ETIP SNET

EUROPEAN TECHNOLOGY AND INNOVATION PLATFORM

SMART NETWORKS FOR ENERGY TRANSITION

Final 10-year ETIP SNET R&I roadmap covering 2017-26

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“Support to R&D strategy in the area of SET Plan activities in smart grids and energy storage”1

by

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FOREWORD AND EXECUTIVE SUMMARY

This Research and Innovation Roadmap (RIR) motivates and describes the 2017-2026 priorities for the European Technology and Innovation Platform for "Smart Networks for the Energy Transition" (ETIP SNET). It is proposed for approval in the 9th of December 2016 meeting of the ETIP SNET Governing Board. This Final 10 year ETIP SNET R&I roadmap covering 2017-26 is the update and a very significant extension of the previous EEGI roadmap 2013-2022: the specified research and innovation (R&I) activities cover a scope larger than the electricity system, encompassing interactions with the gas and heat networks and focusing on the integration of energy storage technologies into the power system.

The contents of the RIR (R&I activities for the decade to come) synthesize consolidated and balanced stakeholder views for the future R&I needs of the electricity (and the energy) system and rely on a monitoring and review of national, European and international projects. The consolidated stakeholders' views have been obtained with first round consultations (with the ETIP SNET 2, the ERA-NET Smart Grid plus and the EERA), a public consultation and a series of nine regional workshops involving national stakeholders. The monitoring of the projects has been ensured by a generic methodology where nearly 123 EC and national projects have been analysed together with 54 international projects. The monitoring process has been used to make sure that the specified R&I activities correspond to research and innovation work which was not (or partially) covered at the time of analysing the projects whereas the consultations have been used to fine-tune the different draft versions of the RIR, taking into account the remarks and suggestions for improvement coming from key stakeholders of the power system community (and the energy system community as a whole).

The RIR has been constructed with three main building blocks. The first building block is a mapping of the main guidelines of the EU climate and Energy Union policies: this analysis yields a set of impacts of these policies on the future energy system, with a focus on the power system for the decade to come. The impacts are then translated into the main and most probable evolutions of the power system in the decade to come, as a result of the "policy push" framework. These evolutions are listed in terms of issues related to generation, loads, network infrastructures, digitalisation of the network, cooperation between network operators, technologies, integration within the energy system and market.

The second building block is the definition of the future challenges for the system operators as a result of the evolutions of the power system. The network operators, together with the other stakeholders of the power (energy) system, will face many challenges increasing the need for flexibility options and which can be classified into four major trends:

- More intermittent generation at different spatial scales sometimes far from the main consumption centres;
- New loads as a result of the electrification of the transport sector and the energy efficiency policies in the building sector;
- The integration of the pan-European transmission electricity network with a regional management layer as well as new links in the energy system;

2 This first round consultation process was extended following exchanges during the third governing board of the ETIP SNET (September 16, 2016) with the associations representing the flexible thermal power generation sector (COGEN-Europe, EPPSA, ETN, EUGINE and EUTurbines).

- The internal energy market where market makers (network operators) will have to manage an increasing number of interactions with market players while ensuring adequacy and security.

The development rates of these trends will be conditioned by public acceptance: grid expansion with overhead lines is less and less accepted by the general public, which forces network operators to use more expensive and challenging technological options, and deploy fast new solutions to operate the network within the suitable security margins.

The third building block is a mapping between the future challenges to be addressed by system operators, together with the other stakeholders of the power (energy) system, and the structure of the RIR. The description of the R&I activities has been organized with a two-level (clusters and functional objectives) tree-like structure as in the previous EEGI roadmap 2013-2022, with several important modifications. For the transmission system R&I activities, both the clusters and functional objectives (FOs) were reshuffled. For the distribution system R&I activities, most the existing clusters and FOs were kept whenever possible and the R&I activities were specified in terms of cross-cutting challenges (upgrading of the network, power system flexibility, power system reliability, ICT and digitalization, market design, DSO regulatory environment).

R&I activities relative to the coordinated activities of the system operators (transmission and distribution) have been specified in each of the relevant functional objectives for the transmission and distribution systems. Contrarily to the previous roadmap (the EGGI 2013-2022 roadmap), since there should be a seamless integration between these two levels in the overall system, there is no longer a need to specify R&I activities in a specific cluster.

Storage integration R&I activities have been mainly specified in two dedicated functional objectives for both the transmission and distribution systems. However, due to the cross-cutting dimension of storage integration, R&I activities have also been defined in other clusters and functional objectives when appropriate. After the extended consultation process (ETIP SNET), two functional objectives for flexible thermal generation have been added for the transmission and distribution systems, addressing the R&I activities for integration (i.e. improvement of the flexibility).

A tentative appraisal of the resources (budget) needed for the implementation of the specified R&I activities is provided. For transmission system R&I activities, the budget has been built with a bottom-up approach by summing up the estimated amounts for each FO within each cluster. For distribution system R&I activities, the budget has been constructed by estimating the necessary amounts to cover the gaps identified in the monitoring process (and therefore the new R&I activities).

For each functional objective, the expected impacts of the R&I activities of the RIR have been listed in terms of the main targets of the Energy Union and the relevant dimensions of the key actions of the SET Plan. For the sake of consistency, this analysis has been summarized per cluster.

KPIs have been defined to reflect the overarching goal of the RIR and to provide quantifiable estimates of the outcomes of the projects relative to the specified R&I activities. For transmission system R&I activities, it is proposed to apply the KPIs used for the previous EEGI

2013-2022 roadmap. For distribution system R&I activities, new KPIs and slight modifications of the existing KPIs are put forward.

1. INTRODUCTION

The purpose of this introductory chapter is to map the main guidelines of the EU climate and Energy Union policies in order to list the impacts of these policies on the future energy system, with a focus on the power system for the decade to come. From this list of impacts, the main challenges to be overcome by the power system, and more especially the electricity network operators, are presented in section 2.

1.1 THE CLIMATE AND ENERGY UNION POLICIES AND THEIR IMPACTS ON THE ENERGY SYSTEM

The energy policies of the European Union (EU) have three main drivers: long-term climate goals, i.e. reduce Europe's green-house gases (GHG) emissions and consequently decarbonize the European economy, security of supply and economic growth. Since the early nineties, the European Commission (EC) has designed and implemented a regulatory framework which has paved the way for an integrated European energy market, in order to provide the energy consumers (households, businesses and industries) with secure, sustainable, competitive and affordable energy. Three rounds of EU energy market legislation, known as energy packages, have been enacted to improve the functioning of the internal energy market and resolve structural problems, viz.

- during the nineties, directives addressing the unbundling of the energy sector (gas and electricity) known as the first energy package,
- in the early two thousands (second energy package), the promotion of renewables and cross-border electricity exchanges as well as an update of the rules for the energy markets (gas and electricity),
- and in 2009 (third energy package), specific directives updating the common rules for the internal market in electricity and gas as well as for regulations on, e.g., the conditions for access to the network for cross-border exchanges in electricity.

This set of energy packages has deeply changed the landscape of the energy system and more especially the electricity system: new market players have emerged (generators, traders, retailers, service providers) together with regulated market makers (transmission system operators and distribution system operators), NRAs (National Regulatory Authorities) in Member States (MS) and ACER (the Agency for Cooperation of Energy Regulators) at the European level. The renewable energy directives (second energy package and the update in the third energy package) have been important drivers for research and innovation (R&I) relative to the power system: the progressive integration of non-dispatchable generation (mainly wind and PV power) challenged network operators which proposed the first technical and organisational solutions to operate the electricity grids within the stability limits and at affordable costs.

In 2011, a long-term perspective was communicated by the EC3 to reach very ambitious goals in terms of decarbonisation of the European economy (80 to 95 % below the 1990 levels by 2050) insisting on energy efficiency, the development of renewable energies, and new energy

3 European Commission, Communication "Energy Roadmap 2050", COM(2011) 885 final, Brussels, 15/12/2011.

infrastructures and storage capacities as well as research and development (R&D) and technological innovation. This long-term perspective was framed in coherence with the 2020 climate and energy targets which were effective since 2009, i.e. 20% share of renewables in the energy mix, 20% in energy efficiency improvements and 20% in GHG emissions reductions compared to the levels of 1990. The previous 2013-2022 EEGI roadmap was designed in this framework with no clear view on the long-term end levels of renewables integration and energy efficiency targets to be expected to meet the ambitious 2050 goals. Such long-term signals are key elements for the power sector stakeholders since they allow the appraisal of the expected level of intermittent generation in the generation mix and the future profiles of the residual loads, and consequently the long-term planning of the electricity network infrastructures (since the lead times can be very long, e.g. it can take more than a decade between the decision for instance for network reinforcements and the full implementation and commissioning of the new overhead lines and/or cables).

Since the publication of the 2013-2022 EEGI roadmap, policy makers adopted, in October 2014, the 2030 climate-energy package which sets new targets in line with the Roadmap for moving to a competitive low carbon economy in 2050[4], the Energy Roadmap 2050[1] and the Transport White Paper[5]. These 2030 targets, i.e. 27% share of renewables in the energy mix, 27% in energy efficiency improvements and 40% in GHG emissions reductions compared to the levels of 1990, define a more ambitious plan, e.g. a revision of the ETS (Emission Trading Scheme) and a new governance scheme to coordinate the energy policies of the MS. This coordination initiative which involves a clear regulatory framework for investors is the Energy Union strategy[6]. This renewed policy framework aims at strengthening the plausibility of the 2030 targets as agreed by the EU leaders. It puts forward five mutually reinforcing and closely intertwined dimensions:

- Energy security, solidarity and trust: this first dimension addresses the gas supply policies at European level;
- A fully integrated European energy market: this second dimension addresses the lack of efficiency of the current market designs. So far, the existing electricity markets have not reached their objectives: the short-term market prices failed to send accurate signals to investors with long-term perspectives, as a result of the strong increase of generation “out of the market” (feed in tariffs). These issues led the MS to choose different national measures, threatening the integration process of the European electricity markets. In addition to the price signal issue, market concentration, weak competition, and insufficient investments still remain an issue. The main propositions for the wholesale electricity markets are to reach higher targets in terms of cross-border connections (from 10% to 15% of the installed electricity production capacity of the MS) and an increased integration of the market makers (regional coordination centres for Transmission System Operators -TSOs- as CORESO to effectively plan and manage the cross-border electricity flows)[7]. For the retail electricity markets, the main proposition is to empower customers so that they have a favourable environment to choose their electricity suppliers and to better control their electricity consumptions.

4 EC, “A Roadmap for moving to a competitive low carbon economy in 2050”, COM(2011) 112 final, March 2011.
5 EC, “White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system”, COM(2011) 144 final, Brussels, March 28 2011.
6 EC, “A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy”, COM(2015) 80 final, February 25 2015.
7 Here, the role of ACER should be significantly reinforced so as to carry out regulatory functions at EU level regarding the market rules.

- Energy efficiency contributing to moderation of demand: this third dimension deals with the effective implementation of ambitious market design initiatives so as to efficiently promote energy efficiency and demand-side response, especially in the building and transport sectors where electrification (e.g. heating via heat pumps and electric mobility) is foreseen.
- Decarbonising the economy: the true market value of emission allowances should be determined by a revised ETS in order to increase electricity production from decarbonized and low-carbon sources in a sustainable way, allowing for economic growth.
- • Research, innovation and competitiveness: this fifth dimension emphasises the need for a new strategy for R&I so as to implement the framework set out in the four other dimensions. It specifies that the EU energy technology and innovation strategy is an integral part of the EU energy policies. The EU R&I strategy relies on a core instrument, the SET (Strategic Energy Technology) Plan 8, which defines the overall framework for promoting strengthened cooperation in R&I between the EU, MS and stakeholders (research and industry), in order to step up the efforts to bring new, efficient and cost-competitive low-carbon technologies faster to the market and deliver the energy transition in a cost-competitive way. The SET Plan R&I strategy is defined in the SET plan integrated roadmap (IR) 9, 10.

During the summer 2015, the EC released an updated SET plan communication 11 defining the new European R&I strategy for the EU for the coming years. This new integrated SET plan (building synergies between national and European -e.g. H2020- R&I programmes) defines a new management structure and ten key actions to accelerate the energy system transformation and meet the priorities of the Energy Union. Two of these key actions have a direct impact on the development of the electricity system and the present roadmap:

- Create technologies and services for smart homes that provide smart solutions to energy consumers (key action 3): energy consumers (including small businesses and the tertiary sector) should be able to control and optimise their energy consumptions (and productions in the case of prosumers) through (new) services provided by (new) market players. This key action will result in the full digitalization of the distribution networks.
- Increase the resilience, security and smartness of the energy system (key action 4): this action defines two features which are important for the structure of the present roadmap: flexibility options so as to operate the electricity network with a large share of non-dispatchable generation units and evolving demand profiles, and the digitalization of the electricity system. The flexibility options that should be investigated are storage, demand-response, new transmission and distribution technologies (power electronics for instance), flexible thermal generation, flexible renewable generation (monitored curtailment, contribution to system services), and the synergies between energy networks, i.e. how to couple the electricity networks with the gas and heat networks. Digitalization of the electricity network mainly concerns the physical and cyber security of the infrastructures as well as the use of data mining (big data), IoT (Internet of Things) and HPC (High Performance Computing) so as to better operate the network, manage the assets and plan the future developments.

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8 EC, "Energy Technologies and Innovation", COM(2013) 253 final, May 2nd 2013.
9 https://setis.ec.europa.eu/set-plan-process/integrated-roadmap-and-action-plan
10 In the present road mapping exercise, compatibility between the RIR and the SET Plan IR is always ensured.
11 EC, "Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation", COM(2015) 6317 final, September 15 2015.

The other key actions have also indirect impacts on the present roadmap, e.g. the electrification of transports (key action 7), the promotion of energy efficient solutions in buildings (key action 5) and in the industry (key action 6) which will modify the load patterns in the years to come. Key action 1 (industrial leadership in renewables) and 2 (e.g. reduce the cost of key technologies such as off-shore wind power components, including HVDC technologies) are in line with the expected targets in terms of wind and PV power penetration.

As matters stand, the EC has engaged in a broad consultation with the relevant stakeholders (public and private sector stakeholders as well as MS) on the way to practically implement these ten key actions. On the basis of the SET Plan IR and the Energy Union priorities, “issues papers” have been prepared in order to come up with “agreements with stakeholders on strategic targets and priorities in each of the action areas, as well as on implementation plans that will aim to deliver the agreed targets and priorities”. These implementation plans will contain recommendations for R&I activities and policy measures at different levels (European, national and regional) so as to efficiently coordinate the funding sources in Europe (and avoid double funding). These implementation plans should be finalized by the end of year 2016–early 2017, after the publication of the present roadmap: as a consequence, for the current road mapping exercise, the latest (draft) available versions of issue papers 3 and 4 have been taken into account 12. The main elements are:

- for issue paper 3, the deployment of smart solutions empowering consumers, i.e. lower energy bills by participation in energy and system services markets via (new) market players,
- and for issue paper 4, (main focus) the integration of the electricity network in the energy system by e.g. coupling with the heat and gas networks at different spatial scales and thus providing additional flexibility options. Other important goals are sustainability (to maximise efficiency and clean energy generation), flexibility (to enhance the grid hosting capacity for renewables using all flexibility options), to be customer centric (so as to ensure fair market conditions for all players, including the end consumers), and economic efficiency (for the market and the regulated players).

Three other policy frameworks impact the present road mapping exercise: the summer package 2015, the EU strategy for heating and cooling and the winter package 2016:

- The summer package 2015 proposed two documents relevant for the energy (electricity) sector. A first communication 13 which stresses the need to better link the wholesale and retail energy markets by empowering end-consumers, i.e. make sure that consumers can easily access to the retail market (switch supplier, participate in demand-response, produce energy) with the necessary environment (data protection and privacy as well as fully interoperable smart solutions) and a second communication which proposes the associated market mechanisms so that flexibility is fairly rewarded and investments in flexibility options are fostered 14.
- A communication on the EU strategy for heating and cooling 15 which clearly highlights the flexibility generated by coupling heating and cooling with the electricity grid (through e.g.

12 https://setis.ec.europa.eu/towards-an-integrated-SET-Plan
13 EC, “Delivering a New Deal for Energy Consumers”, COM(2015) 339 final, July 15 2015.
14 This should help prepare legislative proposals due for end of 2016, following a public consultation.
15 EC, “An EU Strategy for Heating and Cooling”, COM(2016) 51 final, February 16 2016.

heat pumps or CHP producing heat in district heating networks) and taking advantage of thermal storage.

- The winter energy package 2016 with three components of importance for the present road map:
  - Retail energy markets: market participation of the consumers with specific issues related to data privacy and ownership so as to foster market efficiency;
  - Improved electricity market design so as to provide the right investment signals for investment decisions (need for flexibility, new players and new infrastructures in the power system for instance);
  - The interactions and the roles of the different (and new) market players (access to and exchange of standardized data) and market makers (for instance the regional approach for TSOs with regional coordination centres);

In the present section, the main climate and energy policies impacting the energy system (with a focus on electricity) have been reviewed. In the next section, these main elements are summarised so as to anticipate on the probable evolution of the power system for the decades to come.

1.2 EVOLUTION OF THE POWER SYSTEM IN THE DECADES TO COME

The listed policies in section 1.1 imply that the paradigm shift foreseen in the previous 2013-2022 EEGI roadmap might happen faster, probably in the decade to come, thus calling for ambitious R&I activities. Traditionally, the electricity network operators have managed grids with large centralised and dispatchable units with unidirectional flows supplying stochastic loads: tomorrow (and already today in some control zones in Europe), these network operators will have to manage (are managing) stochastic and distributed generation units (small to medium power), bi-directional flows with so far limited part of the demand becoming controllable (but with sometimes negative residual loads).

The main evolutions of the power system in the decades to come, as a result of the “policy push” framework, will be:

- An ever increasing penetration of intermittent renewables with probably no control on the spatial location and the size of the generation units (mainly for PV) and far from the main consumption centres (mainly for wind power) thus calling for the development of new network infrastructures (e.g. HVDC grids in the North Sea), in a context where social acceptance for new overhead lines is an issue;
- New loads resulting from the electrification of transport (electric vehicles -EVs-, tramways) and efficient solutions in the heating and cooling sector (e.g. heat pumps in private homes and district heating systems). The new loads will change the load profiles and possibly increase the share of electricity in the overall energy consumption;
- Controllable distributed loads, as a result of ambitious demand response policies, by relying on technologies and services for smart homes that provide smart solutions to energy consumers;
- New technologies providing flexibility options to the electricity network operators, i.e. e.g. storage, new transmission and distribution technologies (power electronics for instance),

flexible thermal generation, flexible renewable generation (e.g. wind power providing reactive power), and flexible demand;

- Full integration of the power system in the energy system by coupling the electricity network with the gas and heat networks;
- A well-meshed pan-European electricity transmission network resulting from a significant increase of the capacity of cross-border connections (this deployment must be planned by TSOs through extensive cost benefit analyses at the European level, with a common and continuously improving methodology 16);
- Modified management and organisational schemes: regional coordination centres for TSOs (to manage the cross-border flows);
- The full digitalization of both the transmission and the distribution networks with new ICT infrastructures with their associated software layers. This will create threats (cyber security) and opportunities (use of big data and data mining, IoT and HPC for network management);
- New market mechanisms and market players to promote energy efficiency and demand response to be traded in electricity markets (including system services);
- Retail electricity markets empowering customers (favourable environment to choose electricity suppliers and to better control consumptions through new services provided by new market players).

These evolutions are summarized in the Table hereafter with a focus on the evolutions of the power system in the decade to come.

Table 1: evolution of the power system in the decade to come following the climate and Energy Union policies.

	Yesterday	Today and tomorrow
Generation	Large centralised and dispatchable units Spatial location and rated power under control	• Fewer large centralised and dispatchable units with an increasing share of distributed generation, partly stochastic. • Decreasing control on spatial location and rated power
Load	Stochastic demand with controllable industrial loads	• Evolving load profiles due to the electrification of transport and heating/cooling in the building sector • Controllable distributed loads with demand response • Residual loads will be sometimes negative
Network infrastructures	Few cross-border connections	• Significantly increased cross-border connections capacities
Digitalisation of the network	Partial digitalization at TSO level	• Full digitalisation in both transmission and distribution networks: monitoring, automation and control • Cybersecurity issues • Use of big data, IoT and HPC to manage the network

16 A first target of 15% of the installed electricity production capacity of the MS has been mentioned by the EC although further analyses are needed to actually discuss how this target should be applied in practice.

	Yesterday	Today and tomorrow
Network operators (TSOs)	Two regional coordination centres (CORESO and TSC)	• Several coordination centres covering all the ENTSO-E control zones
Network operators (DSOs)	Distribution network expansion and investments based on a 'fit-and-forget' approach	• Distribution network expansion and investments based on a 'connect and manage' approach
Technologies	AC technologies with low penetration of PE-based devices	• Distributed storage technologies • Large penetration of PE (inverters, HVDC converters, DC loads including in private homes) • ICT for smart homes and active consumers (prosumers)
Integration within the energy system	Weak coupling with heat pumps in district heating networks	• Strong coupling with the gas network (via power to gas technologies) offering storage and flexibility via CHPs • Strong coupling with heat pumps in e.g. district heating networks
Market	Few players on the wholesale market	• Dynamic, uncapped, cross-border markets providing flexible capacities on the short run to offset variations from variable renewables • Hedging products against price variability risks • New players in both the wholesale and retail markets • Coupling of the wholesale and retail markets • Market mechanisms for flexibility, energy efficiency and demand response • Empowering customers, i.e. end consumers able to participate in electricity markets via new market players

1.3 THE NEW INTEGRATED (ETIP SNET) ROADMAP

1.3.1 THE CONSULTATIONS AND MONITORING PROCESS

The present roadmap, the ETIP SNET Research and Innovation Roadmap 2017-2025 (RIR), is one of the deliverables that the Grid+Storage consortium must hand over to the EC (DG ENER) and the ETIP SNET (European Technology and Innovation Platform Smart Networks for the Energy Transition) teams in the framework of service contract N° ENER C2/2014-642. The content of the RIR (R&I activities for the decade to come) must synthesize consolidated and balanced stakeholder views for the future R&I needs of the electricity networks and rely on a monitoring and review of projects, programmes in the EU (including at national level) and worldwide. The consolidated stakeholders' views have been obtained by:

- First round consultations with the ETP Smart Grids 17, the ERA-NET Smart Grid plus and the EERA;
- A public consultation 18;
- A series of nine regional workshops involving national stakeholders 19.

The monitoring of the projects has been ensured by a generic methodology where nearly 123 EC and national projects have been analysed (50 projects for TSOs, 51 projects for DSOs 20 and 22 storage projects). The monitoring of the projects has been reported in two separate deliverables, D3.1 and D3.2 dealing with the technical analysis of past, on-going and expected projects. D3.1 has been focussed on the monitoring for the definition of the priorities of the IP 16-18 whereas D3.2 is dedicated to the appraisal of the current knowledge coverage so as to define the R&I activities to be specified in the RIR 21.

