new tools, approaches and expertise. It is difficult to allocate funds for R&D. Talented human resources may be hesitant to consider employment with a TSO due to their perception as conservative and slow to innovate.
- High security requirements and regulatory constraints make TSOs averse to innovations that offer potential breakthroughs yet also involve high risk.
- The large scale of the required investments means that grid infrastructure cannot be modernized overnight.
- Within the current regulatory framework, system optimization is still viewed as a national issue and not from a pan-European perspective (for investment decisions, operational procedures, etc.).
- Each European TSO faces different national regulation and market rules. This presents a barrier to harmonization at the pan-European level.

OPPORTUNITIES

- Strong commitment of policy makers to achieve decarbonization of the European economy encourages TSOs to modernize the transmission system.
- Available technology (e.g., power components, ICT) and research advances (e.g., optimization methodologies) provide TSOs with different alternatives for addressing the upcoming challenges. This is an opportunity to progressively build a new European electricity grid with better and more efficient technologies.
- The trend towards creating the IEM requires TSOs to provide solutions that are valid for all of Europe.
- TSOs become aware that sharing resources helps to optimize operations while avoiding stranded investments and duplication.
- Increased integration of electricity system with other energy sectors (e.g., gas, heat and transportation) introduces TSOs to new partnerships and expertise.
- New business models with new actors (e.g., DSOs take on a more active role in integrating DER) provide TSOs with another means of securely maintaining high-quality energy.

THREATS

- Multiple R&D visions & strategies at the national level; failure to align these with EU climate and energy targets will impede innovation.
- National and European policies give preference to quick fixes instead of pursuing long-term goals. Excessive political and regulatory focus on cost reduction instead of guaranteeing system efficiency and security. This hampers TSO investment in R&D and system innovation.
- Lack of cooperation and communication with technology providers hinders confidence in developing and demonstrating benefits of novel technologies.
- Failure to properly coordinate R&D efforts with technology providers, research institutions and new actors in addressing long-term TSO needs, hence leading to inefficient utilization of resources and failure to establish expertise in time.
- Economic crises that divert attention from energy issues may also hamper system development.

KNOWLEDGE SHARING

ENTSO-E has established the Working Group for Monitoring and Knowledge Sharing (WG MKS) within the Research and Development Committee (RDC) to enable active contribution of ideas and dissemination of results. The following guidelines apply:

- The sharing of results is focused on sharing foreground information, i.e. new knowledge and expertise gained during the project's development. All intellectual property rights (IPR; including but not limited to industrial property rights) to foreground information are owned by the TSOs participating in the project in accordance with the relevant agreements.
- Project results owned by the TSOs are shared within ENTSO-E: TSOs specify, package and validate the project results which are made accessible via ENTSO-E.
- TSOs commit themselves to share project results and necessary background information within ENTSO-E. Project results will be made accessible via ENTSO-E.
- TSOs share (disseminate and facilitate access to) all foreground information, new knowledge and expertise gained during the project's development within ENTSO-E.
- TSOs will grant access to new software developments and to new testing facilities at a reasonable cost.
- ENTSO-E will grant access rights to any TSO details required to generate foreground information in accordance with the relevant agreements.
- All new equipment, prototypes or demonstration facilities are owned by the TSOs participating in the project in accordance with the relevant agreements.
- TSOs manage how knowledge is integrated within ENTSO-E; ENTSO-E enables cross-functional coordination of R&D portfolios in all subjects relating to TSOs business.

MONITORING OF R&D FULFILMENT

The objective of monitoring the R&D achievement is to provide an outline of ENTSO-E's R&D activities, namely to assess to what extent the objectives behind the different proposed R&D activities are either complete, ongoing or have not yet been addressed. The results will be used to perform a gap analysis for further prioritization of specific Clusters and Functional Objectives. This monitoring exercise is performed by WG MKS.

