# ENTSO-E RD&I APPLICATION REPORT 2016

JUNE 2017

## INNOVATIVE EU PROJECTS WITH REAL-LIFE APPLICATIONS

European Network of
Transmission System Operators
for Electricity

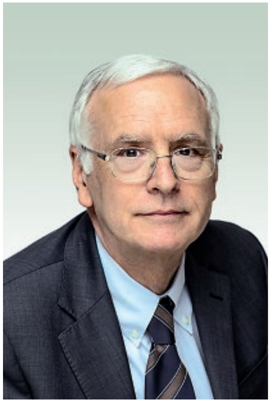
entsoe

# CONTENT

# FOREWORD

## LAURENT SCHMITT, SECRETARY-GENERAL OF ENTSO-E

Transmission systems are the heart of the European electricity system, and the TSOs have a strategic enabling role to play in the transformation of the energy value chain. This can only be done through innovation, readying electric systems to absorb high shares of variable renewables, empowering the customer and enabling the digitalisation of the entire power system. ENTSO-E's RDI activities are all about making the necessary changes while maintaining the security of the supply and facilitating competitive markets. All stages of an RDI activity are important – from building know-how to research, development, piloting and, finally, implementation. At ENTSO-E, we work with our members to support all phases, foster RDI, communicate and exploit impactful results. This Application Report highlights the solutions that the TSOs are developing for a cleaner-energy future.



## CARLO SABELLI, CHAIR OF ENTSO-E'S RESEARCH, DEVELOPMENT & INNOVATION COMMITTEE

Within the Research Development and Innovation Committee at ENTSO-E, we work constantly together with all TSOs to enhance and support innovation for the benefit of the power system, its users and society as a whole. The RDI Roadmap, the Implementation Plans and the Monitoring and Application Reports are some of the highlights and benchmarks in support of the strategic visions of the TSOs. With the new edition of the Application Report, the intention is to show the most remarkable examples of innovation activities carried out by European TSOs within EU-funded projects. This report also assesses the effectiveness of research and innovation activities and adopts a result-driven approach according to ACER opinion. The ENTSO-E Application Report 2016 is a reference document that allows one to measure the success of research and innovation and their practical applications. This is considered an important contribution to shared practices and progress towards common solutions driven by experience.

# PRINCIPLES OF ONGOING INNOVATION FOR TSOs IN EUROPE

**Power transmission systems are the heart of the European electricity system:** Transmission System Operators (TSOs) have a crucial role in the necessary progressive decarbonisation of the electricity sector and the transition to a more sustainable energy system. Decarbonising the power sector can only become a reality if TSOs facilitate this by making transmission systems ready to absorb high shares of variable renewables and ready for digitalisation of the entire power system.

**European TSOs are leading the necessary changes and are creating a modern power system to make the "green transition" a reality.** To that end, Research, Development and Innovation (RD&I) activities are imperative for enabling the necessary changes while maintaining adequate security of supply and system resilience along with facilitating competitive and efficient markets.

RD&I activities are included in the overall efforts of TSOs and range from building know-how to research, development, piloting and, finally, implementation, just as illustrated in Figure 1. It must be mentioned that before reaching a mature product or service, an RD&I dynamic over several years may be required to tackle the complexity of the challenges addressed.

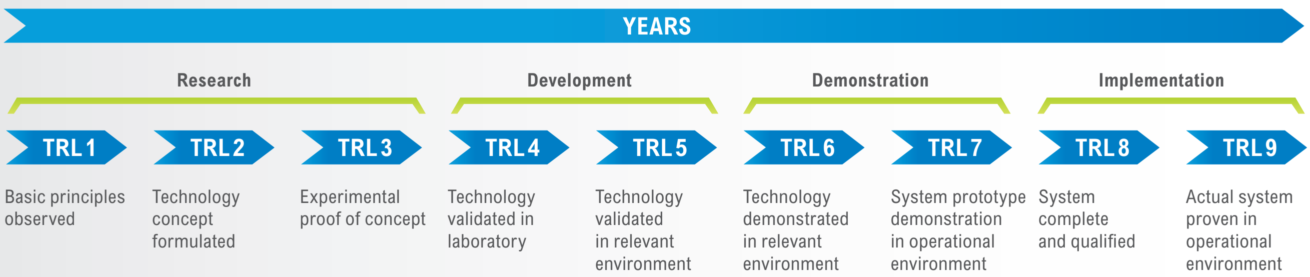



Figure 1: Technology Readiness Levels (TRLs)

Those involved in development do not always benefit from its application. **The innovations developed through RD&I projects will be applied by the TSOs' operational teams – it is at that point the RD&I results are turned into concrete benefits,** as illustrated by Figure 2. The receivers of RD&I results may also be other stakeholders, like, for instance policy makers, power generators, aggregators, consumers, etc. In all cases, involving the beneficiaries of the RD&I project results from the beginning is a critical factor for success. The results of RD&I projects may also nourish new RD&I projects addressing even more complex issues in an evolving environment.

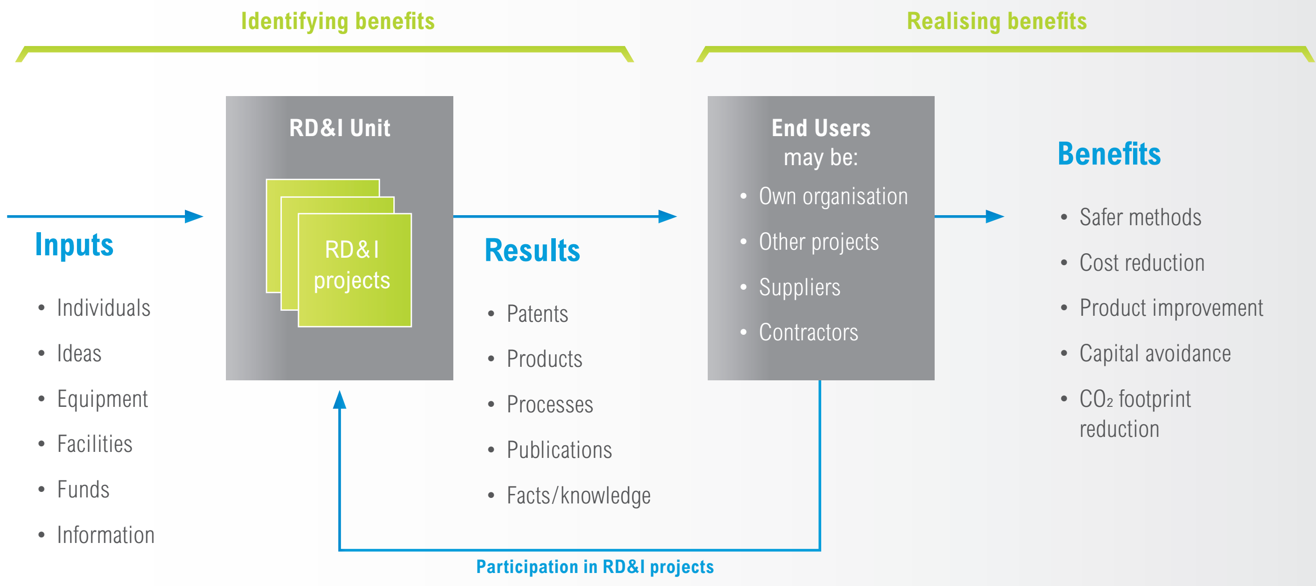



Figure 2: Inputs, outputs and results of RD&I projects;
Figure based on illustration in Mark G. Brown and Raynold A. Svenson, "Measuring RD&I Productivity", Research Technology Management 40 (1998): 30–35 – Adaptation: ENTSO-E.

# APPROACH TO THE RD&I APPLICATION REPORT 2016

**With the present report, there is the intention to show the most remarkable examples of innovation activities carried out by European TSOs.** This report is also a reply to the latest opinion of the Agency for the Cooperation of Energy Regulators (ACER) on ENTSO-E RD&I publications, wherein ENTSO-E was invited to assess the effectiveness of research and innovation activities and adopt a result-driven approach (see Box 1).

**The scope includes projects co-financed by the European Commission (EU projects) in which TSOs have been participating in recent years.** EU projects involving between 10 and 30 partners and lasting three to five years, in general, are normally very complex. They feature a large number of subtasks, each at different TRLs and based on the different partners' backgrounds. The overarching objectives of EU projects have, overall, a long-term perspective, however before reaching that point, a number of intermediate results have to be achieved. Such intermediate results may have independent applications – sometimes before the end of the EU project – and can be applied in TSOs' operational environments ("quick wins"). Regarding the application of major project outcome(s), a consolidation phase – including, for instance, technology qualification, industrialisation, dissemination or change management – may be needed after the end of the project, before the developed technology or methodology is mature enough to be applied in TSOs' operational environments as depicted in Figure 3.

**The aim of the present report is to show concrete examples of results from EU projects which have led to real-life applications.**

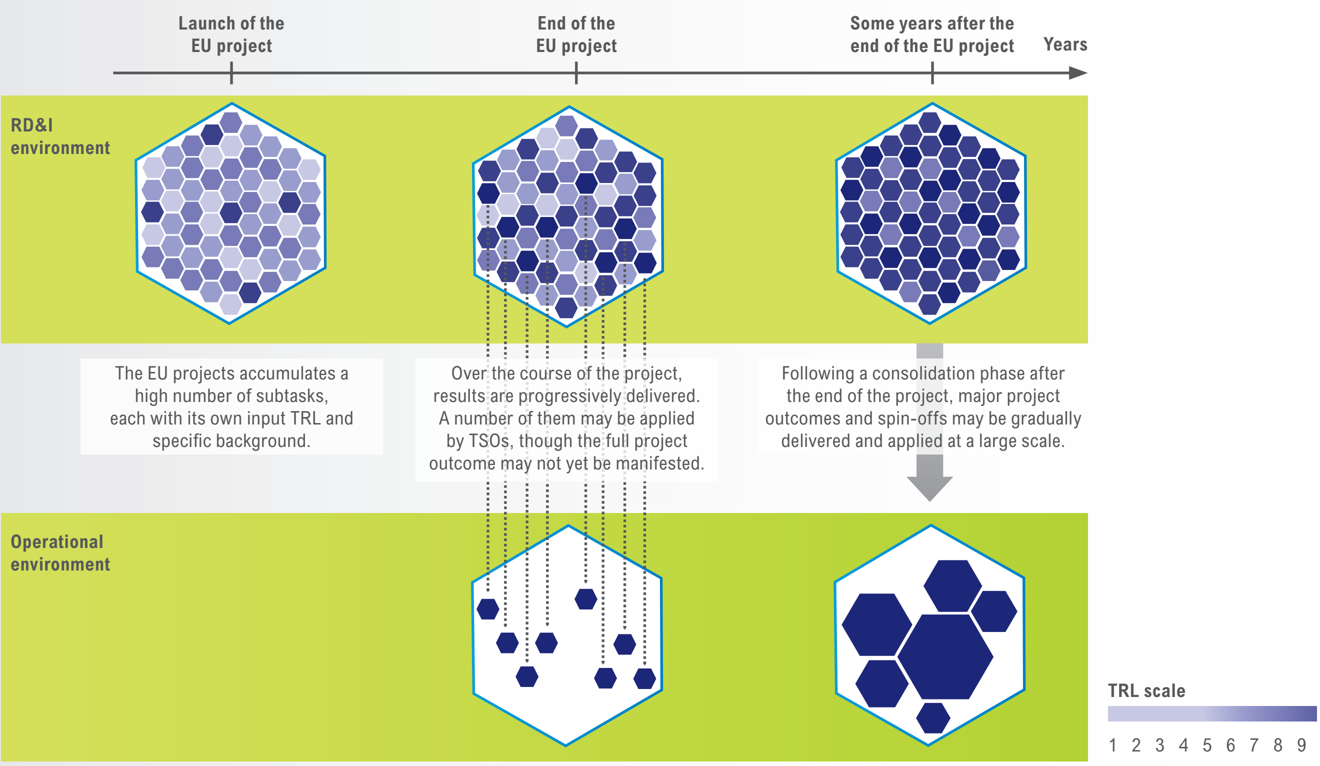



Figure 3: Complexity of EU projects and time to implementation of project outcomes

## Box 1. Background of ENTSO-E RD&I activities

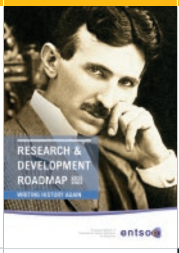
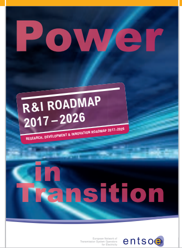
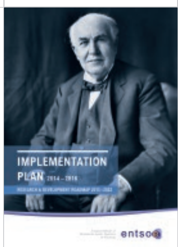
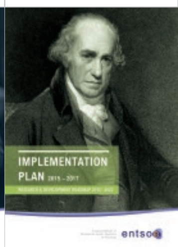
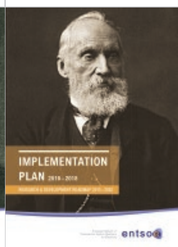
The ENTSO-E RD&I Roadmap outlines the long-term methodology that TSOs are employing for their RD&I policy in response to the EU climate and energy objectives. The most recent roadmap was published in 2016 (ENTSO-E's RD&I Roadmap 2017–2026).

RD&I Implementation Plans derive from the RD&I Roadmap and list the TSOs' RD&I activities over the next three years.

RD&I Monitoring Reports assess RD&I activities in Europe's electricity sector against ENTSO-E's RD&I roadmap. For the RD&I Monitoring Report 2015, extensive interviews were held to identify the deployment potential of RD&I results, and sixteen major findings were determined to be the most promising for short-term deployment by 2020.

Complementing RD&I Monitoring Reports, Application Reports assess the concrete impact of TSOs' EU-funded RDI projects. The present report is the second issue of the Application Report series, following the RD&I Application Report 2014.

ACER usually provides opinions on ENTSO-E Implementation Plans and Roadmaps. Following the recommendations provided by ACER in its Opinion on the ENTSO-E RD&I Roadmap 2017–2026, the present RD&I Application Report 2016 is even more focused on the effectiveness of RD&I and on gauging the benefits of RD&I projects' results.

| ENTSO-E RD&I publications | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Roadmap |  | | | |  | |
| Implementation Plan | |  |  |  | |  |
| Monitoring/ Application Report | | |  |  |  |  |

| Corresponding ACER Opinions | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| | | Opinion on the RD&I roadmap 2013–2022 and Implementation Plan 2014–2016 | Opinion on the RD&I Implementation Plan 2015–2017 | Opinion on the RD&I Implementation Plan 2016–2018 | Opinion on the RD&I Roadmap 2017–2026 | |

# EU PROJECTS CONTRIBUTE TO ADDRESSING THE EU ENERGY SYSTEM'S CHALLENGES

## EU PROJECTS WITHIN THE SCOPE OF THE PRESENT REPORT

**20 EU projects were considered in the present report** as shown in Figure 4, which also features their timelines. A number of these projects were finished several years ago and were also dealt with in the RD&I Application Report 2014. Other projects were completed more recently and in this case, the focus on quick-win applications of intermediate results as the full project outcomes are typically not yet consolidated or ready for deployment. For certain projects, foreseen applications in the very near future were also highlighted. Finally, three projects are still ongoing and have been included in the scope of the present report because a number of the approaches developed are already influencing TSOs in terms of their operational practices.