The different consultations with the main stakeholders together with the monitoring activities have allowed the drafting of the present roadmap: the monitoring process has been used to make sure that the specified R&I activities correspond to research and innovation work which was not (or partially) conducted at the time of analysing the projects whereas the consultations have been used to fine-tune the different draft versions of the RIR, taking into account the remarks and suggestions for improvement coming from key stakeholders of the power system community (as well as the energy system community as a whole).

The structure of the RIR is explained in section 3.2 and the detailed content of the R&I activities is displayed in Appendix 1 for the transmission systems 22 and in Appendix 2 for the distribution systems. Section 2 explains the link between the evolution of the power system and the future challenges to be addressed by the system operators and the stakeholders of the electricity (energy) value chain. The links between the future challenges to be addressed by system operators and the structure of the roadmap are explained in subsections 3.2 to 3.5.

In complement to the specified R&I needs in Appendix 1 and Appendix 2, estimations of the necessary resources, to motivate and drive industrial investments, as well as public private partnerships (PPPs), devoted to support the specified R&I efforts, are presented in section 4. The document ends with a list of the expected outputs, outcomes and impacts, and the KPIs to measure them, cf. section 5, before concluding in section 6.

1.3.2 SPECIFICITIES OF THE PRESENT RIR

The main outcome of the RIR is the definition of a European R&I strategy in the area of the SET Plan activities relative to smart grids and the integration of energy storage taking into account all other flexibility options, including flexible thermal power generation. As a

17 This first round consultation process was extended following exchanges during the third governing board of the ETIP SNET (September 16, 2016) with the associations representing the flexible thermal power generation sector (COGEN-Europe, EPPSA, ETN, EUGINE and EUTurbines).
18 The methodology used for the public consultation(s) is described in two deliverables, D1.1 (Description of process for stakeholder involvement and consultation for the EEGI team RTD&D roadmap implementation plan) and D1.2 (Description of process for stakeholder involvement and consultation for the 10 year EEGI team RTD&D roadmap). D2.1 describes the methodology used for the public consultation of the present roadmap.
19 The recommendations provided by the national stakeholders have been summarized in a specific deliverable (D4.1: Minutes of stakeholder debates (lessons learned) for nine knowledge sharing workshops).
20 Distribution System Operators.
21 In the D3.2 exercise, consistency with the existing ENTSO-E framework has been ensured (cf. ENTSO-E's R&D Monitoring Report 2015).
22 And the pan-European system. Since there are several interconnected transmission systems in Europe, the term "transmission systems" is used, which also includes the pan-European system.

consequence, the main difference between the previous 2013-2022 EEGI roadmap and the RIR is a specific focus on R&I activities relative to storage integration into the electricity (and energy) network(s). Apart from the storage integration focus, the RIR goes beyond the scope of R&I activities specified in the 2013-2022 EEGI roadmap for the electricity grids by paying specific attention to:

- A technological base to open up for the "active customer";
- Interactions with other energy networks (gas and heating/cooling);

in view of increasing the flexibility of the electricity system so as to deal with, amongst others, higher shares of variable renewable electricity generation and new loads.
Energy storage is addressed from the integration point of view, i.e. R&I activities for the improvement of the performances and thus the market uptake of specific storage technologies are not specified in the RIR 23. Integration R&I activities can be related to, for instance:

- market and regulatory issues, e.g. assess the regulatory framework for storage operations and ownership as well as the associated valuation and remuneration for the provision of system services,
- or technical issues, e.g. study the development of self-consumption policies involving local storage so as to better control its effects on the stability of the power system, improve the capabilities of the power electronics so as to allow multi-service business models for storage, etc.

Regarding the interactions with other energy network, as specified in Table 1, the increased use of electricity in the heating and cooling as well as transport sectors, together with emerging power-to-gas technologies, will lead to the stronger integration of the electricity, gas, heating and cooling, and transport sectors, thus intensifying the need for coordination among these different sectors in the future, including integrated R&I activities.

Overall, the RIR aims at providing the stakeholders of the power system (and the whole energy system) with consolidated and balanced views for the future R&I needs involving technology development and market uptake:

- to support the development of transmission and distribution electricity grids as well as energy storage,
- to make such grids able to use flexibility solutions in view of increasing the flexibility of the European electricity (and energy) system in order to deal with higher shares of variable renewable electricity generation (all flexibility options have been considered: network technologies and reinforcements, flexible RES and thermal power generation, demand-response -active customers-, energy storage, IC technologies and infrastructures, coupling with other energy networks),
- to facilitate a technological base to open up for the "active customer" as a potential source of flexibility for the energy system;
- to optimize the interactions of the electricity grid (transmission and distribution) with other energy networks, partly because this increases flexibility of the overall energy system.

23 Such R&I activities will be specified in other EC contracts, e.g. http://www.batstorm-project.eu/downloads

The resulting R&I activities will therefore differ from the existing roadmaps in the sense that they will cover a scope larger than the electricity system, encompassing interactions with the gas and heat networks and focusing on the integration of energy storage technologies and the other flexibility solutions into the power system.

The RIR has been written taking into account the existing EU roadmaps, i.e. the previous EEGI 2013-2022 roadmap, the SET Plan IR, the EASE/EERA Energy Storage Technology Development Roadmap towards 2030 24, and of course the ENTSO-E R&I roadmap. In section 3.8, it will be shown how the present roadmap is in coherence with this existing framework and moreover how it complements these documents.

24 http://ease-storage.eu/category/publications/technical-documents/

2. FUTURE CHALLENGES FOR THE POWER SYSTEM

Table 1 lists the most likely evolutions of the power system in the decades to come following the most recent climate and Energy Union policies. These evolutions imply that network operators will face an increasing number of challenges and R&I activities must be launched in time so as to come up with optimized and cost effective solutions, maximising social welfare. Indeed, the typical time scale needed for developing technologies (including software, management tools and methodologies), demonstrating their performances and validating system integration are of the order of magnitude of a decade. Before listing the challenge to be faced by network operators in the decade to come, based on the foreseeable evolutions listed in Table 1, some complementary remarks must be made:

- When specifying and coordinating R&I activities, **network (system) operators should have a leading role**. Indeed, network operators are regulated players ensuring at the same time the role of market makers and the reliability (adequacy and security) of the power system. As such, they have a pivotal function in the power system. They are the only stakeholders of the value chain which have a systemic view and can study and anticipate the complex dynamics resulting from increasing interactions in the network itself and with (and between) market players;

- **Grid expansion is less and less accepted by the general public**. This has two main impacts: first, low acceptance for overhead lines forces network operators to use cable technologies and reinforce their networks with partial undergrounding and sometimes full undergrounding solutions, which are more expensive and challenging technological options. Secondly, since the time scales for network reinforcement and the installations of new generation units and loads are very different, not being able to install the necessary reinforcements also forces network operators to deploy fast new solutions to operate the network within the suitable security margins.

- **Coupling heating/cooling and electricity production** in the future will be key for the integration of the electricity system since heat (and cooling) will also play a pivotal role in the transition towards a low-carbon power system. Indeed, energy consumption for heating in Europe is still much larger than the demand for electricity even though there is a growing electrification of heating in buildings and to some extent in district heating systems with large heat pumps. Coupling heat and electricity production will also impact the gas grid with CHPs where electricity storage could be performed in different ways (thermal and chemical energy).

- **Coupling electricity with transport** will become increasingly important in the future energy system and will be a significant challenge to electricity grid operators. Similar to the demand for heat, the demand for energy in the transport sector is much larger than the electricity demand in Europe. Transport can be electrified by use of BEVs (Battery EVs) but also by use of chemical fuels produced from electricity (for instance natural gas produced from power-to-gas technologies). Both options, however, will have considerable impacts on the electricity grids design and operation.

- The EU **internal energy market** resulting from the three legislative energy packages has set the basis for opening up the electricity and gas retail markets to competition for the benefit of the consumers. The main issue for the future design 25 of the European internal energy market is how the consumer will bear the costs for the investments to be made in the power system (e.g. generation, network, and ICT infrastructure), and what will be the extended regulatory framework defining the retail market rules.

- In the light of the above remarks and the evolution of the power system listed in Table 1, the challenges to be addressed by network operators are now listed.

2.1 CHALLENGES FOR ELECTRICITY SYSTEM OPERATORS

Electricity system (network) operators will face many challenges as a result of four major trends:

- **More intermittent generation** at different spatial scales (from small scale BIPV -Building Integrated PV- units connected to the low-voltage distribution grids to large scale offshore wind farms connected to the high-voltage distribution grids) sometimes far from the main consumption centres;
- **New loads** (and consequently evolving load profiles) due to the electrification of the transport sector and the energy efficiency policies in the building sector (heat pumps, prosumers, etc.);
- The **integration of the pan-European electricity network** (more cross-border interconnections) with a regional management layer as well as new links in the energy system (connections between electricity networks and other energy networks at different spatial scales, e.g. the gas network for TSOs and heat networks for DSOs);
- The **internal energy market** resulting in an increasing number of interactions with market players while ensuring adequacy and security.

The four above mentioned families of future challenges for network operators are described more specifically in terms of targets in Table 2 hereafter. These targets are linked to the policy drivers identified in section 1 and the associated evolutions of the power system.

Many of the identified evolutions of the power system concern both the transmission and the distribution systems and as a consequence they result in similar challenges for both levels, including for both TSOs and DSOs. For instance, the evolution of the generation mix (Fewer large centralised and dispatchable units with an increasing share of distributed stochastic generation and Decreasing control on spatial location and rated power) imply common challenges, e.g. Improve the observability and the controllability of the network and Improve the accuracy of the generation forecast. The specific R&I activities and the future implementations might however be different since there are evolutions and challenges which are specific to either the TSOs or the DSO.

25 The current market design (the three legislative energy package), will remain valid and should be implemented in all EU28 countries.

2.2 FUTURE CHALLENGES FOR TRANSMISSION SYSTEMS

Some of the challenges listed in Table 2Table 2 are more specific to the transmission systems and concern a large set of stakeholders in addition to TSOs (manufacturers, research institutes, utilities, ICT providers, aggregators, etc.) 26, viz.:

- *Developing pan-European electricity highways with both AC and DC technologies*: European TSOs will have to strengthen their interconnections so as to be able to handle at the pan-European scale the higher shares of renewables (PV and wind). They will also have to strengthen the existing corridors in their own control zones either with new lines (by resorting to undergrounding solutions, partial or full) or links or with parallel routing of DC and AC lines on the same existing towers for instance.
- *Decrease the environmental footprint of the network reinforcements*: due to the increasing opposition to new overhead lines, mainly due to the environmental impact, TSOs will have to, for example, reduce the visual impacts, address EMF (Electro-Magnetic Field) issues, and study the environmental impacts of new technologies and undergrounding solutions.
- *Make use of data mining techniques and HPC to better manage the network, closer to its physical limits*. Data mining techniques and HPC (High Performance Computing) have proven to be key issues for the next generation of decision-making tools allowing network operators to cope with dynamic effects and uncertainties (mainly from renewables): computational power is needed to analyse and detect beforehand and close to real time situations where grid stability constraints might appear 27.
- *Increased TSO collaboration*: TSO collaboration already exists at planning level (cf. the TYNDP exercise of ENTSO-E) and the network codes (NC). There also exists two regional coordination centres: CORESO and TSC. European interconnected TSOs will support the creation of Regional Security Coordination Initiatives (RSCIs) ensuring essential coordination functions such as coordinated security analysis, short and medium term adequacy forecasts, coordinated capacity calculation, outage planning coordination and improved individual grid model/common grid model delivery 28.
- *New materials and technologies to increase the flexibility of the grid*: new technologies will be needed to increase the flexibility of the existing transmission grids, e.g. new types of conductors (using nanotechnologies or superconducting materials), energy storage, and power electronics.
- *Develop methodologies and tools to operate the network closer to its physical limits without jeopardizing its security*. As mentioned above, TSOs will need to develop the expert systems and decision-making support tools to anticipate potential emergencies, give an early warning to the system operators and suggest possible solutions with their estimated probability of success in real-time.
- *Improve defence and restauration plans in areas with a deep penetration of PV and wind power*. With the ever increasing penetration of renewables, TSOs will have to deal with control zones with very high penetration of power electronics, i.e. control zones where the number of generators and loads that are connected to the grid through power electronics interfaces or devices such as inverters represent a significant share of the total generation and load. This will necessitate the development of specific tools for defence and restoration plans.

26 The stakeholders impacted by the R&I activities specified in the RIR for transmission are listed in Appendix 1.
27 www.itesla-project.eu.
28https://www.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/141119_ENTSO-E_Policy_Paper_Future_TSO_Coordination_for_Europe.pdf

Table 2: list of challenges to be addressed by network operators in the decade to come.

Policy drivers	Evolution of the power system	Future challenges for network operators
Generation	• Fewer large centralised and dispatchable units with an increasing share of distributed stochastic generation • Decreasing control on spatial location and rated power	• Improve the observability and the controllability of the network. • Improve the accuracy of the generation forecast. • Develop methodologies and tools to operate the network closer to its physical limits without jeopardizing its security. • Deploy the hardware and software solutions to host renewables in MV and LV networks (monitoring, automation and control). • Identify and support improvements of suitable flexibility options (RES generation, flexible thermal power generation, load, network, storage, integration with other energy network) to ensure adequacy and security • Utilize system services from intermittent generation. • Improve defence and restauration plans in areas with a deep penetration of PV and wind power.
Load	• Evolving load profiles due to the electrification of transport and heating/cooling in the building sector • Controllable distributed loads with demand response • Residual loads will be sometimes negatives	• Use of demand response for system services with well-defined interactions between with the market players and the network operators (and TSO-DSO exchange of information). • Efficient forecast of demand (and residual loads) accounting for the new loads and the demand-response activities of new market players. • Anticipate and plan the impact of the electrification of the building and transport sectors on the

Policy drivers	Evolution of the power system	Future challenges for network operators
		electricity network (new equipment at distribution level especially in urban areas). • Prepare the shift from passive to active consumers by allowing all means for communication via smart meters.
Network infrastructures	• Significantly increased cross-border connections capacities	• Optimising the existing assets and the network capacity making use of new technologies • Developing pan-European electricity highways with both AC and DC technologies • Study and demonstrate new grid architectures both at transmission and distribution level as a source of flexibility. • Decrease the environmental footprint of the network reinforcements. • New planning tools able to account for the full complexity of electricity networks (distributed and intermittent generation, variable and controllable loads, power electronics, storage, etc.).
Digitalisation of the network	• Full digitalisation in both transmission and distribution networks: monitoring, automation and control • Cybersecurity issues • Use of big data, IoT and HPC to manage the network	• Scalable solutions to address large-scale data management (customers, equipment, network, market) issues in the power system. • Make use of IoT and data mining techniques (big data) to develop smart asset management strategies. • Make use of data mining techniques and HPC to better manage the network, closer to its physical limits.

Policy drivers	Evolution of the power system	Future challenges for network operators
		• Coordinate and participate in standardization activities for communication and data exchanges between the different stakeholders of the electricity value chain. • Ensure the physical and cyber-security of the digital substations.
Network operators (TSOs)	• Several coordination centres covering all the ENTSO-E control zones.	• Increased TSO collaboration. • Increased exchange of information between TSOs and DSOs.
Network operators (DSOs)	• Distribution network expansion and investments based on a 'connect and manage' approach	• Standardization and interoperability of system architecture, protocols and data models. • Optimal management and activation of local flexibilities. • Accelerate the large scale deployment and validation of advanced automation and control solutions.
Technologies	• Distributed storage technologies • Large penetration of PE (inverters, HVDC converters, DC loads including in private homes) • ICT for smart homes and active consumers (prosumers)	• Improve storage integration at all time scales (in operation for system services but also when performing planning studies as an additional degree of freedom) as a source of flexibility. • Appraise the real value brought by small to medium scale storage systems in network operations by deploying real-life demonstrations. • New materials and technologies to increase the flexibility of the grid
Integration within the energy system	• Strong coupling with the gas network (via power to gas technologies) offering storage and flexibility via large CHPs	• Interactions with the gas network for storage of chemical energy. • Interactions with the heat network for storage of thermal energy.

Policy drivers	Evolution of the power system	Future challenges for network operators
	• Strong coupling with heat pumps in e.g. district heating networks	• Interactions of the transmission and distribution grids with the gas and heat networks so as to better operate the power system. • Optimisation of the energy system.
Market	• Dynamic, uncapped, cross-border markets providing flexible capacities on the short run to offset variations from variable renewables • Hedging products against price variability risks • New players in both the wholesale and retail markets • Coupling of the wholesale and retail markets • Market mechanisms for energy efficiency and demand response • Empowering end-users, i.e. end users able to participate in electricity markets via new market players	• Validate flow-based market-coupling tools that can be extended geographically and temporally. • Enforcing market design for the integration of renewables at different time scales. • Optimized integration of market and network operations all time scales (from long-term to real time). • Integrate new market players providing system services. • Participate in the assessment of the regulatory framework for storage operations and the associated remuneration of system services. • Enable well-functioning retail markets so as to empower the end users.

2.3 FUTURE CHALLENGES FOR DISTRIBUTION SYSTEMS

Some of the challenges listed in Table 2 are more specific to the distribution systems (apart from DSOs, the impacted stakeholders of the distribution systems are given in Appendix 2), viz.:

- *Enable well-functioning retail markets so as to empower the end users*. DSOs will be involved in the definition of market rules (and the associated regulatory framework) to encourage end customers participate in retail markets (energy efficiency or demand response offers for instance) in a transparent and non-discriminatory way, with a special attention to data privacy.
- *Scalable solutions to address large-scale data management (customers, equipment, network, market) issues in the power system*. DSOs will need efficient data mining algorithms for various applications ranging from generation forecast to load forecast (consumer behaviour) but also failure/ageing models for network components (as for TSOs). Efficient data mining algorithms will also be required by market players (retailers, aggregators, ESCOs, traders, etc.) to boost retail electricity markets and create new business opportunities, in connection with the DSOs.
- *Anticipate and plan the impact of the electrification of the building and transport sectors on the electricity network (new equipment at distribution level especially in urban areas)*. DSOs will need network planning and optimization tools linking with urban planning tools so as to optimize the development of the electricity network taking into account energy efficiency policies at the city scale (interaction with other energy networks, spatial planning). They will also need ICT and simulation tools to assess the steady state and dynamic impacts in operation (especially power quality and voltage profiles) of a large roll-out of EVs on the distribution grids (which will help reduce or defer network reinforcements).
- *Prepare the shift from passive to active consumers by allowing all means for communication via smart meters*. DSOs will have to be involved in the deployment of ICT infrastructures and technologies that will allow the involvement of the end customers and the retail market players providing new energy efficiency services.
- *Deploy the hardware and software solutions to host renewables in MV and LV networks (monitoring, automation and control)*. Despite existing equipment already deployed, especially at medium voltage (MV) level, there is still a need to demonstrate under real operating conditions and at a large scale, an integrated set of new solutions to improve LV (low voltage) and MV network automation and control for operation and maintenance of all distribution grids in Europe, in order to better integrate renewables and new loads.

3. THE STRUCTURE OF THE INTEGRATED ROADMAP

The main goal of section 3 is to motivate the structure of the RIR keeping in mind the future challenges for system operators (together with the stakeholders of the electricity value chain, and to some extent of the whole energy system) identified in section 2 and explain the evolutions compared to the previous roadmap (the EEGI 2013-2022 roadmap).

3.1 THE OVERARCHING GOAL OF THE RIR

The previous EEGI 2013-2022 R&I roadmap was designed in 2012 and aimed at preparing European electricity networks to enable the ambitious 2050 agenda that had been adopted by the European MS so as to achieve a low carbon economy. The single overarching goal was

> *"to allow European electricity networks continuously deliver an effective flexible capacity to integrate actions of grid users at affordable costs".*

Since then the climate and energy policies environment has evolved, cf. section 1.1. As a consequence, the overarching goal of the updated ETIP SNET integrated R&I roadmap needed refocusing compared to the first version, in order to bring about knowledge through R&I which supports the directions of the development of the European power system identified in the previous section. The results of future R&I activities must contribute directly to the optimisation of the full European power system (and its integration into the energy system with a focus on energy storage) under security of supply constraints, and must be able to take into account any unforeseen change of the electricity system between 2017 and 2030. The single overarching goal of the new R&I roadmap is, therefore, to produce new knowledge which aims to:

> *"Optimise the European welfare brought by the electricity value chain while ensuring the proper level of reliability within the energy system of the EU28".*

The update of the overarching goal implies to redefine the KPI(s) which help measure the compliance with the EU climate and energy policy goals. This specific point will be addressed in subsection 5.2.

3.2 STRUCTURE OF THE R&I INTEGRATED ROADMAP

In the previous EEGI 2013-2022 roadmap, the R&I activities were organized with a two-level tree-like structure: the first level of the tree-like structure consisted of clusters and the second level of functional objectives (FOs), i.e. several FOs per cluster 29. Clusters corresponded more or less to the main activities of the network operators, i.e. network operations, asset management, planning and market designs (role of the network operators as market makers). At the transmission system level for instance, these clusters where called Grid architecture (planning), Network operation, Asset management and Market designs (related to the market maker role). In each cluster, the functional objectives contained a family of functions to be ensured by network operators (and other stakeholders of the power system) and where research was needed, e.g.

- the coordinated control of the pan-European network, with a dedicated FO (T7) in cluster 3 (C3) called Innovative tools and methods for coordinated operation with stability margin evaluation 30 .

In the present roadmap it was decided by the Grid+Storage consortium to keep the two-level tree-like structure (clusters and FOs) with substantial modifications so as

- to better account for the SET Plan environment (issue papers 3 and 4 and the SET Plan IR) and more generally the climate and energy policies of the EU,
- to better account for the cross-cluster nature of many projects, i.e. find a tree-like structure that would ease the classification of projects with fewer clusters and FOs,
- to pay attention to key issues such as the integration of storage in the power system as well as all other flexibility solutions, the integration of the power system in the energy system as a whole (interactions between the electricity, the gas and the heat networks), and active retail markets (how to empower customers so as to have large pools of active customers).

Two different approaches were proposed to implement these modifications:

- reshuffle both the clusters and functional objectives, i.e. define -if required- new clusters and FOs (transmission systems),
- keep the existing clusters and FOs whenever possible and specify the R&I activities in terms of cross-cutting challenges such as regulations or the digitalization of the electricity networks (distribution systems).

3.3 CLUSTERS AND FUNCTIONAL OBJECTIVES FOR TRANSMISSION SYSTEMS

3.3.1 SPECIFICATION OF THE TREE-LIKE STRUCTURE

ENTSO-E (with the other Grid+Storage partners) has addressed the policy drivers of the SET Plan environment, and more generally the climate and energy policies of the EU, as the main

29 Clusters were referenced by the capital "C" letter and a figure, e.g. C1 for the first of the five TSO clusters.
30 Cf. the iTesla project: www.itesla-project.eu.

elements to consider when defining the new clusters and FOs so as to improve the readability of the specified R&I activities not only for TSOs but for all stakeholders of the whole electricity value chain.