The monitoring exercise is also considered as Implementation Effectiveness. It focuses at a program management level:

- **Completion** of R&D Roadmap. These indicators measure the contributions of various R&D projects to completing the objectives of the R&D Roadmap. The aim is to determine the completion percentage of each R&D task as well as perform a gap analysis so that future and current R&D tasks can be prioritized.
- **Budget:** This indicator measures the effort committed to each project compared to the forecast values.
- **Time:** This indicator helps determine whether or not a project is on schedule and/or whether delays are expected.

These indicators are assessed using 'traffic lights'. Here, green indicates that projects are on track with no budgetary or time problems, orange denotes minor issues that do not represent a risk for the project, while red signalizes important risks or delays that might endanger the success of the project.

The monitoring data is provided by each project's coordinators and makes use of a template that is sent for completion once a year. A monitoring report of the R&D achievement, on-going activities and gaps is delivered annually.[24)]

The results of the monitoring process will help to perform a gap analysis for prioritizing upcoming R&D activities.

24) 1st monitoring report is done by the WG MKS in 2012
https://www.entsoe.eu/rd/monitoring-of-the-rd-achievement/

REFINING THE R&D ROADMAP

The methodology for updating and refining the ENTSO-E R&D Roadmap and Implementation Plan is visualized in Figure 13.

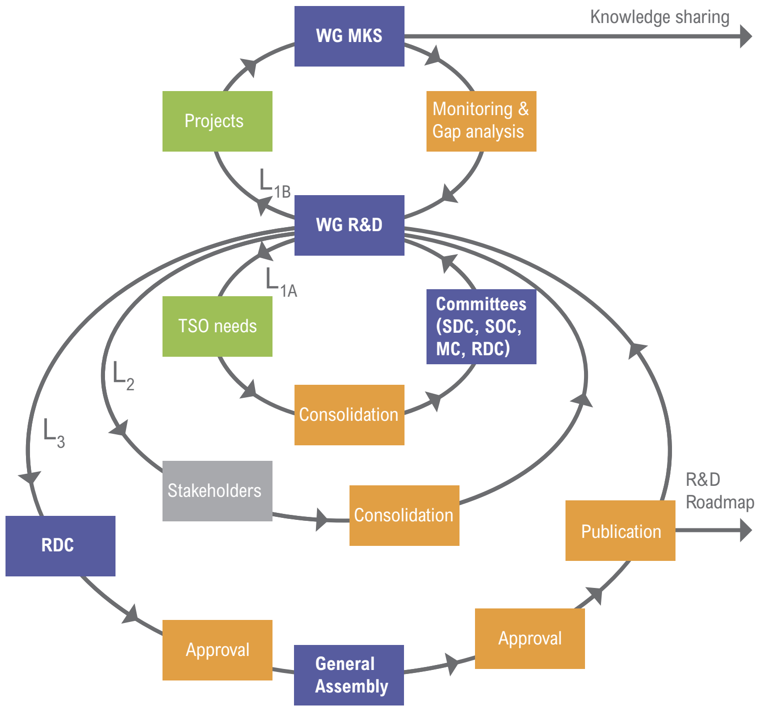


Figure 13: Methodology for updating R&D Roadmap and Implementation Plan

Step 1 involves two parallel streams. In loop 1A (L_{1A}), TSO R&D needs are first assessed and collected. These are consolidated so that they can be validated and updated by committees (System Development Committee (SDC), System Operations Committee (SOC), Market Committee (MC)). At the same time, loop 1B (L_{1B}) demonstrates how the various R&D projects are monitored by WG MKS so that they can determine whether there are any gaps in the R&D coverage (gap analysis).

In step 2 (L_2), external stakeholders (e. g., associations, policy and regulatory authorities such as European Electricity Grid Initiative and other European Industrial Initiatives) are consulted to retrieve feedback and additional input on the ENTSO-E update proposals. No external consultation is planned for the ENTSO-E Implementation Plan since this document is fully derived from the R&D Roadmap and instead places emphasis on TSO priorities and their available resources.