# THE 20 EU PROJECTS WITHIN THE SCOPE OF THE REPORT AND THEIR TIMELINES

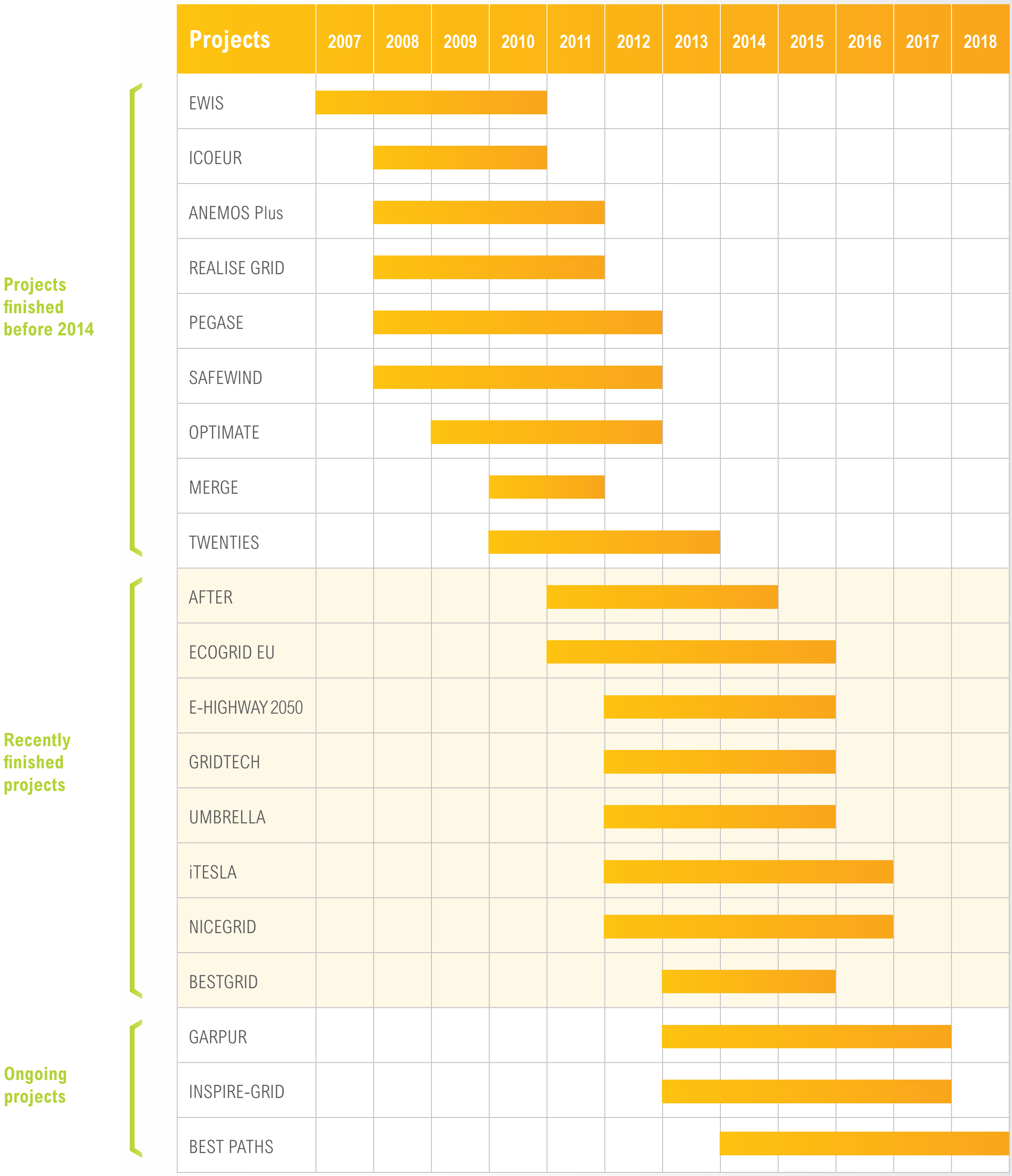



Figure 4: The 20 EU projects within the scope of this report and their timeline

# CHALLENGES FACED BY THE EU POWER SYSTEM

**The current Application Report presents the applications of these EU projects according to the type of challenges they address.** Five main challenges faced by the EU power system are considered here – they have also driven the elaboration of ENTSO-E RD&I Roadmap 2017–2026:

**Cluster 1.**
**Power System Modernisation:** Optimal grid design; smart asset management models and methodologies; enhancement of public awareness and acceptance;

**Cluster 2.**
**Security and System Stability:** Improvement of the observability and controllability of the transmission system; network modelling and dynamic security tools; upgrading of defence and restoration plans; development of new procedures, strategies and models for ancillary services;

**Cluster 3.**
**Power System Flexibility:** Generation of existing and new system flexibility options such as storage solutions, demand response (including the integration of electric vehicles and the modelling of customer behaviour), information and communication technology (ICT) and enhanced renewable energy sources (RES) forecasting techniques, better use of transmission assets;

**Cluster 4.**
**Power System Economics and Efficiency:** Tools and methods to improve the optimisation of energy flows at short-term horizons in the pan-European system; proposals to coordinate investments; and

**Cluster 5.**
**ICT and Digitalisation of the Power System:** "Big data" management; data-mining tools; development of interfaces with neutral and transparent data access; recommendations for standardisation activities and protocols for communications and data exchanges; "Internet of Things" (IoT); cybersecurity.

# APPLICATIONS FROM RD&I PROJECTS AND THEIR BENEFITS

Figure 5 lists the main applications derived from EU projects in different clusters. **It shows that most projects have delivered concrete applications that are being integrated into the TSOs' procedures or activities:**

- **Many project applications are related to the Modernisation of the Power System (Cluster 1):**
  - New scenario setting and planning methodologies integrating energy security, renewables, market developments and consumer engagement;
  - Progress made in facilitating public acceptance of network developments; and
  - Limitations of the costs of network modernisation while maintaining or increasing the system security and efficiency.
- **Security and System Stability (Cluster 2) is an important area of application of RD&I project results:**
  - Standard approaches based on the N-1 concepts no longer being sufficient[1)]
  - Software tools as well as algorithmic and stochastic methods rooted in the concepts of risk and resilience progressively entering TSOs' operational environments,
  - Projects crucial to accelerate the coordination of network operations at the European level.
- **Power System Flexibility (Cluster 3) has only been touched by certain projects,** especially with regards to network flexibility and improving RES forecasts.
- **A number of projects have also contributed to Power System Economics and Efficiency aspects (Cluster 4)** in particular with regards to consumers' and distributed energy resources' participation in power markets. Work is still ongoing pertaining to the modelling of various segments of the electricity markets.
- **No RD&I project has been concentrated on ICT and Digitalisation of the Power System issues so far (Cluster 5);** however, these aspects have been addressed in a transversal manner through different projects presented under the other clusters. For instance, concepts surrounding the IoT and big data management and datamining tools have been addressed by projects dealing with grid analytics; protocols for communications and data exchange are being dealt with by projects focusing on consumer involvement in power markets.

Furthermore, these concrete applications can be categorised according to the type of benefits they bestow as depicted in Figure 2: Safer methods, cost reduction, product improvement, capital avoidance and $CO_2$ footprint reduction. Such categorisation further elaborated upon in Figure 6. In this figure, only one project application is directly connected to "$CO_2$ footprint reduction", however all other RD&I applications also contribute, in a more indirect manner, to this overall benefit.

The most remarkable and recent RD&I applications in TSOs' operational environments are presented in the highlights displayed from pages 17 to 38 of the present report, and they are also summarised in the tables found in Annex 1.

1) According to the (N-1) criterion, the elements remaining in operation within a TSO control area after occurrence of a contingency are capable of accommodating the new operational situation without violating operational security limits.

## 1. POWER SYSTEM MODERNISATION

- Requirements for wind generators in ENTSO-E Network Code resulted from network studies carried out within the **EWIS** project, and were also used as inputs to the Ten-Year Network Development Plan (TYNDP). It has fostered greater integration of wind generation and provided the grounds for harmonisation of network codes across Europe.
- The **MERGE** project served as the basis for network impact assessment for Electrical Vehicle penetration.
- The **REALISEGRID** project supplied the framework to create a harmonised pan-European approach to electricity infrastructure evolution. This approach was employed to evaluate several projects out of the TEN-E Guidelines (2006) and "Priority Interconnection Plan" (2007) and is the starting point for the CBA of the e-Highway2050 project.
- The **e-Highway2050** project delivered a new transmission system long-term scenario and planning tool for the Pan-European Transmission Network (horizon 2020 to 2050). This has granted TSO and academia the opportunity to challenge the local simulations in the context of national strategies, and provided more precise cost-benefit analyses of development options in long-term studies. In parallel, the **GRIDTECH** project assessed the role of innovative grid technologies in network expansion and delivered a toolbox now available to the TSOs.
- Practical tools and guidelines for engaging stakeholders in new transmission projects delivered by the **BEST GRID** project allowed TSOs to review their procedures and organisation, thus leading to shorter time to permitting, reduced opposition to projects and diminished litigation. On the same note, the stakeholders' engagement methods developed by **INSPIRE GRID** are providing similar benefits.
- Thanks to methods and technologies developed within the **BEST PATHS** project, interconnection capacities have been reinforced with limited investment costs. Robots for mounting air-warning markers were also devised to avoid linemen climbing on top of towers, therefore increasing safety for workers.
- The ongoing **GARPUR** project is creating awareness, both at the TSO and policy maker levels, of the advantages of utilising probabilistic reliability management methods.

## 4. POWER SYSTEM ECONOMICS & EFFICIENCY

- The market simulation tool developed by the **OPTIMATE** project as a prototype is being industrialised under the name of PROMETHEUS and will be used to unify several market modelling tools, thus improving the quality of market studies and reducing computation time.
- The **NICE GRID** project provided a real-life assessment of the capabilities of distributed energy resources (storage devices, aggregators, RES producers and consumers) to provide flexibility services to the TSOs (ancillary services, tertiary reserve), which represents useful inputs to prepare the market design of the future.
- The **ECOGRID.EU** project allowed demonstration of the effectiveness of early and continuous implementation of communication initiatives to involve consumers in-electricity markets.

## 5. ICT & DIGITALISATION OF POWER SYSTEM

## 3. POWER SYSTEM FLEXIBILITY

- Methods from the **EWIS** project have led to increasing overhead line transmission capacities and the implementation of operational remedial actions for operational risk assessment, flow control and operational flexibility measures.
- The **ANEMOS.PLUS** project developed probabilistic wind forecast tools allowing TSOs to better quantify the need for additional reserves ensuing from high penetration of wind power.
- On the same note, the methods developed by the **SAFEWIND** project has permitted TSOs to make significant progress in understanding wind generation.

## 2. SECURITY AND SYSTEM STABILITY

- A higher level of power system stability was achieved owing to the application of a new inter-area oscillation analysis tool produced during the **ICOEUR** project. This means that the risk of blackouts at the pan-European level is reduced.
- Significant algorithmic advances in time-domain simulation, nowadays implemented in **EUROSTAG** software and used in operational studies, are based on the results of the **PEGASE** project. Specifically, the permit the reduction of limits and uncertainties associated with dynamic network equivalents, improving performance, flexibility and accuracy of many simulation tools.
- The **TWENTIES** project allowed demonstrating many technologies now broadly implemented in Europe, such as dynamic line rating (DLR), overhead line controllers and real-time thermal rating, live conductor optical systems, HVDC grids and power-flow control devices, to limit the recourse to re-dispatching.
- The software tools for global vulnerability analysis and risk assessment of Power Systems developed by the **AFTER** project will allow identifying measures to increase system resilience, thus enhancing the standard N-1 approach.
- The **UMBRELLA** and **iTESLA** projects demonstrated the need to use the CGMES data format for data exchange in the areas of system development and system operation to allow faster coordination and improved security at the pan-European level.

Figure 5: Main applications of EU project results per cluster

**Safer Methods**

- **ICOEUR:**
  Higher level of power system stability and reduced risk of blackouts
- **UMBRELLA** and **iTESLA**:
  Faster coordination if CGMES data format becomes standard for data exchange;
  iTESLA Open Source license for broad adoption
- **BEST PATHS:** In creased safety for workers

**Cost Reduction**

- **ANEMOS PLUS:**
  Quantification of additional reserve from high penetration of wind power
- **TWENTIES:** Reduction of re-dispatching volumes

**Capital Avoidance**

- **E-HIGHWAY2050:**
  More precise cost-benefits analyses of development options
- **GRIDTECH:**
  More precise cost/benefits analyses, covering a range of transmission and non-transmission technologies
- **GARPUR:**
  Create awareness of advantages of use of probabilistic methods for reliability management
- **BEST PATHS:**
  Reinforcement of network capacities with limited investment costs

**Product Improvement**

- **EWIS:**
  Harmonisation of network codes across Europe
- **REALISEGRID:**
  Increased knowledge of the electricity sector beyond planning aspects
- **PEGASE:**
  Reduction of limits and uncertainties, improving performance, flexibility and accuracy of many simulation tools; training and new skill development
- **SAFEWIND:**
  New forecasting methods for wind generation
- **OPTIMATE:**
  Diminished amount of time required to study market evolutions; improved quality of market studies
- **AFTER:**
  Identification of measures to increase system resilience
- **ECOGRID EU:** Involvement of consumers in power markets
- **NICE GRID:** Assessment of distributed resource involvement in system service provision to prepare the market design of the future
- **BEST GRID, INSPIREGRID:**
  Shorter time to permitting, reduced opposition to projects and diminished litigation

**$CO_2$ Footprint Reduction**

- **EWIS:** Greater integration of wind generation and consequent decrease of emissions

Figure 6: Classification of benefits following the applications of RD&I results

# CONCLUSIONS AND FUTURE WORK

TSOs are actively and jointly participating in RD&I activities at the EU level, and this is in addition to their internal RD&I activities and respective involvement in many other RD&I projects at the national or cross-border level not reported here. The EU projects presented herein gather in total 30 TSOs from Europe and neighbouring countries and shows how efficient and effective the inter-TSO cooperation has become over the last number of years.