- The challenges related to generation (integration of renewables), the new loads (electrification of the transport and building sectors) and the optimal use of the network infrastructures are mainly addressed in terms of flexibility options with a specific cluster dedicated to flexibility options (storage, demand response, interactions with other energy networks, improved RES forecasts, power electronics, flexible thermal power generation) i.e. cluster C3 called "**Power system flexibility from generation, storage, demand and network**";
- The challenges related to the digitalisation of the network (IoT, Big data, standardisation for communication and data exchanges between the different stakeholders of the electricity value chain, cyber-security) are addressed in a dedicated cluster, i.e. cluster **C5** called "**ICT and digitalisation of power system**";
- The challenges related to the modernisation of the existing network infrastructures (including new planning tools and asset management methodologies) and new technologies, including new grid architectures, are addressed in a dedicated cluster, i.e. cluster **C1** called "**Modernisation of the network**";
- All market issues (market design and market simulation tools, including the coupling with the gas markets, at different time scales) are addressed in cluster **C4** called "**Economy and efficiency of power system**";
- Finally, network operations (observability and controllability, decision support tools) are dealt with in cluster **C2** called "**Security and system stability**". In terms of policies, this last cluster is linked to the integration of renewables, the new loads, the regional coordination of the pan-European network and the future electricity markets, i.e. how to operate the grid closer to its stability limits in an evolving environment (generation, load, increased cross-border inter-connections, market).

The new clusters proposed above better account for the cross-cutting character of many projects. As an example, for the TWENTIES project 31 which covered three clusters of the previous 2013-2022 EEGI roadmap (C1: Grid architecture, C2: Power technologies, C3: network operations) and five functional objectives could be covered in the present roadmap by two clusters (C1 and C2) and three functional objectives. Regarding the integration of storage in the power system, it is dealt with in a specific FO in cluster C3 (T10), the integration of the power system and the energy system as a whole (interactions between the electricity, the gas and the heat networks) is also addressed in a specific FO in cluster C3 (T14), and active retail markets (how to empower customers so as to have a large pool in Europe of active customers) is addressed through demand-response issues, also in a specific FO in cluster C3 (T11), cf. Table 5.

31 http://www.twenties-project.eu/

Table 3: list of clusters and functional objectives for transmission system.

Cluster	FO ID	Functional Objectives
C1 – Modernization of the network	T1	Optimal grid planning
	T2	Smart asset management
	T3	New materials and technologies
	T4	Environmental challenges and stakeholders
C2 – Security and system stability	T5	Grid observability
	T6	Grid controllability
	T7	Expert systems and tools
	T8	Reliability and resilience
	T9	Enhanced ancillary services
C3 – Power system flexibility from generation, storage, demand and network	T10	Storage integration
	T11	Demand response
	T12	RES forecast
	T13	Flexible grid use
	T14	Interaction with non-electrical energy networks
	T22[32][33]	Flexible thermal power generation
C4 – Economic	T15	Market-grid integration
	T16	Business models
	T17	Flexible market design
C5 – Digitalization of power system	T18	Big data management
	T19	Standardization and data exchange
	T20	Internet of Things
	T21	Cybersecurity

Table 5 hereafter shows the correspondence between the functional objectives listed in Table 3 and the challenges for network operators listed in Table 2.

3.3.2 CONTENT OF THE FUNCTIONAL OBJECTIVES

The content of the transmission system FOs have been updated by measuring the completion of the objectives set in the ENTSO-E R&D (and the EEGI) Roadmap 2013–2022 following an analysis of the gaps presented in the R&D 2015 Monitoring Report[34]. This analysis has been performed for each of the specific tasks of the FOs listed in the previous ENTSO-E roadmap. In complement to the monitoring work of ENTSO-E, the Grid+Storage consortium has also performed a specific monitoring exercise of passed, on-going and planned projects[35] for each functional objective of the ENTSO-E R&D (and the EEGI) Roadmap 2013–2022. Both

32 The R&I challenges for flexible thermal generation have been included, on short notice, at the end of the drafting process of the present roadmap, after discussions in the ETIP SNET with the following members: COGEN Europe, EPPSA, ETN, EUGINE and EUTurbines.
33 The numbering of the existing FOs was kept as such in order not to interfere with already performed work (e.g. the monitoring report).
34 http://rdmonitoring.entsoe.eu/wp-content/uploads/2016/03/entsoe_RD_Monitoring_Report_2015.pdf
35 D3.2, Technical analysis of past and on-going projects, July 2016. www.gridplusstorage.eu

analyses reached similar conclusions thereby strengthening the use of monitoring tools to specify the R&I activities needed for the next decade.

The full description of the functional objectives for the transmission systems can be found in Appendix 1. Table 4 hereafter explains the structure of the functional objectives.

Table 4: structure of the table describing the transmission system FOs.

FO ID	FO title
Contents	Challenges A piece of text to remind the main challenges to be faced by TSOs and the stakeholders of the power system. Objectives The main (functional) objectives describing the expected outputs of the future R&I activities (projects) addressing the FO. Scope A first description of the main families of R&I activities which will help to reach the expected outputs of the projects. Specific tasks The specific R&I activities to be addressed by the future projects.
Expected outcomes	Main features of the expected projects in terms of outputs, e.g. tools and methodologies, demonstrations, etc.
Expected impacts	Expected outcomes of the projects and their use by TSOs and the stakeholders of the power system.
Contributors	Suggestions regarding the partners that should be involved in the projects. The purpose here is to be as exhaustive as possible.
Additional information	Information regarding the inter-dependencies of the FO with other FOs. Also information regarding past and on-going projects with relevant outcomes for the activities of the FO.
Budget estimation	An estimation of the expected resources to be deployed so as to reach the expected outputs (cf. section 4).
Time line	An estimation of the urgency for the network operators, i.e. when the R&I activities should be launched and how long they should last 36.

36 The time line is an appraisal of the urgency of the activities to be launched so as to come up in due time with the needed solutions. A more precise planning will be provided in the implementation plans (e.g. the IP 17-19).

Table 5: correspondence between the future challenges for transmission system operators and the functional objectives.

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
Generation	• Improve the observability and the controllability of the network.	**T5** – Grid observability **T6** – Grid controllability
	• Improve the accuracy of the generation forecast.	**T12** – RES forecast
	• Develop methodologies and tools to operate the network closer to its physical limits without jeopardizing its security.	**T7** – Expert systems and tools
	• Identify and support improvements of suitable flexibility options (RES generation, flexible thermal power generation, load, network, storage, integration with other energy network) to ensure adequacy and security.	**T10** – Storage integration **T11** – Demand response **T13** – Flexible grid use **T14** – Interaction with non-electrical energy networks **T22** – Flexible thermal power generation
	• Utilize system services from intermittent generation.	**T9** – Enhanced ancillary services
	• Improve defence and restauration plans in areas with a deep penetration of PV and wind power.	**T8** – Reliability and resilience
Load	• Use of demand response for system services with well-defined interactions between with the market players and the network operators (and TSO-DSO exchange of information).	**T5** – Grid observability **T11** – Demand response
	• Efficient forecast of demand (and residual loads) accounting for the new loads and the demand-response activities of new market players.	**T11** – Demand response
Network infrastructures	• Optimising the existing assets making use of new technologies	**T2** – Smart asset management **T3** – New materials and technologies
	• Developing pan-European electricity highways with both AC and DC technologies	**T3** – New materials and technologies **T6** – Grid controllability **T13** – Flexible grid use
	• Study and demonstrate new grid architectures both at transmission and distribution level as a source of flexibility.	**T1** – Optimal grid design **T13** – Flexible grid use

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
	• Decrease the environmental footprint of the network reinforcements.	**T4** – Environmental challenges and stakeholders
	• New planning tools able to account for the full complexity of electricity networks (distributed and intermittent generation, variable and controllable loads, power electronics, storage, etc.).	**T1** – Optimal grid design
Digitalisation of the network	• Make use of IoT and data mining techniques (big data) to develop smart asset management strategies.	**T2** – Smart asset management **T20** – Internet of Things
	• Make use of data mining techniques and HPC to better manage the network, closer to its physical limits.	**T5** – Grid observability
	• Coordinate and participate in standardization activities for communication and data exchanges between the different stakeholders of the electricity value chain.	**T19** – Standardization and data exchange
	• Ensure the physical and cyber-security of the digital substations.	**T21** – Cyber security.
Network operators	• Increased TSO collaboration.	**T19** – Standardization and data exchange
	• Increased exchange of information between TSOs and DSOs.	**T5** – Grid observability **T18** – Big data management
Technologies	• Improve storage integration at all time scales (in operation for system services but also when performing planning studies as an additional degree of freedom) as a source of flexibility. • Appraise the real value brought by small to medium scale storage systems in network operations by deploying real-life demonstrations.	**T10** – Storage integration
	• New materials and technologies to increase the flexibility of the grid	**T3** – New materials and technologies
Integration within the energy system	• Interactions with the gas network for storage of chemical energy.	**T14** – Interaction with non-electrical energy networks

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
	• Interactions with the heat network for storage of thermal energy. • Interactions of the transmission and distribution grids with the gas and heat networks so as to better operate the power system. • Optimisation of the energy system.	
Market	• Validate flow-based market-coupling tools that can be extended geographically and temporally. • Enforcing market design for the integration of renewables at different time scales. • Optimized integration of market and network operations all time scales (from long-term to real time). • Integrate new market players providing system services.	**T15** – Market-grid integration **T16** – Business models **T17** – Flexible market design
	• Participate in the assessment of the regulatory framework for storage operations and the associated remuneration of system services.	**T10** – Storage integration

3.4 CLUSTERS AND FUNCTIONAL OBJECTIVES FOR DISTRIBUTION SYSTEMS

3.4.1 A NEW MATRIX STRUCTURE

As for the transmission systems, the Grid+Storage partners have also considered the policy drivers of the SET Plan environment and more generally the climate and energy policies of the EU as the main elements for the definition of the new clusters and FOs.

Contrarily to the transmission systems, four of the five existing clusters have been kept and the FOs have been slightly modified. However, a second dimension has been added, i.e. the R&I activities have been specified in terms of cross-cutting challenges so as to improve the readability of the functional objectives and more generally for projects addressing these cross-cutting challenges. This has resulted in a matrix-like structure where on the one side there are the clusters and on the other side cross-cutting challenges. The cross-cutting challenges cover R&I activities related to:

- the **upgrading of the network**, i.e. new technologies, tools and methodologies to better improve the operations of the existing infrastructures and develop new grid architectures, e.g. the digitalisation of the MV/LV substations, the hardware and software solutions in substations connecting TSOs and DSOs, new protections schemes for two-way power flows, new planning and optimization tools, etc. This cross-cutting challenge has an R&I scope which is similar to the one of the C1 cluster for transmission systems (modernization of the network);
- **Power system flexibility**, i.e. all flexibility options (hardware and software solutions) to manage the distributed intermittent generation and the distributed new loads (heat pumps, electric vehicles, etc.). This includes e.g. software solutions, new control strategies and the use of energy storage for instance. The coverage of the R&I activities here is the same as the C3 cluster for transmission systems (power system flexibility from generation, storage, demand and network) with however different solutions;
- **Power system reliability**, i.e. the study and the implementation of the available and future solutions to cope with and anticipate all network contingencies, e.g. new protection schemes able to cope with the increasing penetration of PE (including the development of new actuators and sensors), new models and approaches to better understand the life span of all equipment (including storage devices). The R&I coverage of this cross-cutting challenge is strongly related to security and system stability issues addressed for transmission systems in the C2 cluster;
- **ICT and digitalization**, i.e. the study and the implementation of the ICT (hardware solutions and the associated software) to secure all communications between the DSOs and the different stakeholders of the distribution electricity value chain, and to improve the monitoring and the control of both the LV and MV networks. IoT, Big data, standardisation for communication and data exchanges is also included here, as in the C5 cluster for transmission systems (ICT and digitalisation of power system)
- **Market design**, i.e. the study of all incentives (market rules, business models) to foster the advent of demand-response services supplied by (new) market players as well as the all issues related to ancillary services provided by storage operators (ownership, valuation of the ancillary services) and RES generators. This also includes the development of CBA tools to better investigate the social welfare brought by new market designs. This cross-

cutting challenge corresponds to the C4 cluster for transmission systems (economy and efficiency of power system), although the R&I activities address different markets (wholesale and retail markets);

- the **DSOs regulatory environmen**t, i.e. the study of all regulations impacting the operations, asset management and planning activities of DSOs. This includes the regulatory framework of active demand response, access to private consumer data, new electricity tariffs, etc.

It was decided to keep most of the existing clusters because of their good coverage of the key energy policy issues for the distribution system, viz. empowering customers and promoting energy efficiency solutions, cf. cluster C1 (integration of smart customers and buildings) and integrating intermittent generation as well as the new loads, cf. cluster C2 (Integration of decentralised generation, demand, storage and networks). Cluster C2 has actually been extended: the previous C2 cluster did not cover the integration with other energy networks and as a consequence a new specific functional objective was added, cf. D7 in Table 6. In cluster C1, the titles of the cluster and the D2 functional objective were slightly changed to make the connection to energy efficiency policies in buildings more explicit even though this point was addressed in the description of D2 in the previous roadmap.

Table 6: Distribution system clusters and FOs of the RIR (new FOs as well as extended cluster and FO coverages are indicated by underlined text).

Cluster	Functional Objectives	
C1 – Integration of smart customers and buildings	D1	Active demand response
	D2	Energy efficiency from integration with smart homes and buildings
C2 – Integration of decentralised generation, demand, storage and networks	D3	System integration of small DER
	D4	System integration of medium DER
	D5	Integration of storage in network management
	D6	Infrastructure to host EV/PHEV – Electrification of transport
	D7	Integration with other energy networks
	D14 [37] [38]	Integration of flexible decentralised thermal power generation
C3 – Network operations	D8	Monitoring and control of LV network
	D9	Automation and control of MV network
	D10	Smart metering data processing and other big data applications
	D11	Cyber security (system approach)
C4 – Planning and asset management	D12	New planning approaches and tools
	D13	Asset management

37 The R&I challenges for flexible thermal generation have been included, on short notice, at the end of the drafting process of the present roadmap, after discussions in the ETIP SNET with the following members: COGEN Europe, EPPSA, ETN, EUGINE and EUTurbines.
38 The numbering of the existing FOs was kept as such in order not to interfere with already performed work (e.g. the monitoring report).

In the network operation cluster, the FO related to the network management tools (in the previous 2012-2022 EEGI roadmap) was removed: the development of network management tools to better operate the distribution grids, closer to their physical limits, is now mainly addressed in the FOs related to the integration of intermittent generation units (D3 and D4), the new loads (D6) as well as the monitoring and control of the LV and MV networks (D8 and D9). Specific digitalisation issues were added, viz. cyber security (new FO, cf. D11 in Table 6 and big data applications (modified coverage of D10).

The planning and asset management FOs (and consequently the C4 cluster) were kept unchanged with an emphasis on the need for new planning approaches and simulation environments able to cope with the full complexity of the distribution networks (the title of D12 was modified). The C5 cluster (market design) was removed: as explained above, market design is a cross-cutting challenge since impacting most of the activities of the DSOs. Table 7 shows the distribution of the functional objectives in the two-dimensional structure, i.e. clusters and cross-cutting challenges.

Table 7: distribution of the FOs in the two-dimensional structure (clusters and cross-cutting challenges). The titles of the functional objectives have been shortened for the sake of clarity

	Upgrading of the network	Power System Flexibility	Power system reliability	ICT and digitalization	Market design	DSO regulatory environment
C1	Demand (D1) EE (D2)	Demand (D1) EE (D2)	Demand (D1) EE (D2)	Demand (D1) EE (D2)	Demand (D1) EE (D2)	Demand (D1) EE (D2)
C2	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6) Integration of other energy networks (D7)	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6) Integration of other energy networks (D7)	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6) Integration of other energy networks (D7)	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6) Integration of other energy networks (D7)	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6) Integration of other energy networks (D7)	Small DER (D3) Medium DER (D4) Storage (D5) EV (D6)
C3	LV Monitoring (D8) MV Automation (D9) Smart metering (D10) Cyber security (D11	MV Automation (D9) Smart metering (D10) Flexible decentralised thermal generation (D14)	LV Monitoring (D8) MV Automation (D9) Smart metering (D10) Cyber security (D11)	LV Monitoring (D8) MV Automation (D9) Smart metering (D10) Cyber security (D11)	LV Monitoring (D8) MV Automation (D9) Smart metering (D10)	
C4	Planning (D12) Asset (D13)	Planning (D12) Asset (D13)	Asset (D13)	Asset (D13)	Planning (D12) Asset (D13)	

3.4.2 CONTENT OF THE FUNCTIONAL OBJECTIVES

There is a direct correspondence between the FOs of Table 6Table 6: Distribution system clusters and FOs of the RIR (new FOs as well as extended cluster and FO coverages are indicated by underlined text). and the future challenges for network operators identified in section 2 (which are linked to the policy drivers identified in section 1). This correspondence is displayed in Table 9 hereafter.

The content of the distribution system FOs have been updated by following two main guidelines:

- Measure the coverage of the generated knowledge: this was performed by monitoring and assessing passed, ongoing and future projects 39 as for transmission system FOs. When the coverage was sufficient, the corresponding R&I activities were not repeated in the new description. No functional objectives were considered as fully covered, most of them being only partially covered, cf. D3.2;
- Position the R&I activities in the general framework, i.e. the specifications of the Grid+Storage service contract (link the impact of the R&I activities both on the SET plan and the Energy Union policies).

The structure of the functional objectives was slightly amended (compared to the previous EEGI 2013-2022 roadmap) as displayed below in Table 8. The specific tasks are now classified in terms of cross-cutting challenges (replacing the previous classification: Scientific, Technology, Market, Social). The previous "additional information" line was replaced by "Expected projects".

Table 8: structure of the table describing the FOs for distribution systems.

FO ID	FO title
Contents	Challenges A piece of text to remind the main challenges to be faced by TSOs and the stakeholders of the power system. Objectives The main (functional) objectives describing the expected outputs of the future R&I activities (projects) addressing the FO. Scope A first description of the main families of R&I activities which will help to reach the expected outputs of the projects. Specific tasks The specific R&I activities to be addressed by the future project classified in terms of cross-cutting challenges • Upgrading of the network • Power system flexibility • Power system reliability • ICT and digitalization • Market design • DSO regulatory involvement

39 D3.2, Technical analysis of past and on-going projects, July 2016. www.gridplusstorage.eu

FO ID	FO title
Expected benefits	Suggestions regarding the partners that should be involved in the projects. The purpose here is to be as exhaustive as possible.
KPIs	A list of KPIs to be used by the different projects so as to measure the impact of their direct impact on the addressed activities.
Partners involved	Suggestions regarding the partners that should be involved in the projects. The purpose here is to be as exhaustive as possible.
Expected projects	Main features of the expected projects in terms of outputs, e.g. tools and methodologies, demonstrations, etc.
Budget	An estimation of the expected resources to be deployed so as to reach the expected outputs (cf. section 4).
Time line	An estimation of the urgency for the network operators, i.e. when the R&I activities should be launched and how long they should last.[40]

In order to link the impact of the R&I activities with both the SET plan and the Energy Union, a new table was added for each functional objective.

Expected impacts: Energy Union	Energy security, solidarity and trust	A piece of text explaining for each of the relevant pillars of the Energy Union and the SET Plan key actions the main impacts of the R&I activities specified in Table 8 (specific tasks).
	A fully integrated European energy market	
	Energy efficiency contributing to moderation of demand	
	Decarbonising the economy	
Expected impacts: SET Plan	Technology leadership	
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	

The full description of the functional objectives for distribution systems can be found in Appendix 2

40 As for transmission, the time line is an appraisal of the urgency of the activities to be launched so as to come up in due time with the needed solutions. A more precise planning will be provided in the future implementation plans (e.g. the next IP 17-19).

Table 9: correspondence between the future challenges for distribution system operators and the functional objectives.

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
Generation	• Improve the observability and the controllability of the network.	**D8** – Monitoring and control of LV network **D9** – Automation and control of MV network
	• Improve the accuracy of the generation forecast.	**D3** – DSO integration of small DER **D8** – Monitoring and control of LV network **D9** – Automation and control of MV network
	• Deploy the hardware and software solutions to host renewables in MV and LV networks (monitoring, automation and control).	**D8** – Monitoring and control of LV network **D9** – Automation and control of MV network
	• Identify and support improvements of suitable flexibility options (RES generation, flexible thermal power generation, load, network, storage, integration with other energy network) to ensure adequacy and security.	**D1** – Active demand response to **D9** – Automation and control of MV network **D14** – Flexible decentralised thermal power generation
Load	• Use of demand response for system services with well-defined interactions between with the market players and the network operators (and TSO-DSO exchange of information).	**D1** – Active demand response
	• Efficient forecast of demand (and residual loads) accounting for the new loads and the demand-response activities of new market players.	
	• Anticipate and plan the impact of the electrification of the building and transport sectors on the electricity network (new equipment at distribution system level especially in urban areas).	**D2** – Energy efficiency from integration with smart homes and buildings **D6** – Infrastructure to host EV/PHEV – Electrification of transport
	• Prepare the shift from passive to active consumers by allowing all means for communication via smart meters.	**D2** – Energy efficiency from integration with smart homes and buildings
	• Optimising the existing assets making use of new technologies	**D13** – Asset management

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
Network infrastructures	• Study and demonstrate new grid architectures both at transmission and distribution system level as a source of flexibility.	**D3** – DSO integration of small DER
	• New planning tools able to account for the full complexity of electricity networks (distributed and intermittent generation, variable and controllable loads, power electronics, storage, etc.).	**D12** – New planning approaches and tools
Digitalisation of the network	• Scalable solutions to address large-scale data management (customers, equipment, network, market) issues in the power system.	**D10** – Smart metering data processing and other big data applications
	• Make use of IoT and data mining techniques (big data) to develop smart asset management strategies	**D13** – Asset management
	• Coordinate and participate in standardization activities for communication and data exchanges between the different stakeholders of the electricity value chain.	**D1** – Active demand response
	• Ensure the physical and cyber-security of the digital substations.	**D11** – Cyber-security
Network operators	• Increased exchange of information between TSOs and DSOs.	**D1** – Active demand response **D4** – System integration of medium DER **D9** – Automation and control of MV network
	• Standardization and interoperability of system architecture, protocols and data models.	**D10** – Smart metering data processing and other big data applications
	• Optimal management and activation of local flexibilities. • Accelerate the large scale deployment and validation of advanced automation and control solutions	**D8** – Monitoring and control of LV network **D9** – Automation and control of MV network
Technologies	• Improve storage integration at all time scales (in operation for system services but also when performing planning studies as an additional degree of freedom) as a source of flexibility.	**D5** – Integration of storage in network management

Policy drivers	Future challenges for transmission system operators	Corresponding functional objectives
	• Appraise the real value brought by small to medium scale storage systems in network operations by deploying real-life demonstrations.	
Integration within the energy system	• Interactions with the gas network for storage of chemical energy. • Interactions with the heat network for storage of thermal energy. • Interactions of the transmission and distribution grids with the gas and heat networks so as to better operate the power system. • Optimisation of the energy system.	**D7** – Integration with other energy networks
Market	• Optimized integration of market and network operations all time scales (from long-term to real time); • Integrate new market players providing system services • Participate in the assessment of the regulatory framework for storage operations and the associated remuneration of system services. • Enable well-functioning retail markets so as to empower the end users.	**C1** – Integration of smart customers and buildings **C2** – Integration of decentralised generation, demand, storage and networks **C3** – Network operations

3.5 TSO AND DSO COMMON ACTIVITIES

As explained in section 2, network operators (TSOs and DSOs) will have to cope with future challenges in the decades to come but their respective missions will remain the same within costs and resources efficient boundaries. TSOs will have to ensure the overall system reliability (adequacy and security) via frequency control as well as voltage control and congestion management. DSOs will have to keep managing voltage stability and congestion of their grids. As explains at length above, the increasing share of renewables installed in the distribution grid as well as the new loads (electrification of heating and cooling, EVs, etc.), mainly connected at LV (mainly PV) and MV (both PV and wind power) levels, will change the way TSOs and DSOs exchange information and coordinate their activities, both for operations and planning. Indeed, both TSOs and DSOs will have to share a common pool of generation and loads (demand-response) to operate their respective grids and therefore they will have to intensify their coordinated activities.