Finally in step 3 (L_3), the ENTSO-E R&D Roadmap and Implementation Plan is approved by RDC and ENTSO-E Assembly and then ultimately published.

GOVERNANCE

All research work performed through the R&D Roadmap is governed by the following criteria.

Firstly, all research is collaborative and open to other market players and stakeholders. Depending on the scope of the R&D involved, leadership and management responsibilities are to be assumed by the TSOs or relevant partners.

Secondly, all projects within the Functional Objectives will utilize key performance indicators. These determine how much value is added by each task and from the six Innovation Clusters towards achieving the objectives of the SET Plan and implementing the IEM.

ROLES AND RESPONSIBILITIES:

- ENTSO-E is committed to publishing the R&D Roadmap and Implementation Plan and providing information on short-term R&D work within the scope of the ENTSO-E Annual Work Program. The objectives of these deliverables are explained in section 1.
- ENTSO-E contributes to publishing the EEGI Roadmap in coordination with other industry stakeholders (e. g., EDSO-SG) and manufacturers (e. g., T&D Europe). This collaboration will be fostered through the Grid+ project.
- EC is invited to issue calls for proposals relating to the functional objectives of this R&D Roadmap (therefore also belonging to the EEGI Roadmap). This will progressively achieve the objectives of the SET Plan.
- ENTSO-E facilitates, through the RDC, the process of assembling partners for projects addressed by calls for proposals so that TSOs, generation companies, manufacturers, and research institutes can form consortia and submit their proposals to the EC.
- ENTSO-E can participate as a partner in R&D projects if required.

- EC evaluates proposals sent in response to calls for proposals and awards work contracts.
- The awarded consortia are responsible for all contractual commitments, project execution and for submitting progress reports to EC.
- ENTSO-E monitors the R&D Roadmap using specific KPIs.
- ENTSO-E facilitates the dissemination of results based on publications prepared within the framework of the R&D projects.

As regards the role of ENTSO-E bodies, RDC provides the central platform for R&D issues and interacts closely with other committees (SDC, SOC and MC), the Board and the Assembly. All consultation and approval procedures are followed as described in the Articles of Association and Internal Regulations of ENTSO-E.

EU COLLABORATION

ENTSO-E is responsible for implementing the SET Plan 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 EEGI, which coordinates R&D efforts for electricity grids, and therefore contributes to achieving the objectives of the SET Plan.

GOVERNANCE PROCESSES FOR ENTSO-E R&D ROADMAP

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

- Designing and approving the ENTSO-E R&D Roadmap
- Providing support to the EC during drafting calls for proposal
- Monitoring the achievements of R&D performed through this Roadmap
- Disseminating the results throughout the stakeholder community and facilitating scaling-up, replication and implementation of results by the entire ENTSO-E community

KEY PERFORMANCE INDICATORS

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&D objectives presented in this document will have several benefits. Such benefits will only be fully appraised when the different proposed solutions are in the European Transmission System. It is difficult to summarize the different benefits into a single KPI (key performance indicator).

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

The enabling capability of electrical networks means their capacity to connect renewable electricity generation (sustainability), ensuring enough flexibility for the system operation and serving customers according to affordable electricity pricing (market competitiveness), while keeping 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 & users, both from existing and new generation (e.g. RES) to existing and new demands (e.g. electric vehicles), while combining with the other industrial initiatives to be in line with the SET Plan orientations. They do so not only by ensuring an 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:

"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:

- Implementing massively innovative solutions coming from a set of R&D 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 fulfill environmental constraints

The expected contribution of the future deployed solutions to the above-mentioned improvement goal can be further expanded into a set of specific KPIs defined at cluster level.

	Expected network capacity & flexibility improvement / KPI	Related R&I cluster(s)	Compliance with EU policy goals		
			Sustainability	Market competitiveness	SoS
1	Extended asset life time	Asset management			✔
2	Increased RES / DER hosting capacity	Power technologies Network operation Market designs	✔	✔	✔
3	Reduced energy curtailment of RES / DER	Grid architecture Power technologies Network operation Market designs	✔	✔	✔
4	Increased flexibility from energy players		✔	✔	✔
5	Increased quality of service and supply			✔	✔
6	Improved competitiveness of the electricity market	Market designs		✔	
7	Decreased network congestions	Grid architecture Network operation Market designs Asset management	✔	✔	✔

All the above defined KPIs (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&D 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 industrialization costs of the validated solutions.