Such intensive and cooperative RD&I activities are vital to meeting the objectives of the energy transition. RD&I is also a pillar of the Energy Union strategy and will foster the implementation of new technologies as well as economic growth, resulting in job creation. The present RD&I Application Report 2016, supplemented by the existing ENTSO-E's RD&I Monitoring Report 2015, help specify in the most effective way the RD&I needs of the future based upon an objective assessment of past RD&I activities in order to tackle the challenges of the energy transition. TSOs' RD&I activities for the next 10 years are detailed in the ENTSO-E's RD&I Roadmap 2017–2026, and the main achievements of the previous ENTSO-E RD&I Roadmap (covering the years 2013 to 2022) and the main areas of future RD&I are briefly presented in Annex 2 of the current report.

With this RD&I Application Report 2016, it is demonstrated that RD&I activities do have concrete impacts and benefits on the power system. The report features the most remarkable examples of project result applications and their respective benefits. **In parallel to these concrete applications, the considerable knowledge acquired by TSOs and their partners, as well as the ever-increasing inter-TSO cooperation at the pan-European level, are very important indirect benefits even though at times, they are non-measurable at the end of projects.**

ENTSO-E encourages TSO partners in EU projects to systematically prepare and evaluate the effective exploitation of projects results for real-life applications. For instance, in order to maximise the value added and impact of RD&I projects, the Support Services for Exploitation of Research Results (SSERR) of the European Commission (DG for Research and Innovation) or the support of specialised independent experts might be harnessed in ongoing EU projects.

A new framework was created in 2016 for RD&I activities related to energy networks to support the implementation of the SET Plan – the European Technology and Innovation Platform for the Smart Networks for Energy Transition (ETIP SNET). TSOs, of course, have a leading role within this platform together with distribution system operators (DSOs), non-regulated players (generators, storage operators, ICT providers, manufacturers, etc.) and Member States. Within this new framework, a working group, "Innovation Implementation in the Business Environment", has been created to facilitate further transfer of knowledge and utility of research findings, hence leveraging the approach adopted by TSOs with the present report.

# HIGHLIGHTS: MOST REMARKABLE RD&I APPLICATIONS IN TSO OPERATIONAL ENVIRONMENTS

In the following, a number of the main applications of EU-funded projects carried out by TSOs are reported based on interviews with TSO representatives.

**IMPORTANT NOTICE! Project objectives and results are frequently broader than what is illustrated here and only specific applications were extracted out of the wider set of results.**

# CLUSTER 1. POWER SYSTEM MODERNISATION

## NEW SCENARIOS AND PLANNING TOOLS FOR TRANSMISSION NETWORK DEVELOPMENT: RESULTS FROM THE E-HIGHWAY2050 PROJECT

PROJECT FICHE

**e-Highway2050 Project | Project ran from 2012 to 2015 | www.e-highway2050.eu**

| | | | |
|---|---|---|---|
| | The **e-Highway2050 project** aimed at setting up and validating new approaches to the planning of Pan-European Transmission Network, capable of meeting European needs between 2020 and 2050. Starting from the pan-European grid in 2020, a modular approach leading to a portfolio of expansion plans using different optimisation options were proposed to cover the entire time frame 2020–2050. | | |
| **Project coordinator:** | RTE | | |
| **TSOs involved:** | RTE (FR), Amprion (DE), REN (PT), Elia (BE), ČEPS (CZ), Swissgrid (CH), Terna (IT), 50Hertz (DE), APG (AT), Energinet.dk (DK), IPTO (GR), REE (ES) and SVENSKA KRAFTNÄT (SE). | | |
| **Total budget:** | 13 M€ | **EC contribution:** | 9 M€ |

RTE has developed a new transmission system long-term scenario and planning tool and is already using it in new studies. The tool seeks to optimise the energy system, as seen from the transmission operator's perspective, with no control over generation planning; several possible evolutions of the electricity sector are investigated for different energy scenarios. The tool breaks from conventional approaches because it takes more carefully into consideration the influence of the transmission network characteristics and constraints (overloads and congestions) with respect to other long-term planning methods. In particular, this approach enables the carrying out of more precise cost-benefit analyses of development options.

Furthermore, a series of five different European energy scenarios are implemented and studied using the developed methodologies, identifying the network configurations (and the network reinforcements) deemed necessary to facilitate a safe and profitable grid operation by 2050. These scenarios and the related databases (boundary conditions, evolution of generation mixes and loads) are used by TSOs (RTE, energinet.dk) and academia to challenge the local simulations performed within the context of national strategies. Based on e-Highway2050 scenarios, exchanges are also ongoing between AMPRION and environmental non-governmental organisations (NGOs) within the framework of the Renewable Grid Initiative (RGI).

Finally, it is worth mentioning that a database of the performance and cost of generation, transmission, distribution and storage technologies as foreseen in horizons 2030 and 2050 was developed and is available publicly.

### See e-Highway2050 videos at https://www.youtube.com/user/eHighway2050!

- The e-Highway2050 concept
- Interview of Gérald Sanchis, RTE, eHighway2050, Project Coordinator
- Interview of Giles Dickson, WindEurope ( formerly EWEA), CEO
- Interview of Raul Giles, Europacable Utilities Board, Chairman

### Consult the technology performance and cost database at

- www.gridinnovation-on-line.eu/Technology-Database

## PUBLIC PARTICIPATION AND TRANSPARENCY IN POWER GRID PLANNING: RESULTS FROM THE BESTGRID PROJECT

PROJECT FICHE

**BESTGRID Project | Project ran from 2013 to 2015 | www.bestgrid.eu**

| | |
|---|---|
| BEST GRID testing better practices | The **BESTGRID Project** had the following overarching objectives: To improve local public acceptance for grids by applying best practices in participation and transparency in pilot projects, to speed up permitting procedures while respecting environmental protection standards in pilot projects and to support implementation of best practices in future electricity grid "Projects of Common Interest". The methodological activity developed was summarised in two handbooks, the first on grid development and nature protection and the second on transparency and participation. The approach was validated with partners on four real projects in Belgium, Germany, the Netherlands and UK. |
| **Project coordinator:** | Renewables Grid Initiative (RGI) |
| **TSOs involved:** | 50Hertz (DE), Elia (BE), National Grid (UK), TenneT (NL), Terna (IT) |
| **Total budget:** | 1.95 M€ **EC contribution:** 1.46 M€ |

Both 50Hertz (DE) and TenneT (NL) continue to use stakeholder engagement methods that have been developed and tested within the framework of the BESTGRID project.

50Hertz regularly visits municipalities with a mini-van – the mobile citizen office – to inform communities about ongoing and future projects. The information offered by the van has been adjusted on the basis of insights generated via BESTGRID. TenneT employs another approach founded upon knowledge acquired from BESTGRID – the "infomarket" format, suitable for larger audiences.

Both 50Hertz and TenneT have adjusted their internal organisational procedures to ensure that stakeholder

engagement is integrated into all relevant phases of any grid development project. Following BESTGRID, 50Hertz has also modified its public participation team and portfolio of participative tools and methods to secure this.

Along the same lines and inspired by BESTGRID, Elia is reviewing internal processes for stakeholder engagement. A Public Acceptance Officer has joined the Executive Committee and a dedicated division for public acceptance has been set up to assure the interests of society are taken into account companywide.

Terna, which was not directly running pilot project activities within the framework of BESTGRID, has adopted the "info-market" format as a tool for stakeholder engagement and now utilises it on a regular basis.

Finally, collaboration between TSOs and NGOs on concrete matters of nature protection has been orchestrated during the BESTGRID project. The cooperation undertaken during the project was considered positive and worthy of being continued by all participants. As of January 2017, RGI is once again coordinating the setup of concrete on-the-ground NGO-TSO collaboration, starting with joint projects between TenneT, 50Hertz and NABU (the German branch of BirdLife) and Germanwatch. Several other RGI members (both TSOs and NGOs) have signalled their intent to participate in similar TSO-NGO cooperative projects with RGI assuming a coordinating role.


## STAKEHOLDER ENGAGEMENT IN THE DEVELOPMENT OF FUTURE ELECTRICITY GRIDS: RESULTS FROM THE INSPIREGRID PROJECT

PROJECT FICHE

**INSPIRE-Grid | Project running from 2013 to 2017 | www.inspire-grid.eu**

**INSPIRE-Grid** stands for "Improved and eNhanced Stakeholder Participation In Reinforcement of the Electricity Grid". With 10 partners from six different countries, INSPIRE-Grid aims to increase stakeholder engagement in grid expansion projects, better manage conflicts and speed up the permitting process. By way of an interdisciplinary approach, INSPIRE-Grid will develop stakeholder-led processes and design an expert-led European good practice guide.

Methods to facilitate decision making will be newly combined with engagement tools and tested with stakeholders from existing or concluded grid development project case studies. The main outcomes of the project are customised tools, a handbook and a set of recommendations summarised into three policy briefs.

| | | | |
|---|---|---|---|
| **Project coordinator:** | RSE (IT) | | |
| **TSOs involved:** | RTE (FR), Statnett (NO), National Grid (UK) | | |
| **Total budget:** | 3.4 M€ | **EC contribution:** | 2.6 M€ |

Statnett (NO), National Grid (UK) and RTE (FR) are improving their concept of stakeholder engagement in transmission development projects owing to the guidelines developed during the INSPIREgrid project; a particular effort is now devoted to building general competence of the power grid in society and involving stakeholders as early and broadly as possible. Based on the tools developed, transmission project leaders are trained on how to involve and interact with stakeholders during all grid development projects, placing emphasis on the importance of personal trust between the project bearer and individuals in society participants.

The project has been set up and validated in real or simulated cases for four main products:

- A participative web geographic information system (GIS) to support the involvement of the populace in the decision-making process, enhancing their participation and enabling communication of power line route alternatives and expressing opinions on alternatives or effects;
- A formalised multi criteria analysis (MCA) method to reach synthetic conclusions regarding the choices among alternatives and considering conflicting criteria measured in different units;
- A consequential life cycle assessment (LCA) to evaluate and communicate the global impacts of future power lines to explain the need for grid extensions; and
- Guidelines for project developers on the most effective ways to involve local communities in network development projects.

## RELIABILITY 2.0: NEW APPROACH DEVELOPED WITH THE GARPUR PROJECT

PROJECT FICHE

**GARPUR project | Project running from 2013 to 2017 | www.garpur-project.eu**

The **GARPUR project** is developing a new reliability management approach and criteria (RMAC) for the pan-European electric power system. The methodology considers the spatial-temporal variation of the probabilities of exogenous threats (for instance, those related to natural hazards), the socio-economic impact of TSO decisions as well as corrective control measures and probability of failure. It covers the multiple decision-making contexts and timescales (long-term planning, mid-term and asset management, short-term planning to real-time operation).

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| **Project coordinator:** | SINTEF | | |
| **TSOs involved:** | Statnett (NO), Elia (BE), RTE (FR), Landsnet (IS), ESO (BG), ČEPS (CZ), Energinet.dk (DK) | | |
| **Total budget:** | 10.9 M€ | **EC contribution:** | 7.8 M€ |

The novel approach of decision making based on probabilistic assessment of risks is being tested at Stattnet (NO) and other TSOs in view of future applications.

With the project ongoing, the knowledge developed has not yet entered into the standard practice of TSOs, but is being considered for adoption at Statnett with special reference to the evidence that probabilistic methods lead to economic gains, especially with regards to grid investment. Development of an optimal maintenance strategy based on the state of the art to determine the condition and the related failure probability of components in the grid is also being considered based on the proposed GARPUR method.

## FOCUS ON BEST PATHS: AN ONGOING PROJECT WITH SEVERAL PRACTICAL IMPLICATIONS

PROJECT FICHE

**BEST PATHS Project | Project running from 2014 to 2018 | www.bestpaths-project.eu**

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| Best Paths TRANSMISSION FOR SUSTAINABILITY | The **BEST PATHS project** has the objective of overcoming the challenges of integrating renewable energies into Europe's energy mix by developing novel network technologies to increase pan-European transmission network capacity and electricity system flexibility. |
| **Project coordinator:** | Red Eléctrica de España (REE) |
| **TSOs involved:** | REE (ES), Energinet.dk (DK), ELIA (BE), 50Hertz (DE), MAVIR (HU), Terna (IT), Statnett (NO), RTE (FR). |
| **Total budget:** | 62.8 M€ **EC contribution:** 35.5 M€ |

### 1. Increasing the transport capacity of an overhead electrical system

How can one increase the capacity of the electrical system on the coast of Belgium to integrate large offshore wind farms and enhance the interconnection capacity while strictly limiting environmental and visual impact? The solution was found thanks to the results of the BEST PATHS project. Two types of innovative high-temperature, low-sag (HTLS) conductors installed for the first time in Belgium were used for refurbishment of an existing 380 kV line. Furthermore, for upgrading of an existing 150 kV overhead line route to a 380-kV level, this line was partially equipped with new insulating cross-arms to reduce the right of way and environmental footprint, thereby ensuring the greatest level of reliability. Based on the applied classical four bundle 707 AAAC-2Z conductors, the resulting compact 380 kV line exhibited a 10-fold larger transport capacity compared to the existing 150 kV line, which will be dismantled. The STEVIN project of ELIA stretches from Zomergem to Zeebrugge on the coast and leverages the project results both on the new 380 kV line and for the refurbishment of the 150 kV line. Different ELIA group experts have been involved in the BEST PATHS project in order to realise HTLS technology as well as the application of insulated cross-arms as innovative technologies for use in the STEVIN project. Prior to the installation, ELIA outlined specification and installation procedures, organised specific testing protocols, evaluated the electromagnetic field impact of possible configurations and held training programmes for its personnel and contractors, including practical installation simulations in the laboratories.

Example of the tower for the compact 380kV overhead line equipped with insulated cross-arms based on composite insulators (left) in parallel with the existing 150kV line (right)

### 2. Robots for mounting air-warning markers will increase safety for workers

Replacing air-warning markers on a 420kV overhead line without using manned-line baskets was made possible because of the implications of the results of the BEST PATHS project. A special robot was constructed that can automatically clamp markers on the ground wire. The clamping robot was carried in position using a helicopter and the procedures for the live-line operation were completely set up and validated from the theoretical design, to the laboratory testing and, finally, real-world application. Using this robot allowed Statnett to avoid linemen climbing on top of towers and hanging on conductors, hence enhancing their safety and diminishing marker installation time.