In a common publication 41, the associations representing DSOs (EDSO with GEODE, Eurelectric and CEDEC) together with ENTSO-E have listed these intensified coordinated activities:

- A *coordinated access to resources* (flexibility sources from generation and loads through demand response) so that, for instance, activation of large blocks of load shedding by TSOs are anticipated by the impacted DSOs, or the use of reactive power from renewables to support voltage levels simultaneously;
- *Grid visibility and grid data* i.e. intensify the information and data exchange within standardized procedures (communication tools and protocols), for example to coordinate real-time congestion management (caused for instance by the actions of market players with whom DSOs and TSOs have no direct involvement);
- *Regulatory stability* i.e. make sure that the respective regulatory regimes for TSOs and DSOs account for the system point of view (TSOs and DSOs should be able to find the best solutions for operations and planning within their respective grids while optimising the electricity network as a whole).

These coordinated activities will bring benefits to all stakeholders of the electricity value chain:

- End-customers will have the best comprise between the tariffs and the quality of service;
- Market players providing flexibility options (system services) will be able to bid easily, possibly in a single market place so as to fully integrate bids for balancing and congestion management;
- TSOs and DSOs will be able to better operate their network and optimise the planning at the power system level, and as a consequence reduce their fixed and variable costs.

In the present RIR, R&I activities relative to the coordinated activities of TSOs and DSOs have been specified in each of the relevant functional objectives of the TSOs (transmission system level) and the DSOs (distribution system level), cf. Table 10 and Table 11. Contrarily to the previous roadmap (the EGGI 2013-2022 roadmap), it has been considered that since there should be a seamless integration between TSO and DSO activities, there is no longer a need to specify R&I activities in a specific cluster: R&I activities related to TSO and DSO

41 https://www.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/entsoe_pp_TSO-DSO_web.pdf

collaborations should be included in their respective portfolio and not in a specific portfolio to be dealt with and set aside the other R&I activities.

Table 10: common TSO-DSO activities listed in the functional objectives for transmission systems.

Cluster	FO	Common topics: TSO/DSO collaborations
C1 – Modernization of the network	T1	DSO identified as contributors (investment signals to be sent to DSOs, i.e. delivery of planning tools for network development including TSO-DSO system development).
	T4	DSO identified as contributors.
C2 – Security and system stability	T5	Enhance the TSO/DSO communication interface and design new architecture for data exchanging and processing at various system levels and in different time frames, from short-term to long term (from real time operational planning to network planning).
	T6	DSO identified as contributors.
	T8	DSO identified as contributors: joint TSO / DSO approach for defence plans involving DER and micro-grids (expected RES in-feed of DSO at reconnection).
	T9	DSO identified as contributors: new ancillary services with more active contribution from demand and units connected at DSOs networks and from DSO facilities.
C3 – Power system flexibility from generation, storage, demand and network	T10	DSO identified as contributors.
	T11	DSO identified as contributors: integrate demand response at DSO level into TSO operations.
	T12	DSO identified as contributors.
	T14	DSO identified as contributors.
C4 – Economic efficiency of power system	T17	DSO identified as contributors.
C5 – Digitalization of power system	T18	DSO identified as contributors: develop together with TSOs protocols for data transfer

Table 11: common DSO-TSO activities listed in the functional objectives for distribution systems.

Cluster	FO	Common topics: TSO/DSO collaborations
C1 – Modernization of the network	D1	*TSO identified as contributors*: solutions in substation connecting TSOs and DSOs so as to exchange data and allow the provision of AD-based system services from aggregators to TSOs through DSOs. Demonstrate the ability of DSOs to enable aggregators to provide AD-based system services to TSO through coordinated communications between TSOs and DSOs.
C2 - Integration of decentralised generation, demand, storage and networks	D4	*TSO identified as contributors* : energy management platforms allowing the secure connections and data exchange with all market players and the TSOs;
C3 - Network operations	D6	TSO identified as contributors.

Cluster	FO	Common topics: TSO/DSO collaborations
	D9	*TSO identified as contributors*: interactions between TSOs and DSOs (increase observability of the distribution system for transmission network management and controllability with better forecasting and data flow).
C4 – Economic efficiency of power system	D11	*TSO identified as contributors*: engage a common work with TSOs (cybersecurity issues are common to both transmission and distribution system operators at inter-connected infrastructures).

The activities listed in these two tables are in agreement with the above mentioned activities, e.g. A coordinated access to resources (cf. T8, T9, T11 in Table 10 and D1 in Table 11) and Grid visibility and grid data (cf. T5 in Table 10 and D1, D4, D9 in Table 11).

3.6 STORAGE INTEGRATION

As mentioned above, storage 42 has been addressed in the present roadmap from the system integration point of view, i.e. the definition of all R&I activities related to the integration of all storage technologies in the power system and in the energy system as a whole (e.g. technologies where electricity is converted into thermal or chemical energy therefore allowing storage of energy which can be used to produce electricity or as a fuel for mobility or a source to produce heat, etc.). R&I activities are solely related to the integration aspects whereas the improvement of the technologies (efficiency, lifespan, costs, etc.) is addressed by other roadmaps and projects, cf. e.g. www.batstorm-project.eu.

When defining storage integration R&I activities, grid operators and storage players consider the integration aspects of their R&D efforts to encompass three dimensions:

- **Functional integration** of storage-based solutions within the power system - R&I activities address the optimal mixes of technological and application options, interface definitions, studies under real life conditions and the provision of experimental data and numerical simulation studies to validate how much more efficient end-to-end functionalities will be with the support of energy storage solutions. Such activities follow technologies already developed by storage players and that have already reached TRL 7 or TRL 8 43. Future R&I activities will aim to bring the TRL levels of the grid operator innovative solutions (storage integrated into the system) from TRL 6 to TRL 8 44;
- **Temporal integration** of storage-based solutions where R&D activities address the lifecycle of the integrated solutions in terms of reliability and techno-economic performances (life cycle cost -LCC- analyses) as well as manufacturability. These data (especially LCC) are critical when assessing new policies, new market designs and possibly new regulations which make the market uptake of the integrated storage solutions economically efficient. These activities cover also TRL 6 to TRL 9 of grid operators.

42 Energy Storage in the electricity system would be defined as the act of deferring an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier.
43 TRL means “Technology Readiness Level”.
44 Technology providers and grid operators view TRL in a different timescale, where network operators require significant field testing before considering a technology to be deployable (TRL 9). « Interaction between smart grids initiatives – comparison of roadmaps and implementation plans » GRID+ report D2.4 , October 2014

- **Spatial and environmental integration** into the most complex electricity system worldwide - This requires a fine tuning of the optimal scale (i.e. where storage solutions are most attractive, for example, single home, factories, city districts or pan-Europe coverage) and an adjustment to local climates (northern Europe for wind power versus Mediterranean regions for solar resources, seaside versus mountains) and to areas (mega-cities versus countryside, urban areas versus natural protected areas). These activities fall under TRL 9, where integrated solutions have been tested in real-life situations, but where deployment optimisation needs further study and support from national regulatory authorities.

In the present roadmap, storage integration R&I activities have been mainly specified in two dedicated functional objectives for the transmission and distribution systems respectively:

- Functional objective T10 (Storage integration) in cluster C3 (Power system flexibility from generation, storage, demand and networks);
- Functional objective D5 (Integration of storage in network management) in cluster C2 (Integration of decentralised generation, demand, storage and networks).

Due to the cross-cutting dimension of storage integration, R&I activities have also been defined in other clusters and functional objectives, cf. Table 12 and Table 13. These tables show that TSOs and DSOs (and the stakeholders of the power system) have a common view on the use of storage in their different activities:

- Planning, where new planning tools should be able to account for the added value brought by the integration of energy storage solutions;
- Operations, where storage integration is identified as a key component for coupling the power system with the other energy networks, for automation and control, and possibly defence and restoration plan (this last point is identified as an overall system activity, cf. section 3.5). Both TSOs and DSOs (and the stakeholders of the power system) also identify a need to standardise the interfaces (protocols) with storage components.
- Market, where both TSOs and DSOs (and the stakeholders of the power system) agree that adequate market signals should be promoted so as to ensure an optimised sizing and localisation of storage devices, and studies should be launched so as to determine a fair valuation of ancillary services brought by storage.

Table 12 and Table 13 also show that TSO and DSO (and the stakeholders of the power system) have specific views on the R&I activities related to storage integration: the use of storage in islanding for DSOs and the development of market simulation tools accounting for storage. TSOs and other market players also have a need for R&I activities dedicated to the lifespan of storage technologies depending upon their use. This last point is related to the regulatory issues (ownership and operation of storage device) which are mentioned in the specific storage integration functional objectives.

Table 12: mapping of the topics related to storage issues in the different distribution system functional objectives and cross-cutting challenges with the three types of integration (functional, temporal and spatial). [Psf]: Power system flexibility. [Utn]: Upgrading of the network. [Md]: market design. [Gen]: not related to specific tasks but rather to the scope.

Cluster and FO	Challenge/Storage topic	Type of integration
C1-D2	• **[Psf]*** […] Islanding capability at local level to be activated in emergency situations (in the presence of […] **storage**)	Functional
C2-D3	• **[Utn]** New planning tools […] accounting for all components of LV networks (**storage**) including all control systems (especially power electronics).	All
	• **[Utn]** Study and possibly demonstrate the added value of LV DC grids to lower costs of BoS and to better control power flows when coupling PV, **storage** and other DC devices.	Functional, temporal
	• **[Utn]** Create universal interface devices and protocols to enable DSO information exchanges with DER (mainly for third party owned PV and **storage**).	Functional, temporal
	• **[Md]** Recommendations for valuation of ancillary services brought by distributed PV systems (possibly through self-consumption or when connected to **storage** devices)	Functional, temporal
C2-D4	• **[Gen]** Energy **storage** and demand response as solutions to balancing issues, as well as new options to address power quality and network losses management.	Functional, temporal
C2-D6	• **[Gen]** Energy management in public transport electricity network located with storage solutions in substations (connecting with the local DSO) to provide system services to DSOs	Functional
	• **[Psf]** Further develop V2G technology solutions and assess the true costs of implementation and the benefits.	Functional, temporal
C2-D7	• **[Gen]** Thermal storage: quantify and demonstrate the flexibility brought by coupling electricity distribution networks and heating (and cooling) networks.	All
	• **[Gen]** Chemical storage: quantify and demonstrate the flexibility brought by coupling electricity distribution networks and gas networks.	All

	• **[Md]** Market design […] for thermal storage for participation in electricity and heating markets.	Functional, temporal
C3-D8	• **[Utn]** Study automatic control concepts and determine the most cost-effective automation level […] with […] adapted protection schemes and use of decentralized **storage**.	Functional
C3-D9	• **[Utn]** Middleware layers […] as a possible alternative for the management of MV networks hosting large share of renewables (including **storage**).	Functional
	• **[Utn]** Develop protection schemes as well as remote control systems for two-way power flows (communication with power electronics of generation and **storage**) and network switches.	Functional
C4-D12	• **[Utn]** Study all alternatives […] to network reinforcements and new lines/links e.g. by using energy **storage**, […]	All
	• **[Utn]** Methodologies and simulation packages allowing DSOs to determine where the connection of new generation units, loads and **storage** should be encouraged (signal to market players).	All

Table 13: mapping of the topics related to storage issues in the different transmission system functional objectives and cross-cutting challenges with the three types of integration (functional, temporal and spatial).

Cluster and FO	Challenge/Storage topic	Type of integration
C1-T1	• To develop planning methods combining electricity market analysis, production […], demand response capacities and infrastructure, **storage** and environmental constraints, both for the transmission and distribution systems [...].	All
	• To develop probabilistic planning methods respecting the variability of RES, demand response, **storage**, self-consumption and their uncertainty.	All
C1-T3	• To demonstrate the degree to which transfer capacity and performance of assets can be increased through the implementation of different approaches (materials) and technologies. Assessment of new **storage** technologies.	Functional, temporal
	• Develop the technologies to coordinate with **storage** infrastructure and gas as well as heat network.	Functional, temporal
	• Standardization of strategic components and system and multivendor applications with all PE interfaced devices (generation, load, **storage**) connected to the transmission network	Functional, temporal
C2-T6	• Assess the contribution to controllability of large-scale new power technologies […] such as […] energy **storage**, […] and other promising technologies for joint control of on- and off-shore networks, […]	Functional
	• Validate the contribution of RES to voltage and frequency control, as well as balancing, by using different concepts, especially for direct-drive machines: […], local **storage**, etc.	Functional, temporal
C2-T8	• Develop simulation tools and methods that detect weaknesses in the system with respect to reconnecting DER and **storage** systems	Functional, spatial
	• Engage **storage** in defense and restoration tools and plans	Functional, spatial
C2-T9	• Novel ways of providing ancillary services through **storage** systems and their impact on transmission networks	All

	• New actors and market models that enable DER and **storage** to provide ancillary services.	All
C3-T11	• Integrate and demonstrate DR and **storage** integration solutions including the impact of the electrification of transport system […] for off-peak hours and their usage in system balancing;	All
C4-T16	• Several tools […] to be designed and developed: […] global modelling of the major energy carriers, able to account for the different players involved […]. All capacity means ought to be considered (demand response, **energy storage**, generation), regarding their contribution to security of supply.	Functional, temporal

3.7 INTEGRATION OF FLEXIBLE POWER GENERATION

Flexible power generation is one of the main flexibility options that can provide ancillary services to transmission and distribution system operators. Historically, the flexibility brought by power generation has come from dispatchable units, some of them based on RES (hydro power) even though, today, in most European countries a significant part of the flexibility is still provided by fossil-fired thermal power generation. RES dispatchable thermal power generation is developing: biogas -gas turbines- and biomass -boilers-, geothermal and more recently CSP 45. Non-dispatchable renewables such as wind power and PV can also be more predictable provided that adequate forecasting and energy management systems are available. In the present roadmap, R&I activities relative to the flexibility provided by non-dispatchable RES and thermal power generation (TPG) have been specified 46, 47.

The R&I activities for flexible non-dispatchable RES power generation are mainly addressed for transmission systems in T12 (RES forecasting) and for distribution systems in D3 and D4 (System integration of small and medium DER, respectively).

The TPG R&I activities are classified into two categories, i.e. centralised generation (new solutions through the increased flexibility of the thermal power plants to provide e.g. adequate system services) and decentralised generation (increase of flexibility and integration within energy networks). These two categories correspond to two functional objectives for the transmission and distribution systems, respectively:

- T22 (Flexible thermal power generation) in cluster C3 (Power system flexibility from generation, storage, demand and network);
- D14 (Integration of flexible decentralised thermal power generation) in cluster C2 (Integration of decentralised generation, demand, storage and networks).

The cross-cutting feature of the flexible TPG R&I activities is highlighted in other FOs by mentioning where TPG stakeholders could contribute to future projects 48. The possible TPG activities in these FOs for transmission and distribution systems will be further specified in the coming implementation plans, for instance the next 2017-2019 implementation plan of the ETIP SNET to be released in 2017. Some examples are however given hereunder.

Table 14: examples of possible TPG activities in the FOs for transmission and distribution systems.

FO	Possible activities
T1	Power plants technological design to be integrated into grid models.
T10	Increase the integration of storage in thermal power plants in order to improve their flexibility.
D5	Increase the integration of storage in cogeneration units in order to improve their flexibility.

45 Concentrated Solar Power is dispatchable when coupled to thermal storage (e.g. molten salts).
46 TPG allows the coupling of gas, electricity and heat networks through co-generation (CHPs) for instance.
47 The R&I needs for other flexible power generation technologies such as hydro where there are similar needs as for TPG (extension of the operating range, improvement of load following capabilities with power electronics -variable speed machine-) will be addressed in the next road mapping exercise.
48 This possible contribution is mentioned by adding the TPG stakeholders in the list of possible contributors to the relevant FOs.

FO	Possible activities
D7	Optimise the connection, control and management of CHPs connected to district heating networks, including those coordinated as "virtual power plants", so as to provide flexibility.

The R&I needs of the centralised and decentralised flexible TPG sector go beyond integration and flexibility issues, in line with the Strategic Targets set out in the Declaration of Intent of the SET-Plan Action 4.1., for instance technological improvements relative to efficiency, losses and emission reduction: by 2030, 50% of all thermal power plants (new as well as retrofitted) should meet the flexibility requirements demanded by variable RES. This requires:

- Doubling of average ramping-rates;
- Halving efficiency losses for part-load operations;
- Reducing minimum load by 30% compared to the average of today.

3.8 THE RIR WITHIN THE EXISTING FRAMEWORK

The objective of this subsection is to position the RIR (and the specified R&I activities) within the existing framework, i.e. the EEGI roadmap 2013-2022, the ENTSO-E 2017-2026 roadmap, the SET Plan IR and the EASE/EERA Roadmap towards 2030.

- The RIR is an in-depth revisit of the existing contents of the functional objectives of the EEGI 2013-2022 roadmap with a specific focus on the integration of energy storage and other important targets set by the DG Energy regarding the advent of "active customer" and the interactions with other energy networks (gas and heating/cooling). These targets are thoroughly addressed in the RIR in view of increasing the flexibility of the pan-European electricity system and in order to deal with, amongst others, higher shares of variable renewable electricity generation and new loads, cf. Table 1.
- The ENTSO-E roadmap is produced every third year in compliance with Regulation (EC) 714/2009 and submitted to ACER after an internal validation process. ENTSO-E being a partner of the Grid+Storage consortium, it has been proposed to merge the description of the functional objectives for transmission system (which include storage integration), exactly as written in the ENTSO-E 2017-2026 roadmap, in appendix 1 of the present integrated roadmap, following the suggestions for improvement from the partners of the consortium and the different consultations organized by ENTSO-E, including a public consultation 49. In the present roadmap, there are two major differences with the ENTSO-E 2017-2026 roadmap: the introductory chapters are different (i.e. sections 1 to 0) and the impacts are provided in terms of the main targets of the Energy Union and the relevant dimensions of the key actions of the SET Plan (cf. section 5.2). As far as the Grid+Storage public consultation is concerned, some of the remarks that were made regarding the content of the transmission system functional objectives (after the public consultation organized by ENTSO-E) have been reported in a dedicated note 50. These remarks are not part of the ENTSO-E 2017-2026 roadmap.
- The EASE/EERA Roadmap towards 2030 has been used as a reference to better address the technological challenges relative to the integration of different storage technologies as

49https://www.entsoe.eu/news-events/announcements/announcements-archive/Pages/News/Have-your-say-on-our-Research--Innovation-Roadmap-.aspx
50 Public consultation of the Grid+Storage R&I roadmap, www.gridplusstorage.eu (this note is not an official deliverable of the Grid+Storage project).

well as the possible applications in the power system, and the energy system as a whole. EASE being a partner of the Grid+Storage consortium, the consistency between the description of the functional objectives addressing storage issues (T10 for transmission systems and D5 for distribution systems, cf. appendix 1 and 2 respectively) and the content of the EASE/EERA Roadmap towards 2030 has been checked (as a matter of fact, this coherence check has been performed for all functional objectives where storage is addressed as a cross-cutting issue, cf. section 3.6).

- The SET Plan IR: all the consortium members of Grid+Storage have contributed directly or indirectly via the associations to the construction of the Integrated Roadmap of the SET Plan, especially heading 2 of part II (energy grids, storage, demand response, flexible energy generation and cross-technology options).

4. RESOURCES FOR THE R&I ACTIVITIES

In the following, an estimation of the needed resources (expressed in Euros) to address all the R&I activities specified in Appendices 1 and 2 is given. This estimation is provided for a full coverage of the R&I activities (including the successful achievement of the expected outcomes): as such, the appraised resources are a proxy for the total budget for all stakeholders of the power system (and the energy system) over the full set of future projects so as to reach the ambitious targets of the RIR, both for transmission and distribution systems.

4.1 RESOURCES FOR THE R&I ACTIVITIES OF TRANSMISSION SYSTEMS

The estimation of the needed resources for the implementation of the transmission systems' R&I activities in the decade to come are detailed in the ENTSO-E 2017-2026 roadmap. The estimated amount is approximately 1.1 billion euros, cf. Table 15.

Table 15: estimated funding needs for the transmission systems' R&I activities in million euros.

Cluster	FO ID	Functional Objectives	Funding	
C1	T1	Optimal grid planning	40	220
	T2	Smart asset management	40	
	T3	New materials and technologies	120	
	T4	Environmental challenges and stakeholders	20	
C2	T5	Grid observability	70	290
	T6	Grid controllability	60	
	T7	Expert systems and tools	50	
	T8	Reliability and resilience	50	
	T9	Enhanced ancillary services	60	
C3	T10	Storage integration	100	420
	T11	Demand response	80	
	T12	RES forecast	40	
	T13	Flexible grid use	30	
	T14	Interaction with non-electrical energy networks	30	
	T22	Flexible thermal power generation	140	
C4	T15	Market-grid integration	30	70
	T16	Business models	20	
	T17	Flexible market design	20	
C5	T18	Big data management	20	90
	T19	Standardization and data exchange	20	
	T20	Internet of Things	30	
	T21	Cybersecurity	20	

This overall amount has been built with a bottom-up approach by estimating and summing up the estimated amounts for each FO within each cluster. The methodology for the investment estimation relies on a gap analysis which is performed within the framework of the monitoring of the projects.

The analysis includes national, cross-border and European projects. The amount specified in Table 15 for each FO cannot be supported by European funds only: other funding resources will be necessary (national, transnational, private investments).

For the flexible thermal power generation FO, the estimate of the amount has been provided by the involved stakeholders following an analysis of the overall needs to reach the required system flexibility 51. This estimate was not subject to the same scrutiny and systematic approach as the other figures because it was provided during the very last part of the consultation process and within a limited period of time. This analysis will be further developed in the activities of WG (Working Group) 3 of the ETIP-SNET.

4.2 RESOURCES FOR THE R&I ACTIVITIES OF THE DISTRIBUTION SYSTEMS

The estimation of the needed resources for the implementation of the R&I activities for distribution systems are detailed hereafter. The monitoring process (cf. D3.2) has shown that for most of the existing FOs (previous EEGI 2013-2022 roadmap), the coverage of the R&I activities is rather low. As a consequence, it is proposed to rely on the previous analysis to estimate the amount of funding needed per FO. This is detailed in Table 16: the needed amount per FO are the ones of the previous roadmap, taking into account (estimating) the money already spent in passed and ongoing projects at EU level, supplemented by the funding needs for new activities.