The KPI definition is still a work-in-progress with a detailed description and guideline for the calculation methodologies of all the proposed expected KPI values. A full KPI proposal is expected to be ready and published in a separate document in early 2013.

There is no "one size fits all" solution to increase network capacity in Europe: scalable solutions ought to be tuned regionally depending upon regulatory, climate, generation and consumption profiles. The purpose of this roadmap is to provide demonstrated innovative solutions ready for deployment, in order to widen the possible technological options available for the decision-makers.

GLOSSARIES

AC	Alternate Current
ACER	Agency for Cooperation of Energy Regulators
ATC	Available Transfer Capability
BAU	Business as usual scenario
C	Cluster
CACM	Capacity Allocation & Congestion Management
CAPEX	Capital expenditures
CCGT	Combined Cycle Gas Turbine
CEER	Council of European Energy Regulators
CHP	Combine Heat and Power
CMM	Congestion Management Module
DC	Direct Current
DER	Distributed Energy Resources
DFR	Digital fault recording
DG ENER	Directorate General for Energy (European Commission)
DG R&I	Directorate for Research & Innovation (European Commission)
DLR	Dynamic Line Rating
DR	Demand Response
DSM	Demand Side Management
DG	Distributed Generation
DSO(S)	Distribution System Operator(s)
ECE	European Commission for Energy
EDSO-SG	European DSO Association for smart grids
EEGI	European Electricity Grid Initiative =
EER(S)	European Energy Regulator(s)
EII	European Industrial Initiative
EMF	Electro-Magnetic Field
ENTSO-E	the European Association of Transmission System Operators for Electricity
EPRI	Electric Power Research Institute
ESCO	Energy Service Company
EU	European Union
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
FO	Functional Objective
GDP	Gross Domestic Product
GIL	Gas-Insulated Lines
GW	Giga Watt
HMI	Human Machine Interface
HVAC	High Voltage Alternate Current
HVDC	High Voltage Direct Current
ICT	Information Communication Technology
IEA	International Energy Agency
IEM	Internal Electricity Market
IGBT	Insulated-gate bipolar transistor
IPR	Intellectual Property Rights
KPI(S)	Key Performance Indicator(s)
MC	ENTSO-E Market Committee
NC	Network code
NGOS	Non-Governmental Organizations
NRA(S)	National Regulatory Authority(-ies)
OPEX	Operating expenditures
PDC	Power Distribution Center
PMU	Phase-Measurement Units
PST	Phase-Shifting Transformer
PV	Photovoltaic
RDC	ENTSO-E Research and Development Committee
RES	Renewable Energy Source
R&D	Research & Development
RD&D	Research, Development & Demonstration
RTTR	Real Time Thermal Rating
SDC	ENTSO-E System Development Committee
SET PLAN	Strategic Energy Technology Plan
SF6	Sulfur hexafluoride
SOC	ENTSO-E System Operations Committee
SOS	Security of supply
SRA2035	Strategic Research Agenda 2035 (European Technology Platform on Smart Grids)
SUBGRID	Sub-transmission grid (medium voltage grid)
SWOT	Strength / Weaknesses / Opportunities / Threats
T&D EUROPE	European Association of the Electricity Transmission and Distribution Equipment and Services Industry)
THIRD PACKAGE	(Third Internal Energy Market Package) = legislative package for an internal gas and electricity market in the European Union (ownership unbundling)
TSO(S)	Transmission System Operator(s)
TYNDP	Ten Year Network Development Plan
WACS	Wide Area Control Systems
WAMS	Wide Area Monitoring Systems
WAPS	Wide Area Protection Systems

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