### See the video on the Best Paths project:

» http://www.bestpaths-project.eu/en/news/best-paths-video-released

## PRIORITISING NETWORK REINFORCEMENT PROJECTS FOR A SEAMLESS INTEGRATION OF WIND GENERATION: RESULTS FROM THE EWIS PROJECT

PROJECT FICHE

**EWIS Project | Project ran from 2007 to 2014 | www.wind-integration.eu**

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| ewis | The overarching scope of the **EWIS project** (European Wind Integration Study) was to assess short-term network issues arising from wind generation in the period between 2007 and 2015 while preparing the ground work for future plans up to 2020 and providing concrete recommendations. The EWIS project objective was also to quantify and clearly demonstrate the costs related to inaction. |
| **Project coordinator:** | ELIA (BE) |
| **TSOs involved:** | Elia (BE), TenneT DE (DE), 50Hertz (DE), Amprion (DE), ČEPS (CZ), EirGrid (IE), Energinet.dk (DK), IPTO (GR), National Grid (GB), PSE S.A. (PL), REE (ES), REN (PT), RTE (FR), TenneT NL (NL), APG (AT) |
| **Total budget:** | 4 M€ **EC contribution:** 4 M€ |

The results of this project influenced the TYNDP of ENTSO-E. Using the pan-European market and network models developed in the project, the mutual influence of market and network access rules for a seamless integration of wind generators was revealed. The guidelines to prioritise the reinforcement of network pinch-points and to identify beneficial additional measures to those already determined in national plans ( for example, as part of the ongoing regional initiatives) were also employed to build up the German Grid Development Plan process. Since 2012, this approach has been used in Germany to establish grid reinforcement measures for the "Netzentwicklungsplan Strom" in order to evaluate market-based year-round load flow and network contingency and re-dispatch calculations. From the project was generated a year-round market analysis (necessary to represent the effects of wind on a pan-European basis) coupled with detailed representations of the networks (necessary to comprehensively address network performance limitations and ensure reliability and economy).

## ASSESSING THE ROLE OF INNOVATIVE GRID TECHNOLOGIES IN NETWORK EXPANSION: RESULTS FROM THE GRIDTECH PROJECT

PROJECT FICHE

**GridTech Project | Project ran from 2007 to 2014 | www.gridtech.eu**

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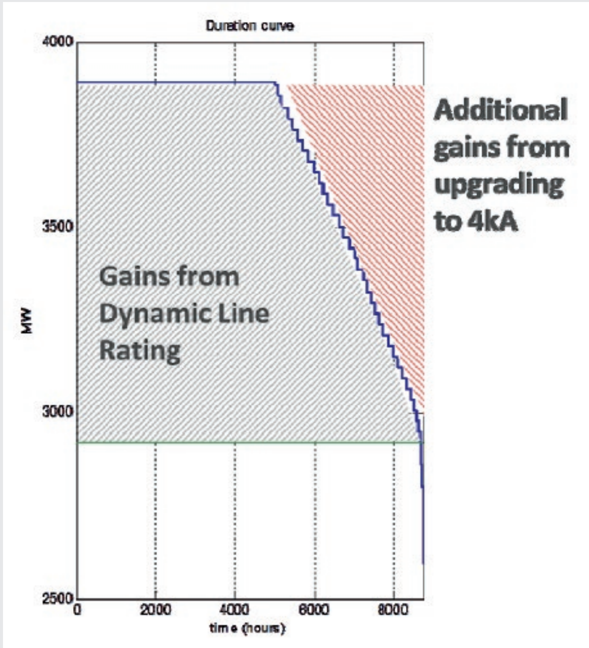
| GridTECH.EU | The main goal of the **GridTech project** is to perform a fully integrated assessment of new grid-impacting technologies and their implementation into the European electricity system. This allows comparing different technological options with the exploitation of the full potential of future electricity production from RES with the lowest possible total electricity system cost. | | |
| **Project coordinator:** | TU WIEN/EEG | | |
| **TSOs involved:** | EirGrid (EI), ESO (BG), TenneT (NL), Terna (IT) | | |
| **Total budget:** | 2 M€ | **EC contribution:** | 1.5 M€ |

What are the potential benefits of using innovative grid technologies, such as HVDC, DLR, storage or demand-response in the expansion of transmission networks? GridTech has carried out a series of cost and benefits assessments with time horizons of 2020, 2030 and 2050, combining a top-down pan-European with a bottom-up target-region scenario analysis.

EirGrid applies the expansion planning toolbox developed in the All-Ireland case studies. The adopted toolbox is able to conduct optimisation studies for automatic transmission-expansion planning while also including in the model the effects of innovative technologies. The toolbox is now fully available and utilised by EirGrid for specific, dedicated system expansion-planning processes related to the united application of transmission and non-transmission (storage, demand side management (DSM)/demand response (DR), electric vehicles, etc.) technologies.

The regional studies performed within the GridTech project by ESO (BG), Terna (IT) and TenneT (NL) have been cited for their evaluation of the impact of new technologies in the long-term (2030–2050), setting key milestones in national transmission-development plans.




Dutch case – Gains from Dynamic Line rating and gains from upgrading to 4 kA

In the Dutch network, the transport of large amounts of offshore-generated wind power via the onshore transmission network has been studied by GridTech. To foster the increased wind production, the transport capacity of the onshore network has to be elevated. The GridTech 2020 case is now being realised in the Netherlands by upgrade of the TenneT 380 kV ring to 4 kA, temporarily preceded by the application of DLR during reconstruction. Application of DLR has indeed been determined by GridTech as very promising and cost-effective for 2020. In the given cases, there is a strong relationship between large amounts of wind power and the cooling of the overhead lines by wind. Furthermore, it is also a realistic option to upgrade the capacity of overhead lines within a limited timeframe. For 2020, the upgrade to 4 kA along with HTLS conductors of existing overhead lines to increase the capacity of the network has been positively evaluated by GridTech. This method of enlarging capacity is often possible without extensive licensing procedures. This makes it very attractive for a rapid increase in transport capacity. It also offers an additional benefit for the 2020 case compared to DLR.

Furthermore, ESO has taken full stock of the GridTech regional case study, including the analyses related to the application of DSM/DR, storage (Pumped Heat Electrical Storage, PHES) and DLR in the Bulgarian national transmission development plan.

**See the video on the GridTech project:**

» https://youtu.be/4MOX1JQ6Ynk

# CLUSTER 2. SECURITY AND SYSTEM STABILITY

## TOWARDS A REFERENCE, OPEN-SOURCE PLATFORM FOR GRID ANALYSIS IN EUROPE: RESULTS FROM THE iTESLA PROJECT

PROJECT FICHE

**iTESLA Project | Project ran from 2012 to 2016 | www.itesla-project.eu**

The **iTesla project** sought to improve network operations with a new security assessment tool able to cope with increasingly uncertain operating conditions and take advantage of the growing flexibility of the grid.

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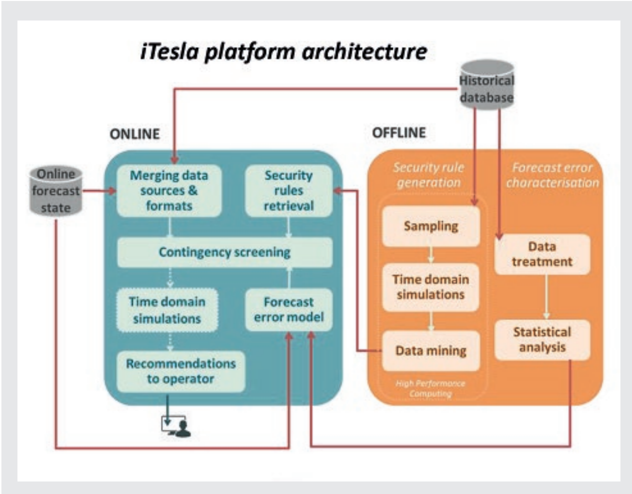
| **Project coordinator:** | RTE | | |
| **TSOs involved:** | RTE (FR), ELIA (BE), National Grid (GB), REN (PT), Statnett (NO), IPTO (GR). | | |
| **Total budget:** | 19.4 M€ | **EC contribution:** | 13.2 M€ |

In 2016, the iTesla project delivered an open-source platform interfacing different modules (for time-domain simulation of power system dynamic behaviour or security analysis) and providing common services, such as data conversion, dynamic data management, data sampling and data mining.

*"Having several TSOs on board the project for the genesis of the platform makes us think that it will be widely adopted by TSOs for grid analysis in Europe"*, says Nicolas Omont, responsible for the interpretation of the iTesla results at RTE. Furthermore, having *"the platform available under an open-source licence will allow its adoption beyond the iTesla consortium"*, adds Omont.




iTesla platform architecture

The platform is intended to facilitate data exchange between TSOs and interoperability between software vendors. However, for such a platform to be efficiently used and shared by several TSOs in Europe, a serious obstacle has to be eliminated – a common data format must be adopted. That is why iTesla has recommended (jointly with the UMBRELLA project) that European TSOs should exchange stationary data of their respective systems in CGMES format[1] as

[1] The Common Grid Model Exchange Standard (CGMES) is a superset of the IEC Common Information Model (CIM) standard. It was developed to meet the necessary requirements for TSO data exchange in the areas of system development and system operation. For more information, visit https://www.entsoe.eu/major-projects/common-information-model-cim/cim-for-grid-models-exchange/standards/Pages/default.aspx.

soon as possible. Identifiers of network elements should be unique and persistent across the datasets in order to be able to perform an advanced security assessment.

Actually, European TSOs should use persistent identifiers for equipment to match them with additional data automatically (e. g., dynamic data) and allow in-depth inclusion of forecast uncertainty in the security analysis process, a significant requirement for the integration of a large share of renewable energy. The incorporation of the additional information, like remedial actions, should be considered in the further development of CGMES. Moreover, a common understanding and as best as possible a harmonisation regarding the detail of grid modelling should be sought by the TSOs.

These recommendations are echoed in the Clean Energy Package proposal published by the European Commission in November 2016[2], in which it is foreseen that *"regional operational centres (ROCs) shall set up efficient processes for the creation of a common system model for each operational planning timeframe"* and that *"common system models shall include relevant data for efficient operational planning and capacity calculation"*.

From that perspective, the iTesla project was successful in the form of having the regional centre CORESO on board – the CORESO will be one of the first users of the CGMES data format. Whatever the split of responsibilities is between TSOs and ROCs, the recommendations of the iTesla project will have to be implemented to optimise cross-border flows and support RES integration in an efficient and safe manner.


iTesla Use Cases

2) More information available at https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition.

## CONTROLLING THE POWER FLOW TO ENSURE SYSTEM SECURITY: RESULTS FROM THE UMBRELLA PROJECT

PROJECT FICHE

**UMBRELLA Project | Project ran from 2012 to 2015 | www.e-umbrella.eu**

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| Umbrella Project | The **UMBRELLA project** had the goal of providing a toolbox prototype for TSOs to ensure secure grid operation in future electricity networks with high penetration of intermittent renewables. |
| **Project coordinator:** | Amprion, TransnetBW (DE), ČEPS (CZ), ELES (SI), PSE (PL), Swissgrid (CH), TenneT TSO BV (NL), APG (AT) |
| **TSOs involved:** | EirGrid (EI), ESO (BG), TenneT (NL), Terna (IT) |
| **Total budget:** | 5 M€ **EC contribution:** 3.9 M€ |

Maintaining a constant equilibrium within the pan-European transmission system is a very delicate operation. The contribution of UMBRELLA to this challenge is via a tool capable of determining the remedial actions during contingency situations to maintain system security at minimal costs considering also the solutions able to set the power flows in the transmission lines (e.g., HVDC and phase shifting transformers (PST)). This optimisation tool was implemented in Germany and has been employed to account for the future optimised operation of HVDC links.

## A NEW HOLISTIC APPROACH TO SYSTEM RESILIENCY: THE AFTER PROJECT

PROJECT FICHE

**AFTER Project | Project ran from 2011 to 2014 | www.after-project.eu**

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| | **AFTER** was aimed at enhancing TSO capabilities for creating, monitoring and managing secure interconnected electrical power system infrastructures, being able to survive major failures and to efficiently restore service supply after major disruptions. | | |
| **Project coordinator:** | RSE | | |
| **TSOs involved:** | ELIA (BE), TERNA (IT), ČEPS (CZ) | | |
| **Total budget:** | 5 M€ | **EC contribution:** | 3.5 M€ |

Although not yet applied to system operation, the approach proposed by this project is worth mentioning regarding the need to supplement the standard N-1 approach. The project developed a risk assessment tool that allows identifying the set of the most dangerous operation conditions in light of the threats affecting the power system, such weather/environmental events (ice and snow storms, pollution, lightning, earthquakes, earthquake-induced landslides, floods, fires, tree contact and component aging) and human-related events (e.g., sabotage). The system identifies the "critical" components which are more prone to fail in the specific threat scenario and evaluates the operational risk considering the "domino" effect of multiple consequent contingencies.

# TECHNOLOGIES AND BUSINESS MODELS TO INTEGRATE LARGE-SCALE RENEWABLE ENERGY SOURCES: RESULTS FROM THE TWENTIES PROJECT

PROJECT FICHE

## TWENTIES Project | Project ran from 2010 to 2013

The **TWENTIES project** looked into how to operate electricity grid systems with large amounts of wind and other renewables. All technologies essential for the seamless integration of large renewable generators were tested, with particular focus on the capability of large wind farms to provide advanced active and reactive regulation services, the technical and economic feasibility of VPP concepts, design and operation of the main building blocks for an HVDC meshed grid and novel solutions for increasing current operational limits, such as DLR tools and power flow controllers.

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|---|---|---|---|
| **Project coordinator:** | Red Electrica de Espana (REE) | | |
| **TSOs involved:** | Elia (BE), Energinet.dk (DK), RTE (FR), 50Hertz (DE), TenneT BV (NL) and REE (ES) | | |
| **Total budget:** | 56.7 M€ | **EC contribution:** | 31.7 M€ |

During the TWENTIES project and thereafter, several TSOs successfully experimented with different DLR systems, mostly based on the use of an optic fibre incorporated into the overhead power line conductor providing real-time information on the conductor's temperature along with the complete length of the line. These data, complemented by weather information coming from meteorological stations along the line as well as historical data, can be used to calculate the real thermal limits (DLR) of the lines with greater accuracy. Elia has equipped all its cross-border lines with DLR and is installing the technology on critical lines of its EHV grid. The DLR system adopted uses a two-day ahead approach and the Ampacimon monitoring devices.


Installation of optic fibres in the REE network

Similar systems are being employed by RTE, for maximising the integration of wind generation, and by TERNA, NCG, 50Hertz, REE and RTE at different system levels for congestion management. In most cases, the DLR is 10 % higher than the conventional seasonal rating value during the day. On days with major wind generation in this area, it can be 25 % higher throughout the course of the day.

Optic fibres are normally incorporated into the ground wire of overhead lines and utilised as an information transmission tool for the purpose of automation, monitoring, control and general civil communication. When the ground wire is not present, however, optic fibres may need to be installed integrated into live conductors. Leveraging the necessity to develop a live conductor optical system based on distributed temperature sensors to monitor the thermal profile of a line and evaluate the line sag, a similar technology was applied by REE in the Canarian system on 66 kV overhead lines. The system is employed as a conventional telecommunication physical channel and has no ampacity applications.