Table 16: estimated funding needs for the distribution system R&I activities in million euros (the clusters and FOs of the previous roadmap are indicated in italic text).

Cluster	Functional Objectives		2013	EC 14-15	New	2016	
C1	D1	Active demand response	140	-16		124	263
	D2	Energy efficiency from integration with smart homes and buildings	100	-11	50	139	
C2	D3	System integration of small DER	80	-12		68	622
	D4	System integration of medium DER	90	-11		79	
	D5	Integration of storage in network management	100			100	
	D6	Infrastructure to host EV/PHEV – Electrification of transport	60		40	100	
	D7	Integration with other energy networks	0		150	150	
	D14	Integration of flexible decentralised thermal power generation				125	

51 Consistent with figures previously communicated during the preparation of the SET-Plan "Towards an integrated roadmap" communication, addressing mainly flexibility improvements of turbomachinery – see collected stakeholders input Annex II.

Cluster	Functional Objectives		2013	EC 14-15	New	2016	
C3	D8	Monitoring and control of LV network	150	-8		142	442
	D9	Automation and control of MV network	100			100	
	D9	*Network management tools*	50			0	
	D10	Smart metering data processing and other big data applications	100			100	
	D11	Cyber security (system approach)	0		100	100	
C4	D12	New planning approaches and tools	50		50	100	148
	D13	Asset management	50	-2		48	
C5	D13	*New approaches for market design*	20			0	0

As for transmission systems, European (EC) funds cannot cover the total needs for the decade to come, e.g. approximately 1.5 billion Euros. Other funding sources will be necessary, e.g. at national and trans-national level, or private investments coming from the different stakeholders.

In Table 16, the amount of resources spent to support non-EC funded projects (mainly national project) has not been accounted for since there is no, up to now, reliable information on the share of funding for each functional objective, as many (national) distribution system projects address several functional objectives, cf. D3.2. As a consequence, the amount specified in the last column on the right of Table 16 indicate an upper limit.

The funding for new activities has been distributed as follows:

- The new FOs D7 and D11 have their specific budgets;
- FOs D2 and D6 have an increased budget due the broader scope of the activities, i.e. smart homes and buildings for D2 and the electrification of the transport sector as a whole for D6;
- The former D9 budget is redeployed in D12 where a significant R&I effort is expected so as to come up with new planning tools able to account for the full picture of the power system.

For the flexible decentralised thermal power generation FO, the estimate of the amount has been provided by the involved stakeholders following an analysis of the overall needs to reach the required system flexibility [52]. As for transmission systems, this estimate was not subject to the same scrutiny and systematic approach as the other figures because it was provided during the very last part of the consultation process and within a limited period of time. This analysis will be further developed in the activities of WG (Working Group) 3 of the ETIP-SNET.

52 Based on internal assessments (COGEN-Europe, EPPSA, ETN, EUGINE and EUTurbines), addressing decentralised next generation CHP, fuel flexibility and new grid services.

5. EXPECTED OUTPUTS, OUTCOMES AND IMPACTS

5.1 LIST OF OUTPUTS, OUTCOMES AND IMPACTS

Outputs means what is expected to be achieved and exploited by a project consortium following R&I activities whereas outcomes means what is expected to be used from the project by the same stakeholders as the ones belonging to the consortium. As a consequence, outputs cannot be listed since depending on the future research and innovation (R&I) works to be conducted in the framework of the R&I activities specified in both appendix 1 and appendix 2.

The main outcomes to be generated by the R&I players in the next decade have already been listed in Table 2 of section 2: these are the future challenges to be addressed by the network operators and by the power system (and the energy system) stakeholders.

The impacts, i.e. the effects that may be expected, sometimes after the projects' (i.e. R&I activities) completion for the European society (and the European economy) as a whole, are given in the present roadmap in terms of:

- the main targets of the Energy Union;
- and the relevant dimensions of the key actions of the SET Plan.

They are listed in the table hereafter.

Table 17: main targets of the energy union and relevant dimensions of the key actions of the SET Plan to appraise the impacts of the roadmap

Expected impacts: Energy Union	Energy security, solidarity and trust
	A fully integrated European energy market
	Energy efficiency contributing to moderation of demand
	Decarbonising the economy
Expected impacts: SET Plan	Technology leadership
	Technology affordability
	New technologies and services to consumers
	Resilience and security of energy system

The impacts have been listed differently for the transmission and the distribution systems' R&I activities: for distribution systems, the impacts have been given for each of the functional objectives (cf. Appendix 2), whereas for transmission systems it is proposed to enumerate them per cluster since the exercise (impacts for each of the functional objectives) has not been included in the ENTSO-E roadmap, cf. Appendix 1. For the sake of consistency, the impacts of the distribution system functional objectives are also displayed and summarized per cluster in Appendix 3.

5.2 KPIS TO MEASURE THE OUTPUTS, OUTCOMES AND IMPACTS OF THE R&I ACTIVITIES

KPIs have already been defined 53 to reflect the overarching goal of the previous EEGI 2013-2022 roadmap and to provide quantifiable estimates of the outcomes of the projects relative to the specified R&I activities. Two kinds of KPIs were proposed:

- the implementation effectiveness 54 KPIs which measured the progress of R&I activities, as a percentage of completion of a functional objective or a set of functional objectives within any of the clusters of the EEGI 2013-2022 roadmap; and
- the expected impact KPIs, which estimated the contribution of the new R&I achievements gained within the EEGI 2013-2022 roadmap

These KPIs have also been used in the present roadmap with slight modifications, especially for the distribution system FOs.

5.2.1 IMPLEMENTATION EFFECTIVENESS KPIS

In their latest roadmap (the ENTSO-E 2017-2026 research, development and innovation roadmap), TSOs have proposed to keep the existing EEGI implementation effectiveness KPIs. The methodology to compute the effectiveness KPIs has been detailed in the 2012 ENTSO-E Monitoring Report 55. These KPIs, which represent an estimate of the coverage of the generated knowledge for each functional objective, is a weighing between the economic value (the cumulated budgets spent on a given functional objective) and an expert view assessing the coverage in terms of generated knowledge (the final KPI is a percentage which is the mean of the economic value and the estimated coverage for past, on-going and expected projects).

For distribution system R&I activities, it has been proposed to simplify the computation of these KPIs and to provide only a percentage based on the expert view, i.e. the economic value has been disregarded since the methodology used in the monitoring process (focussed on specific results which can address several functional objectives -FOs-) has not allowed an accurate estimate of the funds spent on a specific FO 56.

5.2.2 EXPECTED IMPACT KPIS

For the expected impacts KPIs, a three-level structure was proposed:

- Overarching KPIs to appraise the progress brought by EEGI R&I activities towards the overarching goal of the EEGI 2013-2022 roadmap;
- Specific KPIs to appraise the progress brought by R&I activities relative to the different clusters and functional objectives of the EEGI 2013-2022 roadmap;

53 GRID+ project, Deliverable 3.4, "Define EEGI Project and Programme KPIs", April 2013. http://www.gridplus.eu/publicationsandresults/public-deliverables
54 Effectiveness is concerned with measuring the extent to which the objectives have been achieved and the relationship between the intended impact and the actual impact of an activity.
55 ENTSO-E, "Monitoring R&D Roadmap", June 2012 (cf. section 2, "Methodology of monitoring").
56 See D3.1 and D3.2: http://www.gridplusstorage.eu/deliverables.

- Project KPIs to be proposed by each R&I project addressing the R&I activities specified in the different clusters and functional objectives of the EEGI 2013-2022 roadmap.

In general, the definitions of the project KPIs are specific to each individual project and therefore it is not possible to provide a universal set of KPI definitions and calculation methodologies that could be practically applied to all projects. A good example of project KPIs building on the GRID+ methodology can be found here 57.

Table 18 displays the overarching KPIs and the specific KPIs that were proposed in the GRID+ project for the EEGI 2013-2022 roadmap (the methodology to compute them is given in Deliverable D3.4, cf. www.gridplus.eu).

Table 18: overarching KPIs (A1 and A2) and specific KPIs (B1 to B7) of the EEGI 2013-2022 roadmap. The third column shows the KPIs which are recommended for use in the present integrated roadmap for the distribution system functional objectives.

Iden-tifier	Title	Distribution system FOs
A.1	Increased network capacity at affordable cost	
A.2	Increased system flexibility at affordable cost	D1, D2, D5
B.1	Increased RES and DER hosting capacity	
B.2	Reduced energy curtailment of RES and DER	D3, D4, D5, D7, D8, D9
B.3	Power quality and quality of supply	D8, D9
B.4	Extended asset life time	D13
B.5	Increased flexibility from energy players	
B.6	Improved competitiveness of the electricity market	
B.7	Increased hosting capacity for electric vehicles and other new loads	D6

In its road mapping exercise (Research, development and innovation roadmap 2017-2026) ENTSO-E has also proposed to use the existing specific KPIs and to rely on one of the existing overarching KPIs, i.e. *Sustainable network with increased network capacity at affordable cost* which is a proxy of A.2 (Increased network capacity at affordable cost), to measure the progress brought by R&I activities relative to the new clusters and functional objectives. As consequence, in the present integrated roadmap, the B.1 to B.7 KPIs will be recommended for the transmission system clusters and functional objectives.

For the distribution system clusters and functional objectives, it is also recommended to rely on the existing KPIs. Table 18 displays the specific KPIs which can be used for some of the existing and new functional objectives for distribution systems.

Table 18 shows that the A.2 overarching KPI is now used as a specific KPI for three functional objectives related to active demand (D1), energy efficiency (D2) and the integration of storage in network management (D5). Indeed, for these extended (D1 and D2) and new (D5) FOs, the specified R&I activities aim at providing flexibility options to the network operators at an

57 IDE4L, Deliverable D7.1: KPI Definition, December 2014. http://ide4l.eu/results/.

acceptable cost (i.e. since other flexibility options might be available at lower costs) 58. The KPI has been renamed to *Increased system flexibility at acceptable cost*, cf. Table 19.

For D3 (DSO integration of small DER), D4 (System integration of medium DER), D5 (Integration of storage in network management), D7 (Integration with other energy networks), D8 (Monitoring and control of LV networks) and D9 (Automation and control of MV network), a new KPI is introduced, cf. B.1’ in Table 19. This KPI complements the existing B.1 KPI (Increased RES and DER hosting capacity) since B.1 is difficult to compute and it must be linked to economic efficiency, i.e. hosting capacity can always be increased if there are no economic boundaries on the reinforcements to be implemented or the components (power electronics for instance) to be deployed.

Table 19: new (and renamed) specific KPIs for the distribution system functional objectives.

Iden-tifier	Title	Distribution system FOs
A.2	Increased system flexibility at acceptable cost	D1, D2, D5
B.1’	Reduction in cost of DG integration	D3, D4, D5, D7, D8, D9
B.1’a	Reduction in costs to stay within network capacity limits	D3, D4, D5, D7, D8, D9
B.1’b	Reduction in costs to stay within PQ limits	D3, D4, D5, D7, D8, D9
B.2	Reduction in energy not supplied from DER	D3, D4, D5, D7, D8, D9
B.4	Optimise (CAPEX and OPEX) asset lifespan	D13
B.7	Increased network hosting capacity for EVs	D6
B.8	Reduce CAPEX and OPEX of ICT infrastructures	D10, D11
B.9	Planning tools readiness	D12
B.10	Planning rules readiness	D12

The new B.1’ KPI consists of two sub-KIPs:

- B.1’a, “Reduction in costs to stay within network capacity limits”, which is relative to the thermal constraints on the network,
- B.1’b, “Reduction in costs to stay within PQ limits”, which is relative to the power quality and complements the existing power quality KPI (cf. B.3).

The existing B.2 KPI (also used for D3, D4, D5, D7, D8, and D9) has been renamed “Reduction in energy not supplied from DER”.

For D8, it is proposed to use the existing B.3 KPI (Power quality and quality of supply) and to focus on two of the three sub-KPIs (leaving out the sub-KPI relative to the voltage profiles):

- Improving Quality of Service (SAIDI and SAIFI indicators);
- Time reduction for awareness, localisation and isolation of grid fault. Here, it is recommended, whenever possible, to link this KPI to the number of customers affected.

58 For D1, A.2 means active demand to provide demand side flexibility with the objective of shaping the overall demand profile to follow generation profile. The cost of implementation should be considered and a maximum cost used as a constraint. This cost would have to be based on an estimation of what would be considered as an acceptable cost.

For D10 (Smart metering data processing and other big data applications) and D11 (Cyber security), a KPI relative to the costs of deployment (CAPEX) as well as operations and maintenance -O&M- (OPEX) of ICT infrastructures is proposed, cf. B.8 in Table 19. This KPI, “Reduce CAPEX and OPEX of ICT infrastructures”, can be computed as suggested for B.4, i.e. one should make sure that the costs related to ICT infrastructures (costs relative to hardware, software, cybersecurity, etc.) are optimized when deploying and operating the equipment.

Two new KPIs are proposed for D12 (New planning approaches and tools):

- Planning tools readiness: number of available new technologies (or smart grid solutions) that can be evaluated using planning tools (e.g. network modeling software which can model and simulate the implementation of the new solutions and/or technologies);
- Planning rules readiness: number of available new technologies (or smart grid solutions) that are considered within the planning rules as planning options. This is a measure of to what extent the DSOs can plan their network using the implementations of the new solutions and/or technologies (e.g. the impact of active demand or voltage control solutions can be considered when planning the network to meet network capacity limits or to meet PQ requirements).

For D13 (Asset management), it is proposed to rename B.4 in order to focus on the economic efficiency, i.e. “Optimise (CAPEX and OPEX) asset lifespan”.

5.2.3 NEW OVERARCHING KPIS

The single overarching goal of the previous EEGI 2013-2022 roadmap was:

“to allow European electricity networks continuously deliver an effective flexible capacity to integrate actions of grid users at affordable costs”.

The overarching KPIs selected to measure the achievement of this overarching goal were KPIs A1 and A2 as defined in Table 18.

The single overarching goal of the present roadmap is:

“to optimise the European welfare brought by the electricity value chain while ensuring the proper level of reliability within the energy system of the EU28”.

It is proposed to keep the two previous overarching KPIs (A1 and A2) so as to address the economic efficiency issue and to add a new overarching KPI related to reliability, for example the System Average Interruption Frequency Index (SAIFI)

6. CONCLUSIONS

The Final 10 year ETIP SNET R&I roadmap covering 2017-26 (RIR) updates and extends the R&I activities specified in the previous EEGI roadmap 2013-2022: it covers a scope larger than the electricity system, encompassing interactions with the gas and heat networks and focusing on the integration of energy storage technologies (and taking into account all other flexibility options) into the power system.

The single overarching goal of this new R&I roadmap is to produce new knowledge which aims *to optimise the European welfare brought by the electricity value chain while ensuring the proper level of reliability within the energy system of the EU28*. The future R&I activities will contribute directly to the optimisation of the full European power system (and its integration into the energy system with a focus on energy storage) under reliability constraints, and will take into account any unforeseen change of the electricity system between 2017 and 2026.

The RIR proposes to re-organize the new R&I activities in terms of challenges (clusters for transmission system R&I activities and cross-cutting challenges in the description of the functional objectives for distribution system R&I activities), viz.:

- the **modernisation and upgrading of the network**, i.e. new technologies, tools and methodologies to improve the operations of the existing infrastructures and develop new grid architectures;
- **Power system flexibility**, i.e. all flexibility options (hardware and software solutions related to storage, demand response, flexible thermal power generation, interactions with other energy networks, improved RES forecasts, power electronics) to manage the distributed intermittent generation, the distributed new loads and optimise the use of the network infrastructures;
- **Power system reliability** as well as **Security and system stability**, i.e. how to operate the grid closer to its stability limits in an evolving environment (generation, load, increased cross-border inter-connections, market) and how to implement of the available and future solutions (observability and controllability, decision support tools) to cope with and anticipate all network contingencies;
- **ICT and digitalization**, i.e. the challenges related to the digitalisation of the network (IoT, Big data, standardisation for communication and data exchanges between the different stakeholders of the electricity value chain, cyber-security);
- **Market design**, i.e. the study of all market issues (market design and market simulation tools, including the coupling with the gas markets at the transmission system level, at different time scales) and the investigation of all incentives (market rules, business models) to foster the advent of demand-response services supplied by new market players as well as issues related to ancillary services provided by storage operators and RES generators;
- the **DSOs regulatory environment**, i.e. the study of all regulations impacting the operations, asset management and planning activities of DSOs. This includes the regulatory framework of active demand response, access to private consumer data, new electricity tariffs, etc.

7. APPENDIX 1: FUNCTIONAL OBJECTIVES FOR TRANSMISSION SYSTEMS

CLUSTER C1: MODERNISATION OF THE NETWORK

T1	Optimal grid design
Contents	**Challenges:** New planning methodologies and network infrastructure tools are needed to connect energy generation sites involving variable RES and DER to demand areas, as well as to integrate demand response, storage and the interface with other energy/transport networks. The approaches to grid design at the European level must be developed by taking into account a broad spectrum of novel technologies for generation, transmission, storage, and demand response, as well as the evolution of boundary conditions (single European energy market, new business models, climate change, etc.). Moreover, the pan European electricity system should make use of ICT powered "System of System" for which dedicated research priorities on planning and development methodologies are addressed (DG Connect Research Program Horizon2020[59]). The pan European electricity system should become a critical case study to test such new planning and architecture approaches[60]. **Objectives:** The objective is to develop planning tools methodologies and simulation software to assess the options for a pan-European power system, in particular for the transmission system infrastructure. It should also facilitate system simulations at the European level to compare several design options based on different technical, economic and environmental criteria, and accounting for emerging technologies and business models. Another objective is to integrate the planning perspectives: how the grid planning phase can best serve the future operational needs during the grid operation phase. **Scope:** • T1 Addresses the medium-term adequacy and the long-term planning for system development, particularly accounting for the energy scenarios provided by TYNDP and e-Highways 2050. • It also addresses grid planning within uncertainty framework, i.e. probabilistic approaches, no regret options, risk management at planning phase. **Specific tasks:** • To investigate state-of-the-art planning methodologies and software, technology portfolios and different regulatory frameworks. • To develop software tools for cost-benefit assessment of expansion options and for validating the impact on grid planning of coordinated design of architecture, power flow control devices and other expected technologies. • To develop planning software to optimize location, coordination, control and integration of technologies within the existing and future system architecture and operation.

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

	• To develop planning methods that combine electricity market analysis, production capacities (all kinds, including DER), demand response capacities and infrastructure, storage, and environmental constraints, both at the transmission and distribution levels, with the aim of strengthening expected weak points on the grid. • To develop probabilistic planning methods that respect the variability of RES, demand response, storage, self-consumption, and their uncertainty. • To propose network investments at the EU level. • To take into account the expected coordination levels at transmission level and develop a top-down network development approach involving regional initiatives to avoid extra investments or lower system reliability. To account for coupling with other energy networks (especially gas but also heat and cold) in the planning studies (simulations), e.g., dynamic coupling between gas and electricity networks (link with T14). • To account for maintenance operations in the new planning tools (the system must remain operable when maintenance operations are performed). • The flexibility brought by software must be taken into account in the flexibility means (for example, smart substations) • To develop modular infrastructures, both in term of size/capacity and in terms of voltage level.
Expected outcomes	TSOs will be able to optimise network development and identify the most cost-effective technologies based on recognised optimization goals, constraints and maximisation of RES integration. Delivery of planning tools for network development, both for cross-border and TSO-DSO system development, accounting for a broad spectrum of novel technologies (generation, transmission, storage, demand side response and management). As such, it will enable better decision making, leading to: • less investments/cost • higher reliability • maximised RES integration
Expected impacts	This long-term planning approach will enable manufacturers, DSOs, energy retailers and other energy companies to create provisional development plans. Investment signals will be sent to energy generators, load centres, TSOs and DSOs, taking into account European network investments.
Contributors	TSOs, DSOs, Research institutes, Technology providers, TPG stakeholders, Regional initiatives
Additional information	Interdependent with T4, T10, T13. Also builds on previous projects: e-Highway2050, Realisegrid
Budget	40 M€
Timeline	2021 – 2026

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<tr><th>T2</th><th>Smart asset management</th></tr>
<tr><td>Contents</td><td>

Challenges:
The power network is continuously challenged with the choice between implementing maintenance procedures to extend lifetime, upgrading equipment to increase lifetime, replacing failing subsystems or partial replacement of infrastructure. These actions must take into consideration worker safety, the quality of service, and OPEX and CAPEX negotiated with the regulator. Therefore, there is a need to revisit the lifetime prediction modelling based on extended parameters, to define new and reliable monitoring systems, to specify and develop new and relevant heuristics and approximations for integrated, realistic and workable frameworks, and to demonstrate how these approaches can be implemented, scaled up and replicated at effective cost so that the expected benefits are realised.
Objectives:
The objective is to maintain robust and cost effective network infrastructures with reliable performance by optimising asset management through:
• Validation of new monitoring concepts for components and systems in view of scheduling maintenance that maximises network flexibility;
• Elaboration and validation of new selective maintenance methodologies that leverage condition-based, predictive-based and risk-based approaches;
• Development of new failure models by improving the understanding of how working conditions impact the aging of critical network components, creating enhanced monitoring systems or performing ex-post analysis of assets that have been removed from the grid.
• Implementation of new breakthrough technologies, such as robotics or drones, in order to reduce costs and increase human safety and asset availability.
Scope:
Maximizing the value for money through enhanced monitoring of health and improved methodologies to support preventive and selective maintenance decisions; new means for line and substation inspections and monitoring.
Specific tasks:
• To identify parameters (climate conditions, operating conditions, potential for hardware and software, among others) that impact the lifespan of components
• To establish evaluation/estimation protocols for component conditions that are comparable across TSOs, with in-depth analysis and shared experiences
• To validate the added value of individual lifetime assessments compared to an average assessment of several similar components based on generic parameters (age of equipment, switching steps, etc.)
• To develop new ways of detecting component failure based on failure models (probabilistic models, i.e.; link with GARPUR)
• To develop software for estimation of component real life time (to be checked vs manufacturer declared lifetime), based on set of historical data of measured operation conditions (voltage, load, frequency) since in operation.
• To integrate new sensors and new equipment condition monitoring approaches based on distributed technologies
• To implement robotics for automated condition monitoring or diagnostic systems for incipient problem detection, as well as to intervene in hostile environments and avoid the need for human maintenance. Also includes live line maintenance and working practices and the use of drones for network monitoring.
• To propose scaling up and replication rules for new asset management approaches at the pan-European level.

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	• To improve the modelling of rare, severe-impact events through inter-TSO collaboration on related data. • Improve methodologies, methods and software for physical protection of the grid infrastructure and protecting against natural catastrophes, terrorism, cyber-attacks • To link with standardisation is key in terms of assessing the validity of the diagnostic methodologies investigated, validating the measuring chain, and ensuring the safety of operation (especially for live line work).
Expected outcomes	• New approaches for extending the lifetime of existing power components based on improved monitoring and measurement of their health. • New maintenance approaches for managing critical assets based on risk and optimisation, that are shown to reduce operational costs while increasing network flexibility and ensuring adequate power quality. • New specifications and guidelines for interoperability and standardisation to be used by manufacturers of sensors and IT systems to support health monitoring, selective maintenance and enhanced asset management. • Optimised maintenance approaches for new power technologies should be assessed using adapted CBA methodologies. Consequently, new training methodologies will be developed for workers performing asset management (including live line maintenance). • Best practices and guidelines for scaling-up and replication of coordinated asset management techniques.
Expected impacts	• Increased share of renewables in the supply mix due to greater grid flexibility and availability provided by optimal asset management. • Increased grid capacity while maintaining the same level of quality and security of supply, thus leading to a more efficient electricity market. • Optimised costs for asset maintenance activities while increasing the performance of existing assets. • Integration of new power technologies with optimum asset management methodologies.
Contributors	TSOs, Technology providers and Research institutes
Additional information	• Interdependent with T7, T13, and T18. Also builds on a previous project: Realisegrid. • Linked to IoT and big data: use of the data to estimate lifespan and establish ageing/failure models (probabilistic models, cf. needs for GARPUR, for instance).
Budget	40 M€
Timeline	2018 - 2021

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

T4	**Environmental challenges & Stakeholders**
Contents	**Challenges:** The realization of a secure, sustainable and competitive European electricity system requires the development of underlying transmission infrastructure. Hence, there is a need to develop new ways and means to address the public reluctance toward infrastructure investments and to increase public awareness about future long-term energy challenges. Therefore, the current public consultation processes needs to be revisited to both better appraise and understand the reasons for public reluctance to support infrastructure investments. **Objectives:** To improve public acceptance and stakeholders' participation in transmission infrastructure, while also reducing environmental impact. **Scope:** • Improvement of public awareness of long-term energy challenges and the need to build and protect transmission infrastructure to increase the social benefit of electricity use. Assessment of new environmental challenges and improvement of the transmission infrastructure land use and environmental integration. • Possible directions include exploiting new channels for the public consultation processes. • Alternatives to SF6, allowing for the compact design of electric power stations with efficient insulation properties. • New design measures to minimise high-voltage equipment noise, visual impact and sag of overhead lines. • Improving the physical protection of the grid infrastructure against potential dangers, e.g., natural catastrophes, terrorism or cyber-attacks. **Specific tasks:** • Increase communication campaigns, develop social impact studies and increase the involvement of local and territorial bodies in the early stage of planning of the infrastructure. • Deepen studies on human and animal exposure to EMF. • Develop holistic approaches for maintenance accounting of the environmental (e.g., tree growth rate, wind) and operational (e.g., hazard rate) effects on assets' lifetime. • Analyse new technologies that have reduced conductor visibility and reduced sag. • Propose new tower and stations designs with less visual impact, audible noise and EMF. • Implement pilot projects for demonstration and assessment of the methodologies and software developed to protect the grid infrastructure.

	• Conduct pilot projects concerning the implementation of the guidelines for improving the relationship between TSOs and the public, namely consumers. • Investigate the environmental impact of partial undergrounding solutions (cables) and new technologies. • Update the European guidelines on good practice in transparency and public engagement and the permit process. • Produce guidelines for the construction and maintenance of overhead lines, with the goal of improving public acceptance. • Mapping bird-sensitive areas and developing new bird savers to minimize birds collision and nurturing bird nests.
Expected outcomes	Recognition of the general public's need for new infrastructure to be developed in an open, participatory and environmentally sensitive way, and for it to ensure the security of the supply with low carbon emission.
Expected impacts	• Improved stakeholder engagement by improving the understanding between TSOs and the public and reducing the environmental impact of the infrastructure. • Acceleration of the permission and construction processes required to build new infrastructure or refurbish existing infrastructure.
Contributors	TSOs, DSOs, Technology providers, TPS stakeholders, Industries, NGOs
Additional information	Interdependent with T1, T2, T3, T14, and T20. Also builds on previous projects, namely BESTGRID and Life ELIA.
Budget	20 M€
Timeline	2017-2026

CLUSTER C2: SECURITY AND SYSTEM STABILITY

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

	tools. These models will be aggregated to assess the observability at the required level, and should help infer automatic rules for operations at the local level (decentralised intelligence). • Increase observability and improve state estimation accuracy (both steady-state and dynamic) through adequate modelling (not only through modelling protection and automatic system schemes, but also by merging transmission and distribution models). • Exploit the information provided by forecasts of variable generation and flexible demand for observability purposes. • Enhance the TSO/DSO communication interface and design new architecture for data exchange and processing at various system levels, e.g., TSO/DSO boundary substations, and in different time frames, from short-term to long-term, i.e., from real-time operational planning to network planning. • Investigate and develop methodologies, procedures, protocols, standards and tools for inter-TSO communication, in view of determining the amount and type of data exchange which is required to enable an extension of the observable area to neighboring TSO, and, ultimately, to provide detailed and accurate data to regional initiatives. This should aim at mitigating possible negative impact of switching actions from one TSO to other TSOs, and at finding possible efficient cross border remedial actions. • Investigate and develop the methodologies, procedures, protocols, standards and tools for inter-TSO communication, which will determine the amount and type of data exchange required to enable an extension of the observable area to neighbouring TSOs. The aim is to mitigate a possibly negative impact of switching actions from one TSO to other TSOs. • Develop effective data-mining algorithms capable of extracting important information in real time from massive amounts of data. • Implement solutions for WAMS and demonstrate how to utilize such information in a coordinated manner during operations. Observability should also be seen from the operators' point of view, i.e., how to operate a network in new situations with new sets of information resulting from increased data and new tool availability (e.g., iTesla). Critical situations might become even more complex as operations become increasingly automated.
Expected outcomes	Improved monitoring of the electricity system will allow TSOs to make appropriate decisions regarding system operational planning and real-time operation. Validation of the increased role of corrective actions.
Expected impacts	Enhanced security and stability of pan-European transmission system having a high amount of variable RES generation.
Contributors	TSOs, DSOs, Technology providers, Service providers, Generation companies, Regional initiatives
Additional information	Interdependent with T18, T19. Also builds on previous projects: PEGASE, TWENTIES, Real-Smart, UMBRELLA , iTESLA
Budget	70 M€
Timeline	2018-2021

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

Propose new tools and methods to monitor, control and protect an electricity system with low inertia. Identification of suitable methods for building dynamic system-security models and developing the appropriate tools. Existing control and protection schemes must be reviewed and may need to be redefined to allow secure, stable and reliable operation of the network.
Methods and tools to ensure the required level of inertia to the transmission system, and connection of relevant equipment’s to the networks.
Identification of possible links between the electricity system and the other energy systems in the specific view of help increasing inertia (real or synthetic).
Deployment of Wide Area Control (WAC) devices at the pan-European, system-wide level, which will enable the operators to operate the system close to its stability margins without jeopardising its security.

Scope:
Power control devices (FACTS, PST, HVDC, VSC), storage and other technologies are to be demonstrated and validated, as well as single-phase auto-reclosure, and point-on-wave switching.
Specific tasks:

Provide demonstrations of power flow control devices and storage that offer increased flexibility with respect to energy flow across multiple transmission zones and borders.
Increase network controllability by proposing methods and tools for optimal and coordinated use of flexible equipment such as FACTS, PSTs and HVDC links, resulting in safe and cost-effective system operations (thus maximising the global social welfare).
Assess the contribution to controllability of large-scale new power technologies (incl. new materials) such as HVDC, VSC, superconductivity, energy storage, fault current limiters and other promising technologies for joint control of on- and off-shore networks, using fibre-optic temperature monitoring and DLR.
Validate the contribution of RES to voltage and frequency control, as well as balancing, using different concepts, especially for direct-drive machines: VPP, inertia provided by the rotors, PE-based reactive power control, local storage, etc.
Develop new technology and control concepts for providing synthetic inertia from power electronic converters and additional damping of oscillations, for instance

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	conventional rotating machine concepts like the VFT (Variable Frequency Transformer) since these produce no harmonics pollution in the grid. • Assess and demonstrate innovative solutions to counteract the decrease of short circuit current • Consider the large-scale intra-zone oscillation topic, assessing the deployment of the optimal infrastructure, the study and analysis of the data and the measurement of the impact of these intra-zone oscillations • Assess stability in grids with multiple control systems
Expected outcomes	• Control procedures will be provided for system security and ancillary services and will involve not only central power plants but also energy from wind, solar and DER, as well as DSR and energy storage systems. • Refinement, adoption and implementation of a wide range of efficient and practical control methods to enable wind plants to provide ancillary services.
Expected impacts	• Maximising the volume of renewable generation input whilst keeping the system stable. • Clarification of how this may lead to new control/protection schemes and the definition of grid connection rules.
Contributors	TSOs, DSOs, universities, research institutes, technology providers, TPG stakeholders, utilities
Additional information	Interdependent with T3 and T14. Also builds on previous projects: iTesla, MIGRATE, UMBRELLA
Budget	60 M€
Timeline	2020-2026

T7	Expert systems and tools: expert systems, decision-making support tools and advanced automatic control
Contents	**Challenges:** Expert systems simplify the problems faced by complex power systems by processing large amounts of data in a structured way and in a short period of time, enabling high level planning, operation and design decisions. Many TSOs apply restoration strategies based on the operator's experience, with no specific decision support tools. As a consequence, there is no common strategy for system operators and operation planners regarding the restoration of the pan-European system; restoration for interconnected power systems is decentralized. The increased penetration of variable generation sources in the grid can introduce unexpected power flows in both the transmission and distribution systems. Therefore, it is important for TSOs to integrate various decision support tools for RES (e.g., forecasting, contingency analysis, dispatch, security assessment) to help control engineers assess network stability. The contemporary systems broadly utilise local automation, protection and control. However, rapidly changing electricity systems call for better coordination and the use of advanced automatic control. This necessitates the development and massive deployment of smart meters, sensors, control devices, PMUs, and weather measurement, as well as the establishment of a high speed communication infrastructure for monitoring the condition of each element in a power system. TSOs will use these data not only to operate the system optimally, but also to anticipate emerging issues with system stability and security. The internal European energy market will also benefit from this practice, since the market participants will be provided with estimated locational marginal prices in real time that are based on actual system conditions. **Objectives:** Develop expert systems and decision-making support tools to anticipate potential emergencies, provide early warning to system operators and suggest possible solutions based on the estimated probability of success in real time. The developed tools will include, but not be limited to, suggesting changes to network topology based on intelligent switching operations, protective relay settings and dynamic rating of the power system elements according to the actual system conditions. In order to deal with this vast amount of data, as well as with the uncertainty and variability associated with RES, innovative expert systems, highly sophisticated decision-making support tools and advanced automated control systems should be used. **Scope:** Research, innovation, development and demonstration of: • intelligent electronic devices; • sophisticated automatic control devices; • advanced methodologies and algorithm solutions for decision-making support tools with reduced decision cycle time; • integrated expert systems, artificial intelligence, enhanced inference engines, heuristic optimization techniques and neural networks. **Specific tasks:** • Develop expert systems to assist in transient stability analyses of both voltage and frequency; • Develop advanced decision support tools that integrate the probabilistic nature of variable generation in real time applications such as stochastic power flow, stochastic unit commitment, probabilistic reserve allocation, optimal power flow with RES forecasting, etc.;

	• Assist with solving decision problems regarding reactive power and voltage control, determination of loads when applying load shedding schemes, etc.; • Incorporating RES into operation processes via aggregation schemes, utilizing forecasts and benefitting from controllability of RES (for coordinated reactive power/voltage control, congestion management, etc.); • Develop tools for pan-EU system restoration based on coordination of Tie Lines and/or Black Start units, whilst taking into account the system condition, system constraints and available resources to support the decision; • Combine sophisticated sensing technologies, automation and control methods with high-performance, high-speed communication infrastructure through the utilisation of multi-agent system architecture; • Develop new methods that will reduce decision cycle time in decision-making analysis, especially in the case of increased variability, uncertainty of input data, and multiple conflicting evaluations; • Develop and demonstrate innovative expert systems that take into account the uncertainties in the power system using artificial intelligence techniques and probability approaches such as Bayesian analysis. • New control room environment must be developed to enable operators to handle complex decision-making situations (such an evolution could be compared to the aeronautical industry, in which there are automatic pilots and a fully digitalised environment). Specific trainings should also be adapted to the new ergonomic framework. In the tools listed above, the reliability of the ICT system(s) must be accounted for.
Expected outcomes	Advanced automatic control, effective decision-making tools and innovative expert systems will be validated. This will include not only conventional units but also energy from variable generation sources, providing TSOs with real-time assessment of transmission system conditions.
Expected impacts	Implementation of advanced decision tools will increase the overall system's reliability and improve quality of service, at the same time maximising the utilisation of system components.
Contributors	TSOs, ICT providers, Technology providers, Research Institutes
Additional information	Interdependent with T1, T14. Also builds on previous projects: iTesla, UMBRELLA, PEGASE. Interdependent with T21(Cybersecurity) in C5.
Budget	50 M€
Timeline	2020-2026

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

	• Include risk analysis in TSOs' daily business. • Identify specific resilience/vulnerability indicators. • Develop special tools for quantifying resilience. • Investigate the effects of extreme climate events as increasing threats to the transmission system of the future. • Evaluate the current performance of the (N-1) criteria security principles and the required level of reliability from the customer's perspective. Provide an appropriate approach for risk assessment based on probabilistic analyses of both normal and abnormal operations, taking into account correlations in the power system. • Evaluate new stochastic models with respect to market operations on different timescales in order to improve reliability. • Use a system approach to identify possible options for replacing (or complementing) the current reliability principles for different aspects of TSOs' business: grid development, markets, etc. • Define the additional information to be exchanged and the additional coordination needed to support deployment. Ensure effective and sufficient security margins during operation and operational planning. • Develop indicators for the evaluated criteria to help network operators make decisions for preventive and curative actions. • Develop simulation tools and methods for assessing the risk of breakdowns during reconnection. • Develop simulation tools and methods that detect weaknesses in the system with respect to reconnecting DER and storage systems. • Develop simulation tools for interactive system restoration, including advanced forecast tools for wind, solar PV and other variable RES. Assess the system state during the restoration process, and expected RES in-feed of DSO at reconnection. • Engage storage in defense and restoration tools and plans. • Investigate the contribution of DER to system restoration and immediate power reserves; this is relevant from the TSO perspective (e.g., black start capability and coordination of wind turbine generators). This will be assessed considering efficiency and cost-effectiveness when compared to the traditional or usual black-start approach. • Investigate the impact of micro-grids and islanding capabilities, taking into account efficiency and cost-effectiveness. • Train the system operators regarding the evolution of national regulatory schemes in order to foster coordination efforts. • Account for failure modes of ICT (including sensors) in the different simulation tools. • To develop effective and coordinated restoration plans specifically for ICT and software systems, in order to keep running the grid operation in case of natural catastrophes, terrorism and cyber-attacks.
Expected outcomes	• A framework that relates probability functions, normal operations, asset management and planning weakness and resilience into a single integrated approach. • A simulation framework that detects weaknesses in reconnection scenarios involving DER units. • Assessment of the potential contributions of RES, DER, storage and micro-grids to defence plans (black-start capabilities, islanding capabilities). • A joint TSO/DSO approach for defence plans involving DER and micro-grids.

Expected impacts	Regulatory and technical solutions to implement restoration plans at the pan-European level to lessen the impact of power shortages for end users.
Contributors	TSOs, DSOs, ICT companies, Manufacturers, Generation Companies
Additional information	Interdependent with T6, T13. Also builds on previous projects: GARPUR, AFTER, ICOEUR, iTesla, NetzKraft
Budget	50 M€
Timeline	2019-2024

T9	**Enhanced ancillary services for network operation**
Contents	**Challenges:** TSOs are responsible for the secure and reliable operation of their systems, as well as for the interconnections with other transmission systems. As the penetration of variable generation sources rapidly increases, enhanced ancillary services will be required to cope with the increased variability and uncertainty. Flexibility reserves are being developed on different (longer) timescales than contingency and regulating reserves, in order to account for new ramping requirements. In these circumstances, the ancillary services from conventional generation will not be sufficient; such services should also be provided from RES and DG, which must participate more actively in controlling the system, potentially at the same level as conventional plants. This presents the main challenge for future network operation. Storage might also play an important role in providing specific services such as dynamic frequency control (< 1 s). In this context, the necessity of a multi-level process involving both TSOs and DSOs, generation connected to DSOs, and utilities, becomes apparent. Distribution companies previously contributed to ancillary services in transmission systems (reactive compensation on the MV side of the HV/MV transformer, load-tripping schemes, etc.). The evolution of the electricity sector and the expected arrival of aggregators will strongly affect the roles of TSOs and DSOs. The role of conventional generation might also evolve, with power plants used to provide ancillary services as much as to provide energy. **Objectives:** To address technical and regulatory aspects of providing enhanced ancillary services for TSOs from DER, and storage through a new framework involving the services provided by units connected at DSO networks and by DSO facilities. To allow cross-border provision of ancillary services. To allow new players to provide valuable services. **Scope:** New procedures and strategies will be developed to provide new ancillary services from RES combined with those provided by DSOs, new actors such as storage, and existing power plants (natural gas, thermal etc.). **Specific tasks:** • Increase the visibility of variable RES for TSOs (to enable more accurate forecasting). • Perform dynamic calculations of RES production using short-term forecasting models or by continuous updating of the data.

	• Develop new common security provisions that enable the definition of a reliable and efficient amount of reserves and the sharing of these reserves based on acceptable and measurable risk (cf. to project GARPUR) • Assessing processes, principles, and strategies for new ancillary services to manage the high penetration of RES and balancing demand (faster ramping services, frequency response, inertia response, reactive power, and voltage control) • Determine novel ways of providing ancillary services through loads and their impact on transmission networks; the highly variable and unpredictable nature of DER and RES places new constraints on these ancillary services. • Determine novel ways of providing ancillary services through storage systems, and their impact on transmission networks. • Develop simulation environments to test the viability and options of ancillary service provision by aggregated loads at the DSO level. • Technologies and tools for active and reactive power control of DER, with TSO/DSO coordination to provide extra power flow control, load management and islanding. • Create robust optimisation algorithms for coordinated control of DER (robust against uncertainties and variability). • Introduce new actors and market models that enable DER and storage to provide ancillary services. • Develop new models that describe products and services to be tested on selected segments of customers, and determine their impact on future ancillary services in the presence of large-scale DER integration. • Create new market models that account for the price-sensitive nature of loads and their resulting flexibility. • Analyse the legal, contractual and regulatory aspects of ancillary services provided by distributed generation and / or loads, allowing for more aggregated business models. • Share best practices between TSOs and DSOs for the ancillary services provided by units connected at distribution networks.
Expected outcomes	• New ancillary services with more active contributions from demand and units connected at DSO networks and from DSO facilities in terms of active and reactive power reserves, flexibility reserves (short-term and long-term), voltage and frequency control and network restoration. The inherent flexibility of the loads can contribute effectively to ancillary services and can be traded on the market. • Replacement of load shedding through new provided services.
Expected impacts	New recommendations for grid code evolution, based on new ancillary services that can be provided by TSOs
Contributors	TSOs, DSOs, ICT providers, Manufacturers, Service providers, Generation companies, Aggregators, Commercial retailers
Additional information	Interdependent with T10, T11, T12. Also builds on previous projects: SMARTNET, MERGE
Budget	60 M€
Timeline	2022-2026

CLUSTER C3: FLEXIBILITY OF POWER SYSTEM FROM GENERATION, STORAGE, DEMAND AND NETWORK

T10	Storage integration, use of storage services
Contents	**Challenges:** Energy storage technologies and integration have become key elements in smart grid structures. The landscape of the generation field has changed dramatically with the integration of high amounts of variable renewable electricity generation in European electricity systems. In addition, in the electricity sector's new model, demand response will play a relevant role in the future, introducing variability in demand behaviour. A growing challenge exists in balancing the power grid, since these clean power sources lack additional reserves and can be located anywhere in the network. This requires adapting the grid to store electricity more effectively and flexibly through optimal use of disposable conventional and innovative sources, while maintaining the provision of reliable and quality power to customers. **Objectives:** Develop storage availability schemes for system planning and operation purposes, while analysing in parallel the integration of storage technologies, in close contact with the relevant manufacturers, in order to maximize their application possibilities in terms of both performance and time-to-market development. **Scope:** Activities should focus on storage systems that aim to support the balancing of the power system and the security of supply. It is imperative to address all the technical concerns regarding improvement of the power storage process for the purpose of balancing. The economic, regulatory, market and environmental aspects associated with the deployment of storage systems in the power system should also be explored. **Specific tasks:** Address technical and regulatory aspects such as: • Power-to-power cycles with optimal efficiency and minor losses; integration with other energy systems that can regenerate losses, e.g., heat. • Novel solutions for fast power response and energy storage at different voltage levels in the power system; novel solutions for where supplementary services will be located in the storage facility. • System planning tools to determine the optimal distribution of the energy storage to facilitate transmission system operations, as well as in the distribution grids. • Defining technical requirements/specifications to allow storage integration to provide system services. • Simulation tools to better appraise the cycling profiles associated with the envisaged applications and business models. This will, in turn, allow an accurate estimation of the lifespan of the storage system (and the failure modes) and profitability. • Improvement of current system modelling tools to better account for the benefits of storage and to optimise the balancing; measuring the impacts of OPEX and CAPEX using stochastic modelling. • Tools to assess potential revenues from storage, in both liquid markets and non-liquid markets. • Assess the contribution of power-to-gas technologies as a means to store electricity on large scale; use of gas turbines to cover long periods with low RES generation in scenarios with very high penetration of wind and solar generation. • Increase the integration of storage in thermal power plants in order to improve their flexibility.