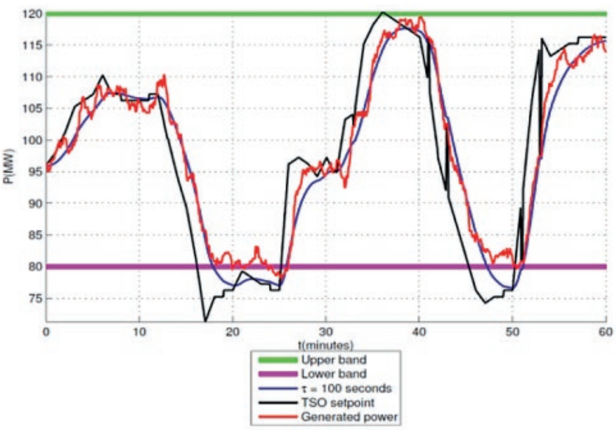
A power flow control device, based on the regulation of the impedance of an overhead line, designed and implemented by ABB and REE is now in operation in the Magallón SS. According to a recent study, this has led to a 23 % decrease in topological manoeuvres, eliminating re-dispatching of more than 550 GWh/year, close to 4.5 % of the total energy re-dispatched in Spain. According to the replicability studies, the economic benefits estimated from the deployment of these systems could reach 1.5 M€/year.

During the TWENTIES project, Iberdrola and Gamesa developed new algorithms, both for the wind turbines and upper-level controls, that proved wind farms could provide voltage control at the transmission level in a coordinated way, and also demonstrated that wind generators can be aggregated to participate in the secondary frequency control service, demonstrating to the TSO they can reliably change their active power output to any point inside the regulation band. Although nowadays, wind generators are consented to take part in this service in Spain, Iberdrola has not yet implemented this feature within their wind farms because of regulatory issues forbidding offering upwards and downwards reserve separately. The TWENTIES project has demonstrated that, because of the forecasting error, a large amount of power would have to be curtailed based on the standing present market rules.

In countries like the USA or UK, to provide secondary frequency control services by wind farms is possible, but even though the regulations are less demanding, market conditions are not yet suitable and Iberdrola's wind farms have to date not taken part in these markets.

Since the end of TWENTIES project, several wind farm operators in Spain have been qualified for and are participating in balancing markets. The capability of this technology to provide balancing services under similar conditions to conventional power plants has been definitively assessed.

A virtual power plant (VPP) is a system that integrates several types of power sources, (such as microCHP, wind turbines, small hydro, photovoltaics, back-up generator sets and batteries) so as to yield a reliable overall power supply. Based on the results of the TWENTIES project, Dong Energy (DK) in collaboration with Energinet.dk, Frauenhofer IWES and REE created Power Hub (https://www.powerhub.dk). This initiative helps energy consumers and producers optimise their economies by enabling them to increase revenues from generation, reduce costs of consumption and generate income from helping balance the energy system. Power Hub can control energy consumption in a way that satisfies the purposes of consumption (e.g., industrial sites, fish farms, pumping water or cooling office buildings) while also considering energy prices and the availability of clean renewable energy. The system has also been implemented in the Faroe Islands since the end of 2012 to recreate the energy balance of an isolated power system by decoupling large industrial units automatically, in less than a second, from the main power system and thereby avoid systemic blackouts.




Frequency control test results

A new controller was developed by Siemens in collaboration with Energinet.dk, DONG Energy and DTU that smoothly ramps down wind turbine power at higher wind speeds to prevent multiple start-ups and shutdowns, notably decreasing wind spillage as well as the risk of power system instability, and even blackouts, under stormy conditions.

## See the videos on the TWENTIES Project Demo 6 in Spain:

- » https://www.youtube.com/watch?v=vTBnzyQ1QcI
- » https://www.youtube.com/watch?v=F86_bnMew40

# CLUSTER 3. POWER SYSTEM FLEXIBILITY

## MORE GRID SECURITY, CAPABILITY AND FLEXIBILITY: RESULTS FROM THE EWIS PROJECT

PROJECT FICHE

**EWIS Project | Project ran from 2007 to 2010 | www.wind-integration.eu**

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| | The overarching scope of the **EWIS project** (European Wind Integration Study) was to evaluate short-term network issues arising from wind generation in the period between 2007 and 2015 while preparing the ground work for future plans up to 2020 and providing concrete recommendations. The EWIS project's objective was also to quantify and clearly demonstrate the costs related to inaction. | | |
| **Project coordinator:** | Elia | | |
| **TSOs involved:** | Elia (BE), TenneT DE (DE), 50Hertz (DE), Amprion (DE), ČEPS (CZ), EirGrid (IE), Energinet.dk (DK), IPTO (GR), National Grid (GB), PSE S.A. (PL), REE (ES), REN (PT), RTE (FR), TenneT NL (NL), APG (AT) | | |
| **Total budget:** | 4 M€ | **EC contribution:** | 4 M€ |

The transmission capacities of overhead lines are limited and in many cases, there are already bottlenecks that restrict power flows. A method to increase the overhead line transmission capacity, depending on ambient weather conditions, has been in operation since 2010 within the TenneT control area using the methods gleaned from the EWIS study. The usability and the effect on the ampacity of overhead lines was verified for 380-kV lines. Additional results from the EWIS project were operational remedial actions for risk assessment, flow control and flexibility measures.

## OPTIMISATION OF RESERVES ASSESSMENT WITH HIGH WIND PENETRATION: RESULTS FROM THE ANEMOS.PLUS PROJECT

PROJECT FICHE

**ANEMOS.plus Project | Project ran from 2008 to 2011 | www.anemos-plus.eu**

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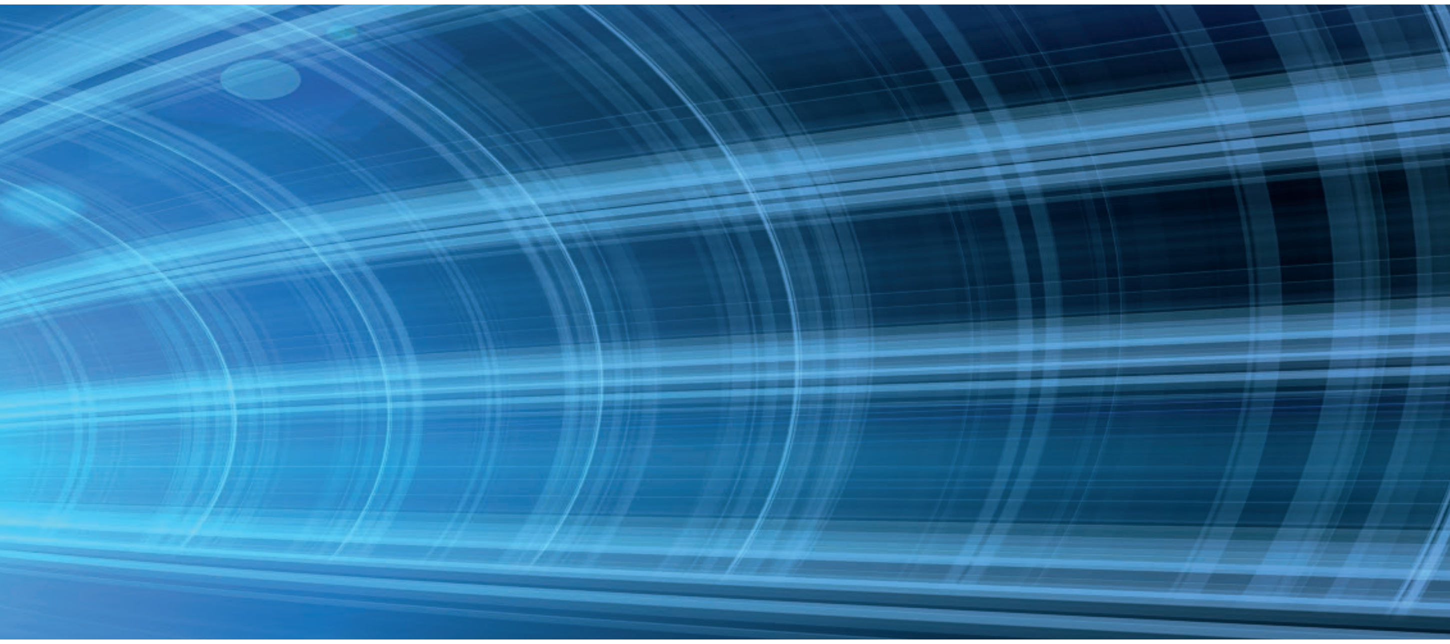
| ANEMOS.plus Wind power forecasting | The **ANEMOS.plus project** addressed the optimal management of electricity grids with large-scale wind power generation. The project developed new intelligent management tools for dealing with the variability of wind power. Emphasis was placed on the integration of wind power forecasts and the related uncertainty in power system key management functions. | | |
| **Project coordinator:** | ARMINES | | |
| **TSOs involved:** | EIRGRID (EI), REE (ES), REN (PT), SONI (UK) | | |
| **Total budget:** | 5.7 M€ | **EC contribution:** | 2.6 M€ |

The ANEMOS.plus project demonstrated the applicability of wind production forecasting tools at the operational level both for managing wind penetration and trading wind generation on electricity markets.

The probabilistic forecasting tool and the method for mobilising reserves developed by ANEMOS.plus were applied by REN at its main control centre, allowing REN to better quantify the need for additional reserves ensuing from high penetration of wind power. The probabilistic approach to wind forecasting produces more data than traditional deterministic forecasting, leading to improved support to system operator decision making and resulting in enhanced assessment of the additional reserves needed because of wind power forecasting errors, ultimately optimising the reserves mobilised in the power market.



# CLUSTER 4. POWER SYSTEM ECONOMICS AND EFFICIENCY

## LOCAL FLEXIBILITIES ARE ABLE TO PARTICIPATE IN BALANCING THE ELECTRICITY SYSTEM: RESULTS FROM THE NICE GRID PROJECT

PROJECT FICHE

**NICE GRID Project | Project ran from 2012 to 2016**

NICE GRID A SMART SOLAR DISTRICT

Optimisation of PV integration and reduction of the peak load into the low voltage grid, by using PV and load forecasts, flexible loads, electric storage, islanding and active customer participation.

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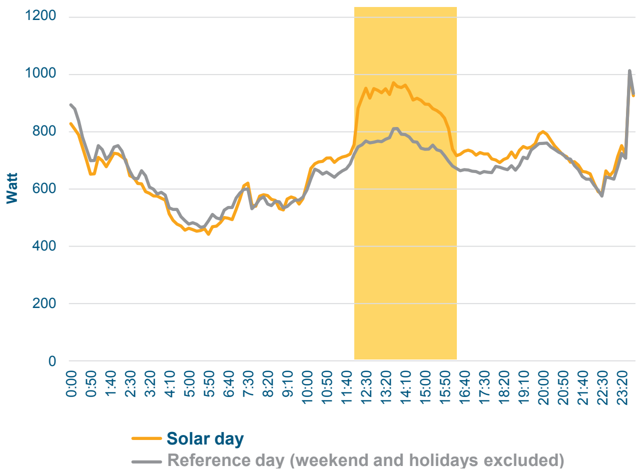
| **Project coordinator:** | ENEDIS | | |
| **TSOs involved:** | RTE (FR) | | |
| **Total budget:** | 30 M€ | **EC contribution:** | 11 M€ |

Thanks to the DSO-led project, Nice Grid, the French TSO, RTE, has been able to test the feasibility and efficiency of the participation of distributed loads through aggregators in demand response use cases.

Within this demonstration project, RTE evaluated how to activate local loads and measure the effectiveness of demand response activation (difference between actual consumption and initially expected value). Both industrial and residential consumers participated in the experimentation, and the results provided useful inputs for preparing the market design of the future at a time where the Clean Energy Package proposed by the European Commission[3)] intends to put the consumer at the centre of the clean energy transition, foreseeing that TSOs, *"when procuring ancillary services, [shall] treat demand response providers, including independent aggregators, in a non-discriminatory manner, on the basis of their technical capabilities"* and that *"Member States shall ensure access to and foster participation of demand response, including through independent aggregators in all organised markets"*.




Average daily load curves with and without requests for participants testing the Smart Water Tank (SWT) offer

3) More information is available at https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition.

## TOWARDS A SINGLE MODELLING ENVIRONMENT FOR MARKET STUDIES: RESULTS FROM THE OPTIMATE PROJECT

PROJECT FICHE

**OPTIMATE Project | Project ran from 2009 to 2012 | www.optimate-platform.eu**

The **OPTIMATE project** aimed at developing a numerical test platform to analyse and to validate new market designs which may allow integrating massive flexible generation dispersed in several regional power markets.

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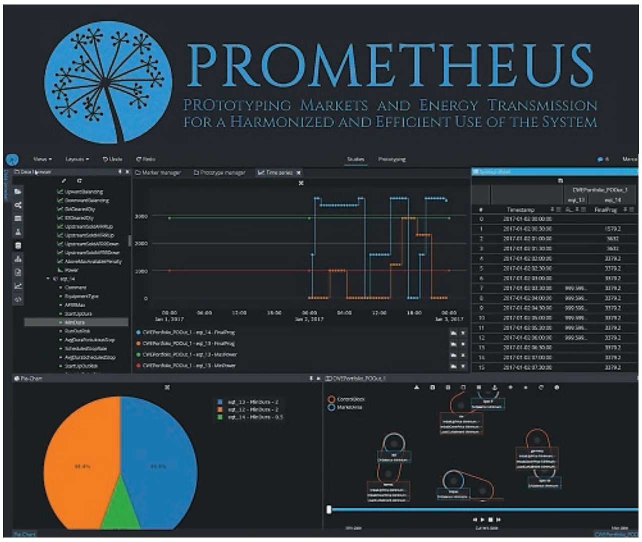
| **Project coordinator:** | Technofi | **Technical director:** | RTE |
| **TSOs involved:** | RTE (FR), ELIA (BE), REE (ES), TransnetBW (DE). | | |
| **Total budget:** | 4.1 M€ | **EC contribution:** | 2.6 M€ |

To prepare the necessary evolutions of the market design to accommodate rising cross-border flows and feed-in of electricity from variable renewable sources, TSOs conduct technical and economic studies by using a variety of simulation tools, modelling, for instance, short-term energy markets, investment decisions, reserve sizing, etc. Starting from a prototype tool which was delivered by the OPTIMATE project in 2012, RTE has been working on industrialising it. The new simulation platform, which should be delivered in 2017 under the name of PROMETHEUS, is intended to unify all market modelling tools utilised by RTE. For instance, tools have been developed to simulate balancing markets in the framework of the TERRE project[4].