	• Develop methodologies to integrate new bulk storage solutions (e.g., power-to-gas, marine storage, CAES). • Asses the value of hybrid technology projects, for example mixing technologies able to perform a high number of cycles with other less CAPEX intensive technologies • Assess and quantify the value for the system of services provided by energy storage
Expected outcomes	• Deployment of low carbon technologies, together with encouragement of increased energy efficiency through storage solutions and services, will lead to cooperation programs amongst the European countries, manufacturers, research institutions and the EC. The timely integration of storage-based solutions will assist with flexible management of the grid and will support development of innovative market models and terms for a more efficient system. • Assessment of regulatory and economic impacts and opportunities for the storage facility made possible by analyses and recommendations
Expected impacts	• Support the power system with fast response power and energy storage, as assessed by feasibility studies of several technologies. • Unleashing of the potential for balancing, congestion management and/or support with ancillary services through pilot demonstration. • Deferred investments for transmission and distribution grid reinforcements, and lower social costs associated with high penetration of fluctuating renewable power generation.
Contributors	TSOs, DSOs, Research institutes, Storage manufacturers and operators, TPG stakeholders, Utilities
Additional information	Interdependent with C4, T3, T6, T9, T7, T12, T14, T15, T16, T17. Also builds on previous projects: ANEMOS Plus, OPTIMATE, From wind power to heat pumps, GridTech, Store
Budget	100 M€
Timeline	2017-2022

T11	Demand response, tools for using DSR, load profile, EV impact
Contents	**Challenges:** The potential benefits of load control, such as peak shaving, and energy savings, must involve large-scale participation of industry, the tertiary sector and end consumers in order to assess the impact on TSO planning and operations. Usage of technologies such as smart meters and energy boxes must be included to add value to traditional demand side response (DSR), raise awareness about consumption patterns and foster active participation of manufacturers, services/businesses and the customer in the energy market. **Objectives:** The main objective is to develop and integrate demand response mechanisms to provide services to the system. • Add flexibility to the system (modulate the load curve) in order to increase overall system efficiency. • Foster active customer participation in the system. **Scope:** Integration of demand-side management tools will allow customers at different levels to make more informed decisions about energy usage and will support TSOs and DSOs in electricity operations. The demand response mechanism will impact

	the market by offering economic incentives and optimizing investments and the use of current assets in the network. Flexible generation needs to be considered as well with increased efficiency at both low and base loads, and faster ramp up times. **Specific tasks:** To achieve these goals, demonstration projects are required for demand-side management: • Define demand requirements and data required by TSOs for optimal DSR utilisation. • Demonstrate active customer (industry, tertiary sector and end consumers) involvement using "indirect" (provided post-consumption) and "direct" (real-time) feedback, in order to achieve a reduction in peak demand. • Integrate and demonstrate DSR and storage solutions, including the impact of transport system electrification (e.g., transport EVs, etc.) for off-peak hours, and their use in system balancing. • Develop simulation tools to include Vehicles to Grid capacity • Model customer/load behaviour and segmentation, and quantify the degree of flexibility provided by distribution networks, e.g., through reconfiguration or other methods. • Test DR models that bring demand response from private customers by, e.g., limiting the rated power during a specific period of time • To increase communication campaigns, to develop social impact studies and increase the involvement of local and territorial bodies in the early stage of planning of the infrastructure. • Assess the value for the system provided by flexible generation
Expected outcomes	• The existence of load control provided by distribution at the TSO level allows TSOs to plan and operate the network in an efficient and economical way. • In the short term, this will assist in reducing technical constraints and power collapse in the electricity grid; in the long term, it will reduce the expenses for energy reserve and prevent bottlenecks at the network level. • Demand side management will boost the development of pay-out schemes for participants in demand response. • Tools and models shall be developed for demand response and for customer behaviour to facilitate the forecasting and operational processes.
Expected impacts	Increased level of flexibility in TSO planning and operations will allow increased integration of RES while maintaining the security of supply at the pan-European level.
Contributors	TSO, DSOs, Manufacturers, Customers, Service providers, Research institutes, Industries, Energy companies
Additional information	Interdependent with T7, T8, T9, T15, T16. Also builds on previous projects: ANEMOS Plus, MERGE, eStorage (still on-going project), 'From wind power to heat pumps', GridTech, OPTIMATE, Ecogrid EU, Gredor, Cell Controller Pilot Project
Budget	80 M€
Timeline	2017 - 2023

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

Additional information	Interdependent with T7, T10, T11, T13, T15, T16. Also builds on previous projects: OPTIMATE, ANEMOS, SAFEWIND, BestPath, GridTech, Realisegrid, Seetsoc, WindGrid, EWIS.
Budget	40 M€
Timeline	2019-2024

T13	**Flexible grid use: dynamic rating equipment, power electronic devices, use of interconnectors**
Contents	**Challenges:** The complexity of the pan-European network requires the development of transmission capacity and system operation to ensure flexibility and therefore security of supply in the presence of increasing volatility. Moreover, the advent of a single pan-European electricity market with a free flow of energy across multiple borders has led to increased cross-border power flows. Advanced transmission technologies must be tested and the management of existing lines must be improved. The integration of new technologies into existing infrastructures presents interoperability issues that must be solved. **Objectives:** • Emerging power and information technologies will be developed and made ready for deployment to increase the flexibility and capacity of the existing power grid. • Interconnectors should no longer be seen merely as fixed load/injections according to the underlying trading mechanisms, but they should also be able to provide grid operators with dispatching resources, both in contingencies and in normal situations. • Achieve increased network flexibility for grid users at optimized OPEX, which allows for a larger share of RES and increased security of supply. **Scope:** The scope includes all devices that can be used to increase the flexibility of grid operation, new services rendered by interconnectors, and new materials/operating modalities that can broaden the palette of tools for use by grid operators to achieve secure and efficient network management. **Specific tasks:** • To demonstrate the degree to which transfer capacity can be increased by means of new operating schemes available through the implementation of different approaches and technologies; to investigate all possible technical solutions within the domain of each application; to perform cost-benefit analyses of different case studies. • To demonstrate power flow control devices that offer increased flexibility with respect to energy flows across multiple transmission zones and borders. • To demonstrate controllable off- and on-shore solutions for the vendor-independent, HVDC multi-terminal networks used to coordinate power flow, frequency control and coordinate protection and communications requirements. • Apply more DLR solutions, to become a standard practice for short term congestion and peak transmission line overloads. • To investigate the influence of parallel routing of DC and AC lines in the same tower or parallel paths to utilise existing infrastructure paths in an optimal manner. • To investigate HVDC reliability, especially for multiterminal and/or meshed DC grids.

Expected outcomes	• Validation of new methodologies for upgrading the existing grid and increasing transmission capacity in a cost-effective and environmentally friendly manner. This will provide relief at network bottlenecks and help bridge short-term investment delays. Furthermore, power flow control devices shall favour new parallel options for transmission line development. • Standards shall be set for health monitoring equipment for power system components at the pan-European level.
Expected impacts	• The flexible use of the grid, through smart and optimised utilization of its components, together with new services from storage, demand side and RES generation (see FOs T10, T11 and T12), shall provide to grid operators valuable tools for efficiently operating the system and synergistically leveraging all means available. • At the same time, the environmental impact and the use of resources shall be minimised, also benefitting grid users and tariff-payers through more cost-effective operation, in terms of both OPEX and CAPEX. • New methodologies will be validated for upgrading the existing grid and increase transmission capacity in a cost-effective and environment-friendly manner. This provides relief at network bottlenecks and helps bridge short-term investment delays. • A more flexible grid will be implemented that integrates RES and helps cope with demand enabling of a low-carbon economy by preparing investment strategies based on least-cost asset replacement strategies.
Contributors	TSOs, Equipment manufacturers, Interconnector companies
Additional information	Interdependent with T6, T9, T10, T11, T12, T17. Also builds on previous projects: BEST PATHS, PROMOTION, PEGAS
Budget	30 M€
Timeline	2021–2026

T14	**Interaction with non-electrical energy networks**
Contents	**Challenges:** Decarbonisation is essential for coping with long-term EU sustainability targets, and electricity is one of the main vectors leading this transition. From the demand-side perspective, electrification of the transport, heating and cooling sectors provides a pathway to fulfil this objective. On the generation side, it could be efficient for the energy system to coordinate and couple electricity generation with the gas supply for the combined cycles. These issues show the increased complexity of trying to balance and manage network problems while still maintaining the security of supply. **Objectives:** • Promote actions that foster the transition towards a new model for a European energy system (heat, transport, gas, electricity). • Develop tools to analyse balancing and congestion issues across the entire energy system and to support gas technologies in restoration plans. **Scope:** • Modelling the interfaces between different energy systems and analysing the mutual benefits among different energy systems (e.g., when utilizing power-to-gas for balancing and for electrification of the heating and transportation sectors).

	• Exploration and demonstration of power-to-gas/heat projects and other interaction projects. **Specific tasks:** • Develop methodologies and tools to assess the impact of the transition towards a new model for a European energy system (heat, transport, gas, electricity) • Joint planning. • Study complex dynamics of the coupled systems when producing large quantities of methane (power-to-gas) to be injected into the gas grid and later used for the production of electricity.
Expected outcomes	• Models and tools to manage balancing and congestion problems. • Methodologies and tools for assessing the impact of the transition towards the new energy model. • Valuable results from pilot projects. • Coordination of activities with other system players.
Expected impacts	• Better and more optimal decision making tools. • More holistic models that make use of the most cost effective solutions for supplying energy.
Contributors	TSOs, DSOs, Utilities, Gas companies, Other system players and stakeholders (Transportation), TPG stakeholders.
Additional information	Interdependent with T6, T8, T10, T12. Also builds on previous projects: Real-Smart, GridTech
Budget	30 M€
Timeline	2017-2021

T22	**Flexible thermal power generation**
Contents	**Challenges** The increasing penetration of renewables (i.e. stochastic generation with no control on the spatial location and the rated power) has resulted in new residual loads profiles (sometimes close to zero and even negative) which in turn challenge flexible thermal generation assets. Indeed, the role of flexible thermal generation has shifted from a baseload to flexible back-up power generation which poses a number of challenges for existing thermal power generation technologies mainly due to increased operating durations at partial loads and steeper ramp rates. **Objectives** The main objective is to have a thermal power generation fleet (including industrial cogeneration) that can react rapidly and contribute to deliver the flexibility needed to allow the integration of an increased share of variable RES, while ensuring the stability of the grid and the security of supply. **Scope** The main scope of the R&I activities are relative to the improvement of the existing thermal power plants for their operational flexibility (ramp-up/shut-down, load capability, fuel flexibility and increased robustness of components). For industrial cogeneration, the main scope is to decouple heat and power and to develop multi-fuel offerings.

	Specific tasks • To improve ramping (up and down), i.e. to move within a specified time from a defined idle state to synchronous operation with a defined power output (start-up/shut-down). • To further increase the rate at which a thermal generation unit can increase or decrease its output (load following capability). • To further reduce the minimum load at which a thermal generation unit can reliably operate. • To improve performances (efficiency and emissions) at partial loads. • To increase the fuel flexibility of thermal power plants, to be able to use different sources fuels (mixing and switching). • To better control the lifespan (improve robustness and operability) of thermal power plants and decrease the outages due to fast cycling. • [Cogeneration] To decouple the use of heat & power (e.g. storage, power-to-heat, power-to-gas) so as to better integrate existing and future units in the grid/energy system. • [Cogeneration] To develop technologies with high electrical efficiency that can use hydrogen, biomass and biofuels.
Expected outcomes	The above mentioned R&I activities will ensure that thermal power generation, including cogeneration, will provide the necessary flexibility so as to address the challenges in the future energy system. By 2030, 50% of all thermal power plants (new as well as retrofitted) should meet the flexibility requirements demanded by variable RES. This requires: • Doubling of average ramping-rates; • Halving efficiency losses for part-load operations; • Reduction of minimum load by 30% compared to today's average. • Optimising the decoupled use of heat and power and integrating the units in the grid/energy system.
Expected impacts	Increased flexibility of thermal power generation, including cogeneration, being able to produce electricity as needed, contributing to the security of supply and stability of the transmission grid.
Contributors	Manufacturers of power plants and components, utilities, EPC contractors, TSOs, DSOs, Research institutes, etc.
Additional information	Among others, interactions with other FOs in C3 are expected, as well as D14
Budget estimation	140 M€
Time line	2017-2025

CLUSTER C4: ECONOMY AND EFFICIENCY OF POWER SYSTEM

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

Budget	30 M€
Timeline	2018-2023

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

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

Expected impacts	RES integration, security of supply, a more cost effective coordination of investments at the pan-European level.
Contributors	TSOs, Research institutes, Generation companies, DSOs, Power exchanges, Regulatory authorities
Additional information	Interdependent with T9, T10, T11, T12, T13. Also builds on a previous project: OPTIMATE
Budget	20 M€
Timeline	2017-2020

CLUSTER C5: ICT AND DIGITALISATION OF THE POWER SYSTEM

T18	**Big Data Management**
Contents	**Challenges:** Data sets are growing rapidly, in part because they are increasingly gathered by cheap and numerous information-sensing mobile devices, aerial (remote) sensing, software logs, cameras, microphones, radio-frequency identification (RFID) readers and wireless sensor networks. The world's technological per-capita capacity to store information has roughly doubled every 40 months since the 1980s; as of 2012, 2.5 Exabytes (2.5×1000^6 Bytes) of data are created every day. One question for large enterprises is how to determine who should own big data initiatives that affect the entire organisation. What has really caused Big Data to go mainstream is the ability to connect not just with data scientists and technologists, but also business people. One of the keys to doing that is visualisation, or being able to show people—not just telling people or showing numbers or charts, but having those charts and graphs and visualisations come alive. The “Internet of Things” (IoT) (T20) is also expected to generate large amounts of data from diverse locations, with a resulting need to quickly aggregate the data, and an increased need to index, store, and process such data more effectively. IoT is one of the platforms of today's Smart City, and Smart Energy Management Systems. Accuracy in big data may lead to more confident decision making, and better decisions can result in greater operational efficiency, cost reduction and reduced risk. Most parties are reluctant to share the information hidden in the available data. Big Data management tools could be the key to opening the door to more professional sharing. **Objectives:** • Develop ENTSO-E strategy for the application of Big Data management tools and applications in selected areas within the electricity sector. The expected value of the strategy shall be quantified/justified via descriptions of cases with high impact and/or increased efficiency resulting from use of the available information and/or prognostic information, thanks to improved data management practices/data processing technologies and intuitive visualisation. The aim of the strategy shall be to enhance TSOs decision making. The primary approach will be to identify and describe cases for transmission system operation, asset management and market facilitation. • Integrate the big data management tools into the planning, asset management and operation activities of TSOs, taking all relevant stakeholders into account.

	Scope and tasks: • Develop a strategy for beneficial and relevant Big Data management initiatives within ENTSO-E through the use of relevant case studies. Develop, together with DSOs, ICT providers' protocols for data transfer, utility business models and decision making support. Develop interfaces between Big Data management and the existing planning and operational tools. • Develop infrastructures or tools able to manage bigdata from different sources: planning tools, management tools, Smart-meters, social medias, etc. • Supporting advanced market platforms.
Expected outcomes	• Development of applications beneficial to the ENTSO-E stakeholders. • A strategy for the ENTSO-E organisation regarding how to apply Big Data management tools and applications in future energy optimisation and operation of the energy system. • Improve awareness within the ENTSO-E organisation of the benefits of applying the concept of BigData management.
Expected impacts	• Long-term cost reduction and more efficient use of the existing electricity network • Increased transparency in operation and price setting. • Motivate sharing of know-how. • Improved advanced asset management. • Improved system analysis on a more advanced level. • New application of distributed energy resources • Lowering of entry barriers.
Contributors	Universities focusing on the topic of Big Data. Companies providing Big Data tools, applications and related services.
Additional information	Create a link to standardization of data object – link to IEC 61850 and to information security for power system control IEC 62351. Interdependent with T5, T19, T20.
Budget	20 M€
Timeline	2017 - 2021

T19	**Standardisation, protocols for communication, and data exchange**
Contents	**Challenges:** The long-term European energy vision (2050) requires a paradigm shift in communication that must be assessed at the pan-European level. Installation of a large amount of RES integration, inclusion of DER, new consumption demands, flexible demands, and energy storage will require a massive amount of communication and coordination among the parties involved, including system balance providers, transmission system operators, distribution system operators, service providers, production units, demand units, market operators, market platform providers, etc. Exchange and sharing of information will be crucial for an efficient use of all energy resources in future scenarios. Standardization is key and could generate a highly competitive market to find the best technical solution, provided that deploying in the different countries incompatible systems is avoided.

	Objectives: The purpose of standardising a harmonised and limited set of protocols to support pan-European communication within the energy sector from a single generating unit to the market platform, as well as the transmission and distribution of energy to demand units, is to provide energy in an efficient manner by lowering the system integration barrier. An additional objective is to lower the integration cost and ease the system integration process through the use of standardised protocols. In order to lower the entrance cost of protocol stacks, it could be relevant to analyse the use of open source societies. The parties with the greatest interest in the outcome of this work stream will be actors in the electricity sector. Manufactures, system integrators, system operators and project developers will have a major interest in the deliverables. **Scope:** To select the most efficient and flexible communication protocol technologies, focusing on integration cost, flexibility and scalability in use. Apply experience from EU FP7 project M/490. **Specific tasks:** • Create recommendations regarding protocols to be promoted for specific communications purposes within the energy communication network system, e.g., the IEC 61850 standard series, IEC 61970 (CIM) standard series, IEC 61968 (CIM) standard series, IEC 62325 (CIM), IEC 61400-25 standard series, ISO/IEC 9594 standard series, ITU-T X500 standard series. • Application guidelines and recommended practices for implementation. • Identify needs for maintaining existing standards. • Develop standards for new needs in protocols services or extensions to existing standards. • Promote standardized information exchange solutions based on standardized protocols. • Promote use of open source initiatives. • To specify and define the specific interchange Data model between TSO-DSO, TSO-other agents (such as demand aggregators, EV charging managers…) in order to ensure the flexible operation of the network.
Expected outcomes	• A common recommendation for a limited list of standardised communication protocols applicable to the entire European energy sector. • Lowering the integration cost for distributed energy resources. • Ease the way for integrating renewables. • Promoting solutions with a reasonable information security level at a reasonable cost.
Expected impacts	• Request for maintenance on several standard series. • Creation of several liaisons to the various working groups within the standardisation bodies. • Increased allocation of resources for attending the various working groups, creating proposals for solutions, and proposing corrections to various standard series.
Contributors	IEC, CENELEC, ISO standardization bodies and their relevant technical committees, e.g. IEC TC57, CENELEC CLC/TC57 ISO/IEC JTC 1/ SC6, ITU X500
Additional information	• ENTSO-E statement on the application of IEC 61850 in Smart Grid applications • ENTSO-E application of IEC61970 and IEC 61968 (CIM) to exchange Common Grid Model (CGM) data.

	• ENTSO-E application of IEC 62325 for energy market communications • Results from EU FP7 project M/490.
Budget	20 M€
Timeline	2022 – 2026

T20	**New technologies, Internet of things**
Contents	**Challenges:** The Internet of Things (IoT) is the network of physical objects—devices, vehicles, buildings and other items embedded with electronics, software, sensors, and network connectivity—that enables the collection and exchange of data. The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems and resulting in improved efficiency, accuracy and economic benefit. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which encompass technologies such as smart grids, smart homes, intelligent transportation and smart cities. Each” ”Thing “ is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020. In addition to aiding the expansion of Internet-connected automation into a variety of new application areas, IoT is expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data, and an increased need to index, store, and process data more effectively. IoT is one of the platforms of today's Smart City and Smart Energy Management Systems In the future, the IoT may become a non-deterministic and open network in which auto-organised or intelligent entities like web services, service oriented architecture (SOA) components, objects standardised by the Organization for the Advancement of Structured Information Standards (OASIS), and virtual objects (avatars) will be interoperable and able to act independently (pursuing their own objectives or shared ones), depending on the context, circumstances or environment. For the past six years, the European Commission has worked actively with Member States towards the development and future deployment of the IoT technology, creating a European Single market for a human-centred IoT and investing in fostering an innovative IoT ecosystem. The European Commission has also set in its Communication “Advancing the Internet of Things in Europe” the Digitalisation of the Energy sector as a key area of research and applications of the IoT approach[61]. **Objectives:** Create awareness in the ENTSO-E organization of the benefits of applying IoT technologies in combination with Big Data applications. Recommend an ENTSO-E strategy for application of IoT in selected areas within the electricity sector. The expected outcome/value of the strategy will be quantified/justified via descriptions of cases involving a high number of distributed

61 https://ec.europa.eu/digital-single-market/en/news/staff-working-document-advancing-internet-things-europe

	sensors and an increased efficiency due to use of IoT. The aim of the strategy shall be to enhance decision-making in targeting the TSOs in the first round. **Scope:** • To study the available IoT applications and expected services. • To recommend a strategy to ENTSO-E for the application of IoT in selected areas within the energy sector. **Specific tasks:** • Assess the potential benefits of intensifying the use of IoT in TSO activities. • Develop an ENTSO-E whitepaper and/or a technical report on the benefits of applying IoT and related tools in the electricity sector. • Create study and white paper regarding the secure application of IoT technologies through the public internet, taking both risks and privacy into account. • Develop the interface tools needed to intensify the use of IoT in TSO planning, asset management and operational activities.
Expected outcomes	Development of applications beneficial to the stakeholders of ENTSO-E. A strategy for how the ENTSO-E organization can apply IoT in the future energy system.
Expected impacts	Increased network security
Contributors	• Universities focusing on the topics of IoT. • Companies providing IoT services and tools. • ITU-T study group SG17 – smart grid devices.
Additional information	Interdependent with T18, T21. Also builds on the JRC report on Smart Grid projects
Budget	30 M€
Timeline	2017 – 2023

T21	**Cybersecurity**
Contents	**Challenges:** Computer security, including cyber security and information security, refers to the protection of IT systems from theft or damage to the hardware, software, and the information on them, as well as from disruption or misdirection of the services they provide. This includes controlling physical access to the hardware, as well as protecting against harm that may come via network access, data and code injection, and malpractice by operators, whether intentional, accidental, or due to being tricked into deviating from secure procedures. This field is of growing importance due to the increasing reliance on computer systems in most industrial sectors and societies. Computer systems now include a wide variety of "smart" devices, including smartphones, televisions and tiny devices, as part of the IoT, and networks include the Internet and private data networks. **Objectives:** The objectives to be dealt with for this task, among others, include the following: • Security measures, monitoring, detection and reactions • Reducing vulnerabilities • IT Security by design for power system security

	• Security architecture • Hardware protection mechanisms • Secure and robust controls and operating systems • Secure coding and encryption • Secure cross-sector identification and authentication • Network and information access control • Response to breaches, and warnings to actors within the sector • Cross-border coordination within the electricity sector. **Scope:** • Publish a strategy for the cybersecurity area within TSO businesses. • Publish a best practice guideline for TSO substation and ICT system security design. • Publish a dissemination plan for promoting the strategic initiatives. **Specific tasks:** • Create a strategy for cybersecurity within ENTSO-E. • Create a best practice guideline for TSO substation and ICT system security design. • Create a dissemination plan for promoting the strategic initiatives.
Expected outcomes	A recommended strategy and design guideline for ENTSO-E to achieve a secure solution based on state-of-the-art information security technologies and the best theory and practices, combining information and power system security.
Expected impacts	Increased network security
Contributors	ITU-T, IEC TC 57, CENELEC TC57X, EC Connect, ENISA, ISO JTC 1, ISO/IEC JTC 1/SC 6, IETF
Additional information	Interdependent with T6, T17, T16. Also builds on: • ITU-T strategy for the IT and banking sectors • EU digital single market – related aspects of the programme • EU digitalization of the power system program initiatives • EU cyber security project reports – strategy outcome
Budget	20 M€
Timeline	2022 - 2026

8. APPENDIX 2: FUNCTIONAL OBJECTIVES FOR DISTRIBUTION SYSTEMS

D1	Active demand response
Contents	**Challenges** Nowadays, Active Demand (AD) is spread among industrial consumers and to a minor extent for commercial customers, including the tertiary sector. However, there is still a major challenge to implement demand response for large numbers of residential and small commercial consumers (so as to reach sufficient load flexibility levels), i.e. to provide end users with information on their consumption and the ability to modify their consumption in response to for example time-based prices signals and other types of incentives, so as to provide system services for DSOs through new market players such as aggregators and storage operators. Some demonstration projects, both at EU and national level, have shown the technical feasibility of the concepts, e.g. active participation of domestic and small commercial consumers in electricity markets through the provision of services by different market players, enabled by comprehensive technical and commercial ICT architectures. There are however three major barriers to be overcome for the wide deployment of AD response: • the low level of remuneration of the participants (which still makes it difficult to promote AD response) as well as the high transaction and investment costs for market players when a large number of small customers are involved, • the reliability of the ICT infrastructure coupling the end-users, the market players and the DSOs, at an affordable and reasonable cost compared with the benefits, • the interactions to be implemented between aggregators and DSOs since a large number of curtailments not anticipated by the DSO could significantly impact the reliability of the distribution network and therefore the power quality for end users. A second challenge related to AD response is to aggregate data in an accurate manner from short-term up to long-term time horizons and to implement an appropriate validation process at DSO level so that AD-based services can be provided by market players to TSOs while allowing DSO to properly manage possible constraints that may arise on the distribution networks (which calls for an enhanced coordination between TSO and DSOs). Few projects have addressed this issue: for TSOs, the main added value of demand response is the provision of balancing services. **Objectives** Some major European DSOs and market players have already tested and demonstrated the technical feasibility of AD response in projects targeting samples of end-users (of the order of magnitude ~100 consumers): Further R&I work must be promoted to foster end-consumers' participation in the retail electricity markets, so as to enable the provision of system services for network flexibility (e.g. the real-time optimisation of power flows at distribution level) and possible transmission level. **Scope** • Define the interactions (market and regulations) between the different market players and the DSOs so that DSOs can activate AD-based system services for optimized operations of the distribution networks. • Specifications of data exchange means (system-wide communication infrastructures and information integration capabilities) between the different market players, the end-users and the network operators. • Coordinate the technical developments (*Monitoring and control of LV networks*-D8) and *Automation and control of MV networks*-D9) with the market development so as to make sure that the means of observation and control are suitable for a wide use of AD-based system services.