Such tools, and others, will be transferred into the PROMETHEUS environment. *"Thanks to PROMETHEUS, we will have a single modelling environment, granting us the opportunity to use coherent datasets for all studies and to make our various models speak to each other. It will also permit us to make certain, in a sustainable manner, there is knowledge sharing and transfer within the team – and also with other RTE teams. The quality of our studies will be improved, and we will save some time when performing them, especially with regards to data formatting"*, says Aurèle Fontaine (Market Models and Economic Studies Team at RTE).




The PROMETHEUS simulation platform

4) The TERRE (Trans-European Replacement Reserve Exchange) project is one of a number of pilot initiatives set up by ENTSO-E at the request of ACER with the goal of exploring the feasibility of the concepts of the Network Code on Electricity Balancing. More information is available at https://www.entsoe.eu/major-projects/network-code-implementation/cross-border-electricity-balancing-pilot-projects/Pages/default.aspx.

## THE IMPORTANCE OF ENGAGING CONSUMERS IN MARKET DEVELOPMENT PROJECTS: RESULTS FROM THE ECOGRID EU PROJECT

PROJECT FICHE

**EcoGrid EU Project | Project ran from 2011 to 2015 | www.eu-ecogrid.net**

EcoGrid eu
www.eu-ecogrid.net

The objective of the **EcoGrid EU project** was to develop and demonstrate at a large scale a generally applicable real-time market concept for smart electricity distribution networks with high penetration of RES and active user participation. The fundamental idea of EcoGrid EU was to balance the power system by repeatedly issuing a real-time price signal for flexible resources to respond to. The price signal is continuously updated in order to keep the power system balanced by increasing the price when there is a power deficit in the system, and vice versa. EcoGrid EU evaluated an advanced market concept where distributed energy resources and flexible electricity demand dynamically received and responded to variable electricity prices.

| | | | |
|---|---|---|---|
| **Project coordinator:** | SINTEF (NO) | | |
| **TSOs involved:** | Energinet.dk (DK), Elia (BE) | | |
| **Total budget:** | 20.6 M€ | **EC contribution:** | 12.7 M€ |

The success of projects where the final consumer is at the centre of the applications strongly depends on a robust internal communication routine between all stakeholders, including members of the project staff. Employees with technical skills need to acquire certain communication skills and vice versa; communication staff had to elaborate certain knowledge of the technical aspects of the project. In this respect, the Ecogrid EU project was a success on the island of Bornholm in Denmark – the participants said that the project had contributed positively to the local community and had enhanced the international image of Bornholm. Approximately 80 % of households expressed their intention of continuing in a similar experiment. The majority of participants were also very satisfied with the customer service they had received. The demonstration house, Villa Smart, in Rønne, Bornholm, was a crowd-puller for both the press and the outside world. The learnings from this project are now being applied in the design and implementation of new projects by Energinet.dk, called Ecogrid 2, which are concentrated on user-friendly design in home automation, leveraging the lessons learned from the challenges that emerged during the first phase of the project.

### See the videos on the EcoGrid EU project:

- » Have a taste of the future
- » The Electricity Customers of the Future
- » Lego-model of the Smart Grid on Bornholm
- » EcoGrid EU - the Power System of the Future

# ANNEXES

## ANNEX 1



## ANNEX 2

# ANNEX 1

# LIST OF PROJECTS ANALYSED, MAIN FINDINGS, APPLICATIONS AND BENEFITS

The tables on the following pages show for each of the projects analysed, the main findings, how TSOs are applying them and the corresponding benefits. The cluster(s) of the ENTSO-E RD&I roadmap addressed by those results are also indicated.

> The first table corresponds to the projects already included in the RD&I Application Report 2014. For several of them, new developments have taken place, illustrating the fact that the time to implementation of RD&I results may be longer than the project lifetime, as previously explained.

> The second table corresponds to the new projects. In certain cases, benefits cannot be observed yet; therefore, the benefits which are expected are listed instead

# PROJECTS INCLUDED IN R&D APPLICATION REPORT 2014

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **EWIS** | | | |
| • Network studies to identify where European grid reinforcements are needed in the presence of high penetration of wind generation<br>• Method to increase the overhead line-transmission capacity<br>• European market model to quantify benefits from wind power | • ENTSO-E network codes: requirements for wind power generators<br>• DLR procedures applied at National Grid, TenneT and others<br>• Approach used in German Grid Development Plan process – to evaluate market-based year-round load flow and network contingency<br>• Reinforcement of European network provided to ENTSO-E as input for the TYNDP | **Cluster 1** (Power System Modernisation)<br>and<br>**Cluster 3** (Power System Flexibility) | • Higher integration of wind generation and consequent reduction of emissions<br>• Harmonisation of network |
| **ICOEUR** | | | |
| • New inter-area oscillation analysis tool to assess dynamic system security at the pan-European level | • Re-calculation of the setting of power system stabiliser for the main power plants (Terna) | **Cluster 2** (Security and System Stability) | • Higher level of power system stability<br>• Reduced risk of blackouts |
| **ANEMOS PLUS** | | | |
| • Accurate RES forecast (wind) based on probabilistic approach; more information than the traditional deterministic forecast, providing better support to system operator decision making<br>• Assessment of necessary conventional reserves | • Probabilistic forecast tool and the method to mobilise reserves developed by and are applied by REN at its main control centre | **Cluster 3** (Power System Flexibility) | • Quantification of additional reserve from high penetration of wind power |
| **REALISEGRID** | | | |
| • Framework to foster creation of harmonised pan-European approach to electricity infrastructure evolution based on overall evaluation of costs and benefits deriving from transmission-expansion investments | • Assessment of several projects out of the TEN-E Guidelines (2006) and "Priority Interconnection Plan" (2007)<br>• Approach is the starting point for the CBA of e-Highway2050 | **Cluster 1** (Power System Modernisation | • Increased knowledge of the electricity sector beyond planning aspects |

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **PEGASE** | | | |
| • New tools for real-time operation and operational planning using new algorithms for time-domain simulations with dedicated solvers that filter out high-frequency transients to reduce computational time and employing the same net-work component models as those utilised to study electromechanical transients, thus ensuring consistency of the studies | • Many algorithmic advances in time-domain simulations implemented in EUROSTAG soft-ware now used in operational studies (RTE) | **Cluster 2**<br>(Security and System Stability) | • Reduction of limits and uncertainties associated with dynamic network equivalents, improving performance, flexibility and accuracy of many simulation tools<br>• Training and new skills development |
| **SAFEWIND** | | | |
| • New forecasting methods for wind generation focusing on uncertainty and challenging situations/extremes<br>• Models for 'alarming', providing information for the level of predictability in the (very) short-term<br>• Models for 'warning', providing information for the level of predictability in the medium-term (next days) | • Significant progress in TSO understanding of wind generation (RTE) | **Cluster 3**<br>(Power System Flexibility) | • Use of the project's results in new studies |
| **OPTIMATE** | | | |
| • European market simulation tool usable by any stakeholder comprised of assessing short-term market design issues and improving operational market-related activities<br>• Simulation platform to evaluate market behaviour from day-ahead to real-time with different designs and countries | • Application in Market4RES project – integration of EU electricity wholesale markets into a power system with a high mix of renewables<br>• ELIA uses the platform for research projects and training<br>• RTE is currently industrialising the tool via a new platform known as PROMETHEUS aimed at unifying all market modelling tools | **Cluster 4**<br>(Power System Economics & Efficiency) | • Reduction of time required to study market evolutions<br>• Improved quality of market studies |

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **MERGE** | | | |
| • Management and control concepts for the safe integration of EVs<br>• Suite of planning simulation tools which can be also utilised to gauge the impact of EV integration-control strategies | • Identification of policies and regulations to EV integration;<br>• Short- and long-term planning and network impact assessment for EV penetration (REE, REN)<br>• Probabilistic and fuzzy analyses adequacy assessment of the Iberian transmission system (REE, REN) | **Cluster 1**<br>(Power System Modernisation) | • Grounds for network impact assessment for EV penetration |
| **TWENTIES** | | | |
| • Development of active and reactive power controllers for wind farms<br>• Novel solutions for increasing current operational limits, DLR and power flow controllers<br>• Design and operation of main building blocks for HVDC grid<br>• Technical and economic feasibility of VPP concept | • Development of active and reactive power controllers for wind farms<br>• Novel solutions for increasing current operational limits, DLR and power flow controllers<br>• design and operation of main building blocks for HVDC grid<br>• Technical and economic feasibility of VPP concept | **Cluster 2**<br>(Security and System Stability) | • Power flow control devices can eliminate re-dispatching of more than 550 GWh/year, which represents 4.5 % of the total energy currently re-dispatched in Spain |

## NEW PROJECTS

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **AFTER** | | | |
| • Software tool for global vulnerability analysis and risk assessment of power systems<br>• Identification of most risky contingencies for system operation and of the most vulnerable components<br>• Decision making pertaining to adequate protection measures to avoid contingencies; software tool for system restoration after major disruptions by adaptive and efficient restoration plans<br>• Monitoring parameters necessary for risk assessment | • Project results not yet implemented by TSOs | **Cluster 2**<br>(Security and System Stability) | • Identification of measures to increase system resilience |
| **ECOGRID EU** | | | |
| • Real-time market concept for smart electricity distribution networks with high penetration of RES and active user participation (based on the response by flexible resources to a real-time price signal)<br>• Methods and tools for consumer engagement in flexibility initiatives | • Demonstration of the effectiveness of early and continuous implementation of communication initiatives to involve consumers<br>• The learnings from this project are now being applied to the design and implementation of new projects by Energinet.dk | **Cluster 4**<br>(Power System Economics & Efficiency) | • 80 % of households expressed their intention of continuing in a similar experiment |
| **e-HIGHWAY2050** | | | |
| • New transmission system long-term scenario and planning tool for Pan-European Transmission Network (horizon 2020 to 2050) considering network behaviour in more detail<br>• Set of scenarios for 2030 and 2050 European transmission system<br>• Database of technologies performance and costs in a 2050 perspective | • TSOs (RTE, energinet.dk) and academia to challenge the local simulations made in the context of national strategies | **Cluster 1**<br>(Power System Modernisation) and<br>**Cluster 2**<br>(Security and System Stability) | • More precise cost-benefit analyses of development options in long-term scenario studies |

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **GRIDTECH** | | | |
| • Assessment of new grid-impacting technologies<br>• Comparison of different technological options | • Expansion-planning toolbox combining transmission and non-transmission technologies (Eirgrid)<br>• Evaluation of the effects of new technologies utilised in national transmission development plans (ESO, Terna and TenneT) | **Cluster 1**<br>(Power System Modernisation) | • More precise cost-benefit analyses covering a range of transmission and non-transmission technologies |
| **UMBRELLA** | | | |
| • Toolbox prototype based on optimisation algorithms identifying remedial measures to maintain system security at minimal costs, considering load flow control devices (HVDC, PSTs)<br>• Recommendation to European TSOs to employ CGMES data format to exchange stationary data | • Implemented in Germany to consider the future optimised operation of HVDC links<br>• Regional centre Transmission System Operator Security Cooperation (TSC) plans to integrate approach into a decision-support tool | **Cluster 2**<br>(Security and System Stability) | • Use of CGMES data format for data exchange in the area of system operation will allow more rapid coordination |
| **iTESLA** | | | |
| • New open-source system security assessment tool interfacing different modules (for time-domain simulation of power system dynamic behaviour or security analysis)<br>• Recommendation to European TSOs to use CGMES data format to exchange stationary data | • The platform is intended to facilitate data exchange between TSOs and interoperability between software vendors | **Cluster 2**<br>(Security and System Stability) | • Open-source licence will allow its adoption beyond the iTesla consortium<br>• Use of CGMES data format for data exchange in the area of system operation will allow quicker coordination |
| **NICE GRID** | | | |
| • Real-life assessment of the capabilities of distributed energy resources (DER; from storage devices, aggregators, RES producers and consumers) to provide flexibility services to the TSOs (ancillary services, tertiary reserves) | • RTE has tested the feasibility and efficiency of the participation of distributed loads through aggregators | **Cluster 3**<br>(Power System Flexibility)<br>and<br>**Cluster 4**<br>(Power System Economics & Efficiency) | • Useful inputs to prepare the market design of the future |

| Projects and their main results | Applications | Challenges addressed/ cluster in RD&I roadmap | Observed benefits |
|---|---|---|---|
| **BEST GRID** | | | |
| • Stakeholder engagement methods – mobile citizen office, “Infomarket” | • Project is ongoing, therefore the full project outcome cannot be applied yet<br>• However, the project has already assisted creating awareness of probabilistic methods and preparing the ground (for the seven TSOs involved) for a disruptive approach on reliability management | **Cluster 1**<br>(Power System Modernisation) | • Shorter time to permitting, reduced opposition to projects and diminished litigation |
| **GARPUR** | | | |
| • RMAC for the pan-European electric power system, considering threats in time and space, and the socio-economic impact of TSO decisions and corrective control measures and their probability of failure | • Project is ongoing, therefore the full project outcome cannot be applied yet<br>• However, the project has already assisted creating awareness of probabilistic methods and preparing the ground (for the seven TSOs involved) for a disruptive approach on reliability management | **Cluster 1**<br>(Power System Modernisation) | • Create awareness of advantages of using probabilistic methods to reliability management |
| **INSPIREGRID** | | | |
| • Stakeholder engagement methods - participative GIS, guidelines, design option priorities based on multicriteria analysis and life cycle assessment | • Practical tools and guidelines for engaging stakeholders in new transmission projects. New approaches for investments based on trust and competence (Statnett) | **Cluster 1**<br>(Power System Modernisation) | • Shorter time to permitting, reduced opposition to projects and diminished litigation |
| **BEST PATHS** | | | |
| • Novel network technologies to increase transmission network capacities and electricity system flexibility | • Innovative high temperature four bundle 707 AAAC-2Z low-sag conductor and insulated cross-arms based on composite insulators (Elia)<br>• DLR tools (50Hertz)<br>• Clamping robot for air-warning markers (Statnett) | **Cluster 1**<br>(Power System Modernisation) | • Reinforcement of network capacities with limited investment costs<br>• Increased safety for workers |

# ANNEX 2

# MAIN ACHIEVEMENTS RELATED TO THE ENTSO-E RD&I ROADMAP 2013–2022 AND MAIN AREAS OF FUTURE RD&I IN THE ENTSO-E ROADMAP 2017–2026

The main achievements of past and ongoing RD&I projects with regards to the activities specified in the previous ENTSO-E R&D Roadmap (covering 2013–2022) are presented in the first section of this annex. Sources of information are the ENTSO-E's RD&I Monitoring Report 2015 and the Grid+Storage Monitoring Report. RD&I areas which have not been addressed by previous or projects in process are indicated in blue.

The second section of this annex features the structure and main RD&I areas of the new ENTSO-E Roadmap (covering 2017–2026), which have been defined based on the aforementioned gap analysis combined with a challenge-oriented approach.

# 1. MAIN ACHIEVEMENTS RELATED TO THE ENTSO-E RD&I ROADMAP 2013-2022

## C1. GRID ARCHITECTURE

**(T1) Definition of scenarios for pan-European network expansion:**
Thanks to EU projects like EWIS, e-Highway2050, GRIDTECH, MERGE and GARPUR, this objective has been covered at 90 %. **There is still work to be done on the coupling of gas and electricity transmission networks at the EU level, although this has been addressed at the national level in certain Member States.**

**(T2) Planning methodology for the future pan-European transmission system:**
Owing to the results of the aforementioned projects, and to SAFEWIND, Inspire-GRID and the ongoing PROMOTION project, this objective has been addressed 80 %. **Planning issues surrounding the complete picture of the energy system must still be dealt with.**

**(T14) Increasing public acceptance of the transmission infrastructure:**
For the most part, the projects, BESTGRID and INSPIRE-GRID, have addressed this topic, but the LIFE ELIA-RTE, TWENTIES, e-HIGHWAY2050 and BEST PATHS projects also contributed to it. It is thought that two-thirds of this functional objective was covered by project achievements. **Certain environmental impacts because of, for example, coating and nanotechnologies, audible noise and electric and magnetic fields (EMF), must be further investigated. In addition, there continues to be the need to evaluate the impact of natural disasters and on extending the results at the EU level.**

## C2. POWER TECHNOLOGIES

**(T3) Demonstration of power technology to increase network flexibility and operational means:**
The TWENTIES, BEST PATHS, ICOEUR, ECOGRID EU and PROMOTION projects have dealt with this objective approximately 75 %. **There is still a requirement for efficient multi-vendor solutions regarding HVDC multi-terminal networks. More effort should also be exerted at the EU level regarding the use of Phasor Measurement Units (PMUs) in wide-area monitoring systems (WAMS) for control purposes. In addition, issues related to the implementation of DC lines within the existing AC grid, using the same infrastructure, have not been fully covered.**

**(T4) Demonstration of novel network architectures:**
The ongoing BEST PATHS, PROMOTION and MIGRATE projects are addressing this objective, which should allow dealing with roughly half of this item. However, **work is still outstanding in terms of fault current limiters and other promising technologies, ultra-high voltage, extension of synchronous areas and their connection with back-to-back HVDC, methods for coordinating load frequency control in off-shore networks, reliability and standard DC voltage.**

**(T5) Interfaces for large-scale demonstration of renewable integration:**
The TWENTIES and BEST PATHS projects have allowed coverage of 90 % of this objective. **Regarding the monitoring and control of the network in order to avoid large-scale intra-zone oscillations, a large EU-level demonstration project is necessary.**

## C3. NETWORK OPERATION

**(T6) Innovative tools and methods to observe and control the pan-European network:**
Several EU projects (EWIS, TWENTIES, ICOEUR, SAFEWIND, AFTER, REAL SMART, UMBRELLA, BEST PATHS and MIGRATE) have addressed this objective by approximately 80 %. **However, local state models must still be aggregated for assessing observability and controllability at the pan-European level. There is also still work to be done on flexible demand forecasting at the transmission level.**

**(T7) Innovative tools and methods for coordinated operation with stability margin evaluation:**
Similarly, this objective has been addressed by 90 % through several projects, such as TWENTIES, AFTER, EWIS, ICOEUR, iTESLA, UMBRELLA, BEST PATHS and MIGRATE. **Outstanding efforts are still necessary for new approaches to coordinate defence and restoration plans with a high share of renewables.**

**(T8) Improved training tools and methods to ensure better coordination at the regional and pan-European levels:**
This objective has not been addressed in any depth. Further RD&I work should be conducted here. In particular, a real-time simulation of the entire interconnected European power system would be needed for training purposes.

**(T9) Innovative tools and approaches for pan-European network reliability assessment:**
The GARPUR, but also SECONOMICS, ICOEUR, UMBRELLA and SMARTNET projects have primarily addressed this topic, which is therefore covered at nearly 75 %. **Still, a clear view of the application of the new reliability principles by the TSOs should be further pursued. In addition, there is a necessity for further work on information exchange.**

## C4. MARKET DESIGN

**(T10) Advanced pan-European market tools for ancillary services and balancing, including active demand management:**
The ANEMOS PLUS, OPTIMATE, ECOGRID EU, EBADGE, MARKET4RES and FUTUREFLOW projects have addressed this objective by roughly 80 %. **Further work is required with regards to market mechanisms incentivising both the maximisation of the provision of ancillary services and the minimisation of the use of ancillary services. There is also work to be performed on the development of a framework allowing efficient data exchange at the EU level.**

**(T11) Advanced tools for capacity allocation and congestion management:**
The EWIS, OPTIMATE, ECOGRID EU, MARKET4RES and FUTUREFLOW projects have been dedicated to this objective, the coverage of which is assessed to be 40 %. **Still, the possibility of more efficient options for congestion management have to be analysed for the pan-European electricity market.**

**(T12) Tools and market mechanisms for ensuring system adequacy and efficiency in electric systems integrating very large amounts of RES generation:**
This objective has been addressed by approximately 30 % through the OPTIMATE, MARKET4RES and PROMOTION projects, though **work is still needing to carried out on the participation of storage devices in day-ahead and in intraday markets as well as on RES active and reactive power control. Investment incentive regimes should also be examined. In addition, concrete proposals for grid-tariff mechanisms for active demand-side management are still required.**

## C5. ASSET MANAGEMENT

**(T15) Developing approaches to determine and maximise the lifetime of critical power components for existing and future networks:**
Only the BEST PATHS project is addressing this topic, which is therefore covered by just 10 %. **Efforts should be expended on the lifespan of power lines, evaluation/estimation protocols for component state of health, methodologies to expand the lifespan of components, monitoring and analysis of the results from equipment operation, new measurement device specifications, environmental and worker safety issues, etc.**

**(T16) Development and validation of tools which optimise asset maintenance at the system level based on quantitative cost-benefit analysis:**
The SECONOMICS, GARPUR and LIFE ELIA-RTE projects have addressed 30 % of this topic, **which merits additional work in most aspects.**

**(T17) Demonstrations of new asset management approaches at EU level:**
**It appears that most of the activities considered for this objective have not yet been dealt with.**

## C6. JOINT TSO/DSO ACTIVITIES

**(TD1) Increased observability of the distribution system for transmission network management and control:**
At the EU level, the SAFEWIND project, along with several national projects, have addressed this objective, with roughly 15% of the specified activities having been covered. **For instance, new modelling methods and tools for steady-state (static parameters) and dynamic analyses (capacities up to 1 MW) should be developed, as well as new methodologies for data processing at various system levels (DSO, TSO). New architecture, control systems and communications (including GIS assistance) that allow multiple new generators to be connected and share information with TSOs are also recommended to be designed.**

**(TD2) The integration of DSM at the DSO level into TSO operations:**
The ADVANCED, GRIDTECH, INCREASE, REALVALUE and SMARTNET projects at the EU level, as well as numerous national projects, have addressed this topic, but they are still in the preliminary stages, making this objective addressed by only 20 %. **RD&I efforts should continue to aim to meet this objective.**

**(TD3) Ancillary services provided through DSOs:**
The INCREASE, INGRID and SMARTNET projects are addressing this topic as well as a number of national projects, meaning activities are covered by approximately 70 %. **Still, work remains to be performed regarding the provision of ancillary services through aggregated loads.**

**(TD4) Improved defence and restoration plan:**
The SECONOMICS and BEST PATHS projects have partially addressed this topic (by roughly 15 %). **Micro-grids and islanding capabilities have been addressed, though wider tests are needed. Furthermore, training work is still outstanding.**

**(TD5) Methodologies for scaling up and replicating:**
**This deserves further evaluation based on the outcomes of the GRID+ project as only 10 % of the specified tasks have been addressed.**

# 2. MAIN AREAS OF FUTURE RD&I WITHIN THE ENTSO-E ROADMAP 2017–2026

The areas of future RD&I shall address the gaps identified in the previous section (blue). At the same time, changes in policy and developments in other sectors are also drivers of developments and the proposal for ENTSO-E's RD&I activities, as explained in ENTSO-E RD&I Roadmap 2017–2026.

New clusters of RD&I activities have therefore been defined, as presented by Figure 7. The table that follows features a short description of each of the new clusters and maps the activities foreseen by the previous roadmap which remain unresolved according to the monitoring of past and ongoing projects.

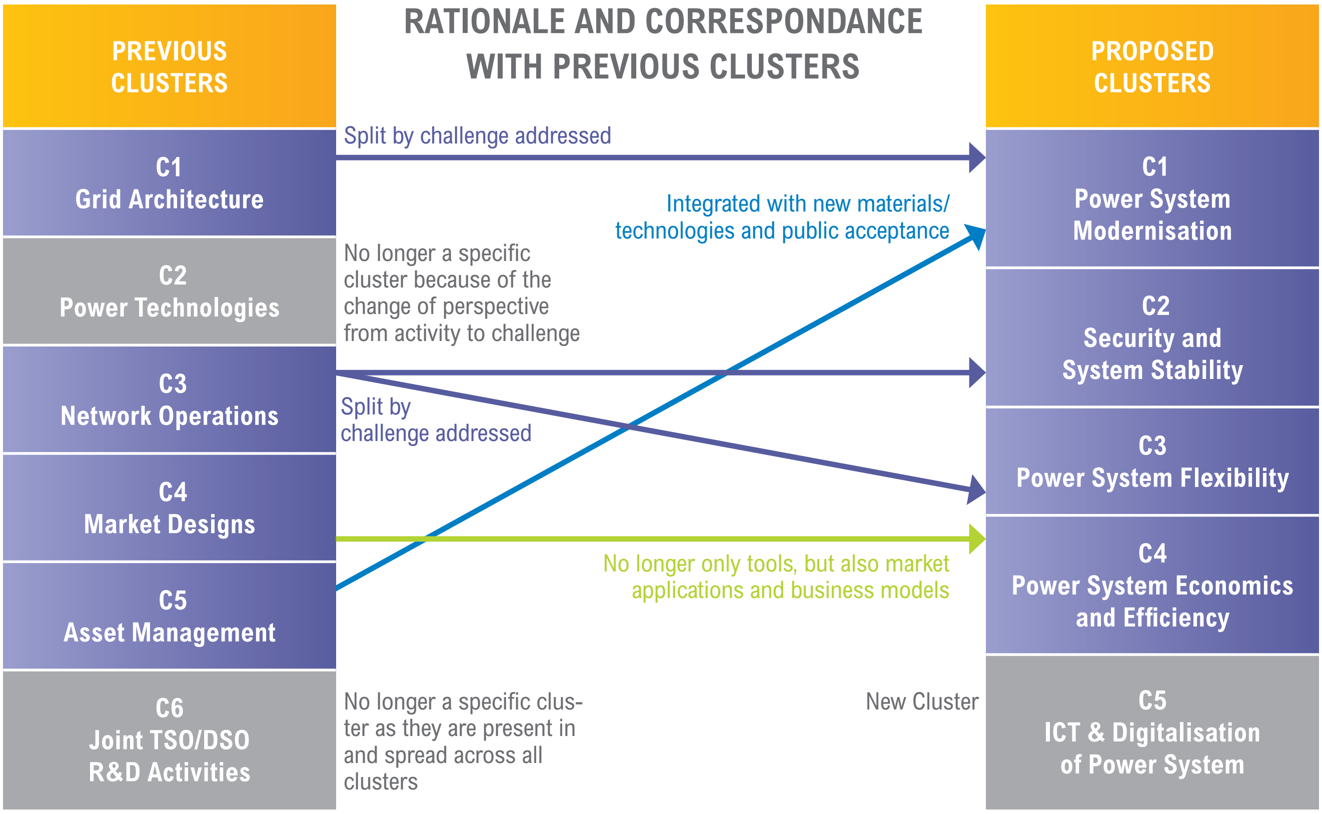



Figure 7: Correspondence between the previous and new roadmap clusters

| Clusters of the new roadmap | Main topics from the previous roadmap remaining unresolved | New additional topics addressed by the RD&I Roadmap 2017–2026 |
|---|---|---|
| **C1. Power System Modernisation** | | |
| This cluster seeks to develop an optimal grid design based on the use of the most cost-effective technologies/solutions, which should enable more flexibility (through the employment of DR, storage or interfacing with other energy networks). It also looks to smart asset management models and methodologies, and the improvement of public awareness and acceptance. | • Planning issues addressing the full picture of the energy system<br>• New methods to assess the lifespan of power lines, evaluation/estimation for component state of health and methodologies to increase the lifespan of components, monitoring and analysis of the results from equipment operation<br>• Development and demonstrations of new asset management tools and approaches<br>• Environmental impacts from, for example, coating and nanotechnologies, audible noise and EMF<br>• Environmental and worker safety issues | **Optimal grid design:**<br>• Coupling with other energy networks (gas, heat, cold)<br>• Assessment of new storage technologies<br>• Probabilistic planning methods<br>• Accounting for maintenance operations in the new planning tools<br>• Investigation of lower and higher frequency networks as an alternative to DC links<br>• Modelling of rare, severe-impact events<br>**Smart asset management:**<br>• Estimation of component real lifetimes<br>• Elaboration of guidelines for the construction and maintenance of overhead lines<br>**New materials and technologies:**<br>• Assessment of the need for new components and systems to reduce the effect of extreme environmental stressors both for AC and DC-applications<br>• Standardisation of strategic components and system and multivendor applications for PE-interfaced devices<br>• Development of superconductor fault current limiter to avoid strong short circuit currents in the new grid architectures<br>**Environmental challenges and stakeholders:**<br>• Increase communication campaigns, involvement of local and territorial bodies and studies on human and animal exposure to EMF<br>• New approaches with less visual impact, audible noise, EMF and effects on fauna |

| Clusters of the new roadmap | Main topics from the previous roadmap remaining unresolved | New additional topics addressed by the RD&I Roadmap 2017–2026 |
|---|---|---|
| **C2. Security and System Stability** | | |
| This cluster addresses the improvement of the observability and controllability of the transmission system. This will be carried out through the development of methods, technologies and tools able to handle, process and interchange measured and forecasted data in real-time across TSOs, but also DSOs. Network modelling and dynamic security tools are part of this cluster. The overall objective is to enhance defence and restoration plans for the pan-European grid. The operation of the power system will be based on the development of new procedures, strategies and models for ancillary services coming from different sources: RES, DSOs, energy storage, etc. | • Local aggregated state models for assessing observability and controllability at the pan-European level<br>• Use of PMUs in WAMS for control purposes<br>• More efficient options for congestion management for the pan-European electricity market<br>• New approaches to coordinate defence and restoration plans with high share of renewables<br>• Large European demonstrator to validate network monitoring and control methods and tools in order to avoid large-scale intra-zone oscillations<br>• New modelling methods and tools for steady-state (static parameters) and dynamic analyses (capacities up to 1 MW)<br>• Real-time simulation of the entire interconnected European power system for training purposes<br>• Impact of natural disasters | **Grid observability:**<br>• New sensors for distributed observability of the transmission system (e. g., WAMS, voltage, position, temperature, environmental conditions, events) for dynamic state estimation (e. g., DLR)<br>**Grid controllability:**<br>• Models and tools for the assessment of the state of the system and its accuracy (steady state and dynamic)<br>• Analysis of data related to the forecasting of energy sources (e. g., RES) and loads (e. g., DSM), including the data models for information exchange in view of inter-TSO coordination and data-mining algorithms<br>• Tools and technologies for the control of the power system – contribution of large-scale power technologies, including the provision of synthetic inertia and the compensation of the decrease of short circuit currents<br>• FACTS, PSTs, use of storage, contribution of RES to voltage and frequency control<br>**Expert systems and tools:**<br>• Development of expert systems to assist in transient stability analyses of both voltage and frequency (including reactive control and load shedding), integration of the probabilistic nature of variable generation<br>• Development of tools for pan-EU system restoration based on coordination of tie lines and/or black start units, whilst considering the system condition, constraints and available resources to support the decision<br>• Creation and demonstration of innovative expert systems to reduce decision cycle time that take into account the uncertainties in the power system, especially in the case of increased variability, uncertainty of input data and multiple conflicting evaluations, using artificial intelligence techniques and probability approaches, such as Bayesian analysis<br>• Development of a new control room environment to enable operators to handle complex decision-making situations |

>>

| Clusters of the new roadmap | Main topics from the previous roadmap remaining unresolved | New additional topics addressed by the RD&I Roadmap 2017–2026 |
|---|---|---|
| **C2. Security and System Stability** | | |
| | | **Reliability and resilience:**<br>• Inclusion of risk analysis in TSO daily business and identification of specific resilience/vulnerability indicators, re-evaluating N-1 approaches and related security margins into new probabilistically based approaches<br>• Analysis of the effects of extreme climate events as increasing threats to the power system<br>• Re-evaluation of defence and restoration plans, including the engagement of storage, the impact of micro-grids and islanding capabilities considering efficiency and cost-effectiveness<br>• Accounting for failure modes of ICT (including sensors) in the different simulation tools, including coordinated restoration plans specifically for ICT and software systems, in order to keep the grid operational in case of natural catastrophes, terrorism and cyber attacks<br>**Enhanced ancillary services:**<br>• Determination of novel ways to provide ancillary services through storage systems and their impact on transmission networks<br>• Sharing of best practices between TSOs and DSOs regarding the ancillary services provided by units connected via distribution networks |

| Clusters of the new roadmap | Main topics from the previous roadmap remaining unresolved | New additional topics addressed by the RD&I Roadmap 2017–2026 |
|---|---|---|
| **C3. Power System Flexibility** | | |
| This cluster supports the deployment of existing and new system flexibility options, such as:<br>• Storage solutions for fast-responding power (time dimension) and energy (less capacity needed) as well as for novel solutions for system services. Technical requirements, economic, market and environmental aspects must be evaluated.<br>• DR encompassing the development of tools and specifications for the control of such resources. This also address the integration of electric vehicles and the modelling of customer behaviour and quantifying the degree of flexibility provided by the distribution networks.<br>• ICT and enhanced RES forecast techniques would support the ideal capacity operation of the power system while maintaining the quality and security of the supply.<br>• The enhanced use of transmission assets.<br>• The interaction with non-electrical energy networks. | • Flexible demand forecasting at the transmission level<br>• Integration of DSM at the DSO level into TSO operations<br>• Ancillary services provided through DSOs and aggregated load<br>• Coupling between gas and electricity transmission networks at the EU level<br>• Extended experimentation on micro-grids and islanding capabilities | **Storage integration and use of storage services:**<br>• Investigation of technical and regulatory aspects, such as power-to-power cycles with optimal efficiency and minor losses<br>• Integration with other energy systems that can regenerate losses (e. g., heat)<br>• Novel solutions for fast power response and energy storage at different voltage levels within the power system<br>• New fixes for where supplementary services will be located in the storage facility<br>• System planning tools to determine the optimal distribution of energy storage to facilitate TSOs as well as within the distribution grids<br>• Definition of technical requirements/specifications to permit storage integration to provide system services<br>• Simulation tools to better appraise the cycling profiles associated with the envisaged applications and business models<br>• Improvement of current system modelling tools to better account for the benefits of storage and to optimise balancing<br>• Measuring the impacts of OPEX and CAPEX using stochastic modelling<br>• Tools to assess potential revenues from storage in both the liquid markets and non-liquid markets<br>• Assessment of the contribution of power-to-gas technologies as a means to store electricity at a large scale<br>• Use of gas turbines to cover long periods with low RES generation in scenarios with very high penetration of wind and solar generation<br>• Development of methodologies to integrate new bulk storage solutions (e. g., power-to-gas, marine storage, compressed air energy storage (CAES))<br>• Assessment of the value of hybrid technology projects, like, for example, mixing technologies able to perform a high number of cycles with other less CAPEX intensive technologies<br>• Assessment and quantification of the value for the system of services provided by energy storage |

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|---|---|---|
| **C3. Power System Flexibility** | | |
| | | **DR and EV impact:**<br>• Integration and demonstration of DR and storage solutions, including the effect of transport system electrification (e. g., transport EVs, etc.) for off-peak hours and their employment in system balancing<br>• Development of simulation tools to include vehicles-to-grid capacity<br>• Testing of DR models that consider DR from private customers by, e. g., limiting the rated power during a specific period of time<br>• Assessment of the value for the system provided by flexible generation<br><br>**Improved RES forecasting:**<br>• Improvement of RES forecasting accuracy by testing hybrid approaches that combine weather forecasting, local ad-hoc models, historical data and on-line measurement<br>• Measurement of improvements in accuracy because of use of high-performance computers<br>• Validation of integration scenarios where the network becomes more user-friendly and can cope with variable generation from RES<br>• Estimation of secondary/tertiary power reserves against RES forecast accuracy/errors<br>• Design and demonstration of market tools and investment incentives that support and promote RES generation flexibility, together with conventional sources of energy, for optimal balancing of the power system and facilitating system adequacy and efficiency<br><br>**Flexible grid use:**<br>• Application of more DLR solutions to become a standard practice for short-term congestion and peak transmission line overloads<br>• Investigation of HVDC reliability, especially for multi-terminal and/or meshed DC grids<br><br>**Interaction with non-electrical energy networks:**<br>• Development of methodologies and tools to assess the impact of the transition towards a new model for a European energy system (heat, transport, gas, electricity)<br>• Joint planning<br>• Study of complex dynamics of coupled systems when producing large quantities of methane (power-to-gas) to be injected into the gas grid and later utilised for the production of electricity |

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| **C4. Power System Economics & Efficiency** | | |
| This cluster has the objective of proposing means to enable interactions between the European electricity markets and the pan-European transmission system. The goal is to accomplish the creation of a more efficient market with an optimised energy mix and security of supply through integration of market and grid operations. All time horizons are treated in this cluster. On the one hand, tools and methods will be put forth that enhance the optimisation of energy flows at short-term horizons in the pan-European system considering the intermittency generated by RES. On the other hand, the cluster seeks to put forward proposals to coordinate investments in a context where the quality of the market prices to generate the correct signals for investment is regularly questioned. | • Assessment of the participation of storage devices in day-ahead and intraday markets as well as of RES active and reactive power control<br>• Investment incentive regimes<br>• Concrete proposals for grid-tariff mechanisms for active DSM<br>• Market mechanisms incentivising both the maximisation of the provision of ancillary services and the minimisation of the use of ancillary services | **Market/grid operation integration:**<br>• Validation of a flow-based market coupling approach that can be extended geographically and temporally (intraday horizons)<br>• Definition and validation of a stochastic flow-based approach that enables better coordination between the market and the real network capacities<br>• Introduction of simulation options that account for interactions between the various regulatory frameworks<br>• Definition of the modelling approaches and the associated data on transmission and generation that are vital to delivering meaningful results<br>**Business models:**<br>• Various tools to be developed to globally model the energy sector, taking into account the different roles and actors (with these roles) and their own interests, various regulatory frameworks and market designs. The interactions between the roles/actors should be modelled, as well<br>• Several tools to be designed and developed, involving a global modelling of the major energy carriers, able to consider the different roles and players involved, with their own interests and within different regulatory frameworks and market designs that shape their interactions, and accounting for all capacity means (DR, energy storage, generation) regarding their contribution to security of supply<br>**Flexible market design:**<br>• Short-term: Development of models and simulation tools to demonstrate the results of enforcing specific market designs for integrating renewables into power balancing and system services while accounting for infrastructure development<br>• Longer-term: Development of market models to drive more cost-effective investments in a coordinated manner. Design of mechanisms that assure both system adequacy and security |

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| **C5. ICT & Digitalisation of Power System** | | |
| This cluster aims to consider big data management through data-mining tools and the development of interfaces with neutral and transparent data access. The cluster also considers recommendations for standardisation activities and protocols for communications and data exchanges, the use of new technologies, such as the IoT and cybersecurity issues. ICT is an enabling technology for managing the flexible energy system described in C3. | • New methodologies for data processing at various system levels (DSO, TSO)<br>• New architecture, control systems and communications (including GIS assistance) that allow multiple new generators to be connected and share information with TSOs<br>• Development of a framework allowing an efficient data exchange at the EU level in terms of ancillary services<br>• Data management for the application of new reliability principles by the TSOs | **Big data management:**<br>• Development of a strategy for beneficial and relevant big data management initiatives within ENTSO-E through the use of relevant case studies<br>• Development, together with DSOs and ICT providers, of protocols for data transfer, utility business models and decision-making support<br>• Development of interfaces between big data management and the existing planning and operational tools<br>• Development of infrastructures or tools able to manage big data from different sources – planning tools, management tools, smart meters, social media, etc.<br><br>**Standardisation and protocols:**<br>• Creation of recommendations regarding protocols to be promoted for specific communications purposes within the energy communication network system, e. g., the IEC 61850 standard series, IEC 61970 (CIM) standard series, IEC 61968 (CIM) standard series, IEC 62325 (CIM), IEC 61400-25 standard series, ISO/IEC 9594 standard series, ITU-T X500 standard series<br>• Application guidelines and recommended practices for implementation<br>• Identification of needs for maintaining existing standards<br>• Development of standards for new needs in protocols services or extensions to existing standards<br>• Promotion of standardised information exchange solutions based on standardised protocols<br>• Advancement of the use of open-source initiatives<br>• Specification and definition of the specific interchange data model between TSO-DSO, TSO-other agents (such as demand aggregators, EV charging managers, etc.) in order to ensure the flexible operation of the network |

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| **C5. ICT & Digitalisation of Power System** | | |
| | | **New technologies, IoT:**<br>• Assessment of the potential benefits of intensifying the utility of IoT in TSO activities<br>• Produce studies and white papers regarding the secure application of IoT technologies through the public internet, taking both risks and privacy into account<br>• Development of interface tools needed to build up the use of IoT in TSO planning, asset management and operational activities<br>• Development of an ENTSO-E whitepaper and/or a technical report on the benefits of applying IoT and related tools in the electricity sector<br>**Cybersecurity:**<br>• Creation of a strategy for cybersecurity at ENTSO-E<br>• Creation of a best practice guideline for TSO substation and ICT system security design<br>• Creation of a dissemination plan for promoting strategic initiatives |

# ABBREVIATIONS

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| **AC** | Alternating current |
| **ANEMOS PLUS** | "Advanced Tools for the Management of Electricity Grids with Large-Scale Wind Generation" project |
| **BEST PATHS** | "Beyond State-of-the-art Technologies for re-Powering AC corridors and multi-Terminal HVDC Systems" project |
| **CAPEX** | Capital expenditure |
| **CBA** | Cost-benefit analysis |
| **$CO_2$** | Carbon dioxide |
| **CWE** | Central Western Europe |
| **DC** | Direct Current |
| **DLR** | Dynamic line rating |
| **EENS** | Expected Energy Not Supplied |
| **EMS** | Energy management system |
| **ENTSO-E** | European Network of Transmission System Operators for Electricity |
| **ETN** | European Transmission Network |
| **EU** | European Union |
| **EV** | Electric Vehicles |
| **EWIS** | "European Wind Integration Study" project |
| **FACTS** | Flexible AC Transmission System |
| **HVDC** | High Voltage Direct Current |
| **HWRT** | High Wind Ride Through |
| **ICOEUR** | "Intelligent Coordination of Operation and Emergency Control of EU and Russian Power Grids" project |
| **IT** | Information Technology |
| **iTESLA** | "Innovative Tools for Electrical System Security within Large Areas" project |
| **MERGE** | "Mobile Energy Resources in Grids of Electricity" project |
| **OPEX** | Operating expense |
| **OPTIMATE** | "Model for pan-European Electricity Market" project |
| **PEGASE** | "Pan-European Grid Advanced Simulation and state Estimation" project |
| **PFC** | Power Flow Controlling |
| **R&D** | Research and Development |
| **REALISE-GRID** | "Research, methodologies and technologies for the effecive development of pan-European key grid infrastructure to support the achievement of reliable, competitive and sustainable electricity supply" project |
| **RES** | Renewable Energy Sources |
| **TSO** | Transmission System Operator |
| **TWENTIES** | "Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions" project |
| **UCTE** | Co-ordination of Transmission of Electricity |
| **VPP** | Virtual Power Plant |
| **WAMS** | Wide-Area Monitoring Systems |
| **WINDGRID** | "Wind on the grid: an integrated approach" project |
| **WCMS** | Wind Farm Cluster Management System |

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## THANK YOU FOR YOUR SUPPORT

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|---|---|
| **SONJA BERLIJN** | Statnett |
| **MART VAN DER MEIJDEN** | TenneT |
| **YANNICK JACQUEMART** | RTE |

# IMPRINT

**PUBLISHER:**
ENTSO-E AISBL,
Avenue de Cortenbergh 100
1000 Brussels – Belgium

**PICTURES:**
p. 1, 2, 7, 10, 12, 17, 25, 30–31, 34–35, 63: iStockphoto
p. 19, 20: BESTGRID Project
p. 23, 24: Best Paths Project
p. 27: TenneT
p. 32: REE
p. 38: EcoGrid Project

**DESIGN:**
DreiDreizehn GmbH, Berlin
www.313.de

**PUBLISHING DATE:**
June 2017

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