	• Assess an adequate range of contracts to reflect the different consumer categories (by studying specific consumer behavior in the EU28, considering for instance local differences), the related technological infrastructures and demand-response technologies to support the commercial offers. • Define DSO-TSO collaboration (interaction purposes, etc.) and detailed analyses of the information to be shared (data specifications, privacy and cyber-security constraints, cf. D11) when AD-based system services are directly provided by aggregators to TSOs through DSOs. **Specific tasks** ***Upgrading of the network*** • Hardware and software solutions for demand aggregation connected with local energy management platform (connecting all market players).). • Hardware and software solutions for AMI to measure electricity consumption and send time-of use tariffs when needed as well as other applications and services. • Hardware and software solutions in substation connecting TSOs and DSOs so as to exchange data and allow the provision of AD-based system services from aggregators to TSOs through DSOs. **Power system flexibility** • Measure the flexibility brought by AD response in operation at a significant spatial scale (several thousands of customers) as well as the economic evaluation and the impact on the grid. **Power system reliability** • Demonstrate the use of AD response at a significant spatial scale (several thousands of customers) under stringent constraints (congestions for instance). • Demonstrate the ability of DSOs to enable aggregators to provide AD-based system services to TSO through coordinated communications between TSOs and DSOs. • Development and implementation of innovative and efficient solution for the exploitation of AD in emergency situations. **ICT and digitalization** • Develop and test devices enabling visualization and control of end-consumers' electricity consumption (for instance in-home displays with control functionalities) using low-cost and end-user friendly technologies (wireless technologies, PLC, smart phones, etc.). • Develop and test devices enabling control of end-consumers' equipment such as smart-energy management boxes, smart plugs, smart appliances, interfaces for load control and solutions to communicate with consumers, including the inverters for prosumers. • Develop and test a communication infrastructure to support the whole system allowing demand aggregation and control (cf. ***Upgrading of the network***) and M2M solutions adapted to the type of services required for the grid. • Participate in standardization activities so as to make sure that all components of the value chain are interoperable. **Market design** • Study possible new incentive mechanisms to promote large scale participation on AD schemes, or explore the possibility of mandatory cutbacks during peak consumption times in order to guarantee grid reliability and stability. • To carry out sociological studies and develop training and information programs to improve the awareness of end consumers and their understanding of the structure, functioning and the needs of the electricity systems. • Improvement of the models and simulation algorithms allowing the quantification of the impacts of AD response market mechanisms with market simulations at distribution level (including the coupling with market simulations at transmission level

	for the provision of system services by aggregators to TSOs). Market simulators should be able to tackle all time scales: long-term, day-ahead, intraday and real time markets. • Design adapted incentives (and associated market mechanisms) accounting for the end consumer's acceptance of load flexibility and maximizing their participation in AD-based schemes (tailor made tariffs such as time-of use/dynamic tariffs and real-time prices and combinations with capacity-based grid tariffs). • Study the rebound and deferral effects and provide reliable models to predict them so as to provide DSOs with methods to anticipate their impacts on network operations. • Methods to assess accurately the amount of shifted energy or modified consumption in AD-response schemes for end-consumers (methods must be transparent and based on data from a trusted third party such as the DSO; methods must also be able to extract the true shifted energy or modified consumption as one component of a load control strategy). • Recommendations to enable the integration of active demand in electricity markets (retail and wholesale) with a fair burden sharing and reward for all stakeholders based upon quantified business models. • Study the potential for cross-border AD-based service provisions (cooperation between connected DSOs). **DSO regulatory involvement** • Recommendations to cope with possible commercial and regulatory barriers that could impede the implementation at a pan-European scale of active demand solutions. • Study compensation mechanisms for mandatory partial consumption cutbacks related to the promotion of grid reliability and stability in peak consumption periods.	
Expected benefits	These developments will ensure the participation of the end consumers in AD response markets, while creating new business opportunities for market players, viz.: • Opportunities for aggregators and retailers to reach sufficient volumes to ensure profitability and eligibility in electricity markets; • Development of electricity retail markets allowing new market players to provide their services. This will lead to additional flexibility options for the reliability of distribution networks, viz.: • controlled integration of AD, RES , distributed storage and EV at a significant spatial scale, • increased network stability and reliability through the provision of AD-based system services, • possible investment deferral to cover the peak load demand,	
KPIs	• Increased system flexibility at acceptable cost [%]	
Partners involved	Network operators (DSOs and TSOs), retailers, aggregators, generators, BRPs, equipment manufacturers, ICT solution providers, regulatory bodies, R&D institutes, end-user associations and organizations promoting standards.	
Expected projects	Projects in D1 should propose large-scale demonstrations involving all stakeholders to demonstrate the benefits for all parties.	
Budget	124 million Euros	
Time line		
Expected impacts:	**Energy security, solidarity and trust**	The benefits brought by AD-based system services will allow DSOs to better host the new loads (EVs, heat pumps, etc.) and the increasing penetration of PV (at LV level) and wind power - and to some extent PV- at MV level.

Energy Union	**A fully integrated European energy market**	The work carried out in D1 will allow commercial activities around AD response and therefore new business opportunities for the (new) players of the retail and wholesale markets.
	Energy efficiency contributing to moderation of demand	All tasks of D1 contribute to AD response which promotes the moderation of demand for end users all over Europe.
	Decarbonising the economy	Peak shaving and load shifting will decrease the need for resorting to peaking unit emitting significant amounts of CO_2. AD based system services will also allow the increased penetration of PV and wind generation, thus reducing the CO_2 emissions of the electricity sector. AD based system services will also allow the increased penetration of new uses such as EVs and heat pumps.
Expected impacts: SET Plan	**Technology leadership**	European manufacturers (ICT and grid component) will benefit from participating in the projects by testing the market uptake of their new products, which in turn will strengthen their leading positions.
	Technology affordability	ICT manufacturers will focus their development on the affordability of the AD-response solutions to be deployed at the end end-user premises. This will result in low-cost hardware for the end-users adopting AD-based tariffs.
	New technologies and services to consumers	Products and services will be proposed to the European end-users so as to better control their electricity consumption and decrease their electricity bill.
	Resilience and security of energy system	The provision of AD-based system services will increase the number of degrees of freedom for DSOs when operating the distribution grids close to their physical limits.

D2	**Energy efficiency from integration of smart homes and buildings**
Contents	**Challenges** Energy efficiency in urban areas is a major issue for the member states since cities represent most of the energy consumptions (and the associated CO_2 emissions) for electricity, heating and cooling, as well as gas (40% of the energy used in the members states is consumed in buildings). Electrification of heating/cooling (heating and cooling represents 80% of the energy used in buildings in Europe, cf. COM(2015) 339) and transport (30% of the final energy consumption in Europe, cf. COM(2015) 80) is going to change load profiles at different spatial and time scales: at the city scale, the electricity consumptions will evolve due to the increasing coupling between the electricity network and the other networks, including water networks, waste networks, etc. At the local scale (homes, buildings, districts), large refurbishment programs and new zero (or positive) energy homes and buildings are also going to change the load (and generation possibly with local storage-) characteristics. These major changes will necessitate an adaptation of the existing MV/LV distribution networks: this results in a major challenge for DSOs to deploy and industrialise smart grid solutions so as to host and manage the new loads (and generation sources) coming from the wide promotion of energy efficiency in urban areas. The wide deployment of energy efficiency programs will also necessitate the involvement of the end customers and an increased competition in retails markets (with a better linking with the wholesale markets). Empowering consumers to act will be possible thanks to the wide roll out of new technologies, including smart meters, and new offers provided by companies selling energy services. This in turn will imply

transparent and non-discriminatory access to data, with a special attention to data protection. As a consequence, another major challenge for DSOs will be to manage all the necessary interactions with the market players so as to manage the network and adapt to new regulatory regimes pushing for lower electricity consumptions.

Objectives

The main objective of D2 is the deployment of smart grid technologies in urban areas in order to reach the goals set by the EC in terms of energy efficiency in buildings. The fulfilment of this objective implies a close cooperation between network operators and market players (retailers and aggregators) so as to optimize the operation and planning of the network, taking into account the interactions with the other urban networks (cf. D7).

Scope

The activities to be carried out in D2 should cover all necessary developments related to the large scale adoption of energy efficiency by end-users while maintaining the distribution grids in a secure state and at affordable costs. These activities should address

- New approaches to operate and plan distribution networks in urban areas under new constraints related to energy efficiency policies;
- ICT infrastructures and technologies that will allow the involvement of the end customers and the retail market players providing new energy efficiency services;
- Regulatory conditions to prepare all energy players (regulated and non-regulated) for a new era with lower electricity volumes.

Specific tasks

Upgrading of the network

- Network planning and optimization tools linking with urban planning tools so as to optimize the development of the electricity network taking into account energy efficiency policies at the city scale (interaction with other energy network, spatial planning).

Power system flexibility

- Advanced ICT infrastructures coupling DSOs and market players so as to estimate customer participation in energy efficiency (cf. D1).
- Assess the optimal level of intelligence at different spatial scales depending on the city and the existing network topologies (i.e. multilevel operations of the distribution network).

Power system reliability

- Study the benefits of deploying smart secondary substation with an islanding capability to be activated in emergency situations (in the presence of distributed generation and storage).
- Study the optimal load sharing between primary substations in real time depending on the local constraints at city level.

ICT and digitalization

- Enable in-home ICT technologies empowering the consumer to act in a user friendly environment (hardware and software solutions for connections with smart appliances, for measurement and control devices such as smart plugs and voltage clamps, for visualization such as in-home displays, web portals and smartphone apps).
- Develop and test solutions for direct load control (in close collaboration with telecom operators) via the smart meters and/or the energy boxes installed by service providers.
- Verify that all in-home ICT technologies are fully interoperable (smart appliances, smart meters, energy boxes, monitoring and control devices). A gap analysis of existing standards is also recommended.

	Market design • Market rules (and the associated regulatory framework) to help customer participate in retail markets (energy efficiency offers) in a transparent and non-discriminatory way, with a special attention to data privacy. • Business models for all stakeholders (especially retailers and aggregators) promoting energy efficiency at the end-user level (in relation with AD response, cf. D1). • Further study customer acceptance and involvement for energy efficiency measures by taking into account the full environment, i.e. ergonomics (ICT environment), market (price signals), and behavior (rebound effects and arbitrage between comfort and wealth). **DSO regulatory involvement** • Propose new regulatory options in a context of lower energy volumes.	
Expected benefits	The close collaboration between DSOs and market players offering energy efficiency services should support the advent of AD response, thus allowing increased distribution network flexibility and reliability. The associate deployment of smart solutions in cities will in turn pave the way for the secure penetration of the new uses of electricity in the transport sector (e.g. electric vehicles) and in the building sector (e.g. heat pumps).	
KPIs	• Increased system flexibility at acceptable cost [%]	
Partners involved	DSOs, retailer, aggregators and ESCOs, telecom operators, equipment manufacturers (including smart appliances), ICT solution providers, regulatory bodies, R&D institutes.	
Expected projects	Projects in D2 should propose large-scale demonstrations in cities involving all stakeholders to demonstrate the benefits for all parties. These projects should be merged with smart cities initiatives so as to integrate other key issues such as the interaction with other energy networks, city planning and performance monitoring.	
Budget	139 million Euros	
Time line		
Expected impacts: Energy Union	**Energy security, solidarity and trust**	The ability of network operators to better integrate the future development of urban areas will ensure the wide deployment of energy efficiency policies in buildings.
	A fully integrated European energy market	The work to be carried out in D2 will provide the necessary environment to both end users and market players so as to have growing retail markets, by allowing commercial activities and business opportunities related to energy efficiency.
	Energy efficiency contributing to moderation of demand	All tasks of D2 contribute to the promotion of energy efficiency for end users all over Europe.
	Decarbonising the economy	Energy efficiency together with AD response will increase the flexibility options at hand for DSOs thus reducing the CO_2 emissions of the electricity sector.
Expected impacts : SET Plan	**Technology leadership**	European manufacturers (ICT and network component) will benefit from participating in the projects by testing the market uptake of their new products, which is turn will strengthen their leading positions.
	Technology affordability	The wide deployment of energy efficiency in buildings will help ICT manufacturers to improve the affordability of the in-home energy hardware and software solutions (economies of scale).

	New technologies and services to consumers	Products and services will be proposed to the European end-users so as to better control their electricity consumption and optimize their electricity bill.
	Resilience and security of energy system	The combination of energy efficiency services with the provision of AD-based system services will increase the number of degrees of freedom for DSOs when operating the distribution grids close to their physical limits.

D3	**DSO integration of small DER**
Contents	**Challenges** A significant part of the installed PV power in Europe (almost 70% in Germany) is connected to the LV (low voltage) network and new developments are still expected both in urban areas (e.g. BIPV, i.e. Building Integrated PV in France) and in rural areas. As a consequence, there is today a major challenge to find an efficient way for the integration of renewable-based distributed generation (mainly PV), i.e. by maximising the use of the existing assets while deploying monitoring and control equipment (cf. D8, *Monitoring and control of LV network*). As a consequence maintaining power quality, i.e. voltage profiles in the suitable voltage band according to EN 50160 while monitoring -when possible- the maximum loads (in order not to exceed the assets maximum ratings, such as the thermal limits of transformers and lines), has become a major challenge for European DSOs. In spite of significant research efforts made by major European DSOs, following successful demonstrations in large EU-funded collaborative project, the hosting capacity of LV networks is still limited in many cases. Several voltage control options have been investigated in demonstrations or studied by simulations, e.g. local (PV inverters) voltage control through reactive and active power management as well as distribution transformers with OLTC (On-Load-Tap-Change) allowing decoupling of, to some extent, the low voltage from the medium voltage. **Objectives** The main objective of D3 is to increase the penetration of small DER (mainly PV) in the LV networks, within a well-planned process, covering the full range of encountered combinations between the spatial distribution of PV and network topologies, while keeping the network within its stability limits. Monitoring and control (D8) in combination with the implementation of advanced Network Energy Management systems will help DSOs to better operate the LV distribution grids hosting large amounts of PV. **Scope** A dedicated ICT infrastructure for monitoring and control of distributed PV (or other clean sources) associated to Network Energy Management platforms will allow the active control of small scale DER. The following activities should be considered: • Energy Management solutions for local generation-load balancing (including energy storage, demand response, etc.) and able to handle faults, isolation, power outages and islanding operations. • Market mechanisms for the participation of end users in electricity markets (specific attention should be put on the role and interactions between the different market players). • Improve power quality, e.g. voltage profiles, harmonics and power oscillations. **Specific tasks** ***Upgrading of the network*** • New planning tools so as to provide a complete simulation environment allowing dynamic studies and accounting for all components of LV networks (generation,

<table>
<tr><td></td><td>storage, loads, and topology) including all control systems (especially power electronics).
• New actuators (e.g. switches) and new sensors (e.g. fault detectors, voltage and current sensors) allowing new control strategies.
• Study and possibly demonstrate the added value of LV DC grids to lower costs of BoS (Balance of System) and to better control power flows when coupling DER, storage and other DC devices (research is needed for safety, especially in homes).
• Training of operators so as to adapt to new Network Energy Management platforms.
Power system flexibility
• Large scale use of on-load tap changers (and other alternatives) in secondary substations, including the use of reactive power based on voltage control.
• Testing smart meters with capabilities to contribute to almost real-time monitoring in critical zones at critical moments.
• Smart inverters providing grid support functions (active and reactive power control) and therefore allowing innovative control strategies so as to locally optimise balancing.
• Network Energy Management platforms (with the associated monitoring and control systems) able to interact with all local market players and with embedded functionalities such as self-healing capabilities for fault management.
• Accurate forecasting tools (generation and loads) at short-term time scales and local spatial scales.
• Create universal interface devices and protocols to enable DSO information exchanges with DER (mainly for third party owned PV and storage) from different manufacturers and using different technologies.
Power system reliability
• Develop new protection schemes able to cope with the increasing penetration of power electronics (inverters).
• Develop models and the associated simulation software for the evaluation of harmonic distortion and power oscillations in LV network hosting large amount of inverters (power electronics).
• Develop accurate state estimators based upon the new monitoring devices.
• Develop new tools to detect unwanted electrical islands.
ICT and digitalization
• ICT infrastructure supporting PV integration, i.e. monitoring and control of distributed PV systems.
• Standardization in data exchange protocols/interfaces between all equipment and players, including DSOs.
Market design
• Recommendations for valuation of ancillary services brought by distributed PV systems (possibly through self-consumption or when connected to storage devices).
• Recommendations for the participation of prosumers in electricity markets (including the studies of local energy markets).
Incentive schemes and contractual mechanisms for prosumers for short time DER control hand over to DSOs for grid management purposes.
DSO regulatory involvement
• Recommendations for the access to generation data of prosumers.
• Regulatory framework for temporary use of distributed DER for grid management purposes.</td></tr>
<tr><td>Expected benefits</td><td>The main expected benefit is the increase of the hosting capacity for PV generation in the LV networks (cf. KPIs). Other benefits will be</td></tr>
</table>

	• the development of Network Energy Management platforms allowing the full use of the monitoring and control devices to be rolled out as well as secure connections and data exchange with all market players, • new business opportunities related to ancillary services (e.g. voltage control, active/reactive power regulation flexibility, etc.).	
KPIs	• Reduction in cost of DG integration [%] ◦ Reduction in costs to stay within network capacity limits [%] ◦ Reduction in costs to stay within PQ limits [%] • Reduction in energy not supplied from DER [%]	
Partners involved	Equipment manufacturers, ICT and system architecture companies, R&D institutes, market players (retailers, generators, storage operators consumers and prosumers), DSOs, regulators, TPG stakeholders.	
Expected projects	Typical projects in D4 include enabling methods and technologies as well as large scale demonstrations for the industrialization and pan-European roll out of Energy Management platforms allowing DSOs to monitor and control the LV network as well as to interact with all market players.	
Budget	68 million Euros	
Time line		
Expected impacts: Energy Union	**Energy security, solidarity and trust**	Maximizing the potential for renewable electricity production in Europe contributes the energy security endeavor of the EC.
	A fully integrated European energy market	The Network Energy Management platforms to be developed and deployed will give market players the technical means to create new businesses, especially to find profitable business models related to active customers and possibly system services from renewables.
	Energy efficiency contributing to moderation of demand	The Network Energy Management platforms to be developed, allowing communication and data exchange with all market players, will ease the possibilities for proposing energy efficiency services, including demand response, to the end-users.
	Decarbonising the economy	Maximizing the integration of electricity production from renewables will decrease the CO_2 content of the delivered kWh and therefore will decrease the footprint of all grid users.
Expected impacts : SET Plan	**Technology leadership**	The equipment to be developed, both by power system component manufacturers and ICT manufacturers, will bring new business opportunities. This should result in technological leadership in a sector where European players address global markets.
	Technology affordability	The developments of smart inverters and other power electronics components should drive down the costs (economies of scale).
	New technologies and services to consumers	The energy management platform(s) will allow market players to offer new services (and the associated technologies) to the end customers connected to the LV network. This will also create new business opportunities for equipment manufacturers (PV systems).
	Resilience and security of energy system	The contribution of distributed PV to system services will improve the resilience of the electricity networks by offering more degrees of freedom to DSOs when operating the distribution grid close to its physical limits.

D4	System integration of medium DER
Contents	**Challenges** Most of the installed wind power in Europe is connected to MV networks (and also HV for some DSOs), as well as a significant number of large scale PV power plants (most of the small PV units being connected to the LV network). This massive and ever increasing penetration of intermittent and distributed generation impacts the operations of MV networks mainly by causing voltage profile problems and issues associated with reverse power flows, in complex and diverse network topologies, also resulting from small DER units feeding in low voltage (LV) levels of the network. As a consequence, maintaining power quality (e.g. operating within voltage, harmonics distortion and power oscillations limits) has become a major challenge for DSOs. Since existing power distribution systems were designed for unidirectional power flows, there is still today a limited capacity to integrate intermittent generation sources in MV networks in spite of significant efforts made by major European DSOs following successful demonstrations in large EU-funded collaborative projects: network operators have no direct access to energy production units (due to the legal unbundling of electricity generation, trading and distribution), and as a consequence keeping the voltage within defined limits remains a major challenge. An increased distribution grid hosting capacity for intermittent renewable energy sources requires active, real-time, large scale integrated management of distributed generation using novel technologies (including standards) allowing the implementation of active control (cf. D9, *Automation and control of MV networks*). At last, DER integration is not limited to wind and PV power, e.g. CHPs (cf. D14, integration of decentralised flexible thermal generation), small hydro: more demonstration projects and further developments are needed to increase the hosting capacity of MV grids so as to cover the full range of possible topologies and generation portfolios. **Objectives** The main objective of D4 is to increase the penetration of medium DER in the MV(HV) networks, covering the full range of encountered combinations between generation portfolios and network topologies, while complying with power quality limits and keeping the network within its stability limits. Active Control (D9) in combination with the implementation of advanced Network Operation and Energy Management systems will help DSOs to better operate the distribution grids hosting large amounts of DER. **Scope** A dedicated ICT infrastructure for monitoring and control of RES associated to Network Operation and Energy Management systems will allow for the active control of medium DER. The following activities should be considered: • Energy Management solutions for DER generation dispatching including the optimisation of the management of the distribution network from a technical and economic perspective, taking into account: generation-load balance, power quality, grid losses reduction, improved asset management, reliability and islanding. Specific attention should be put on the role and interactions between the different market players. • Market mechanisms for DER: new business opportunities should be explored in order to stimulate the participation of DER into power markets. New renewable energy support schemes based on market rules should be explored, so as to contribute to distribution grid reliability; • Energy storage and demand response as solutions to balancing issues, as well as new options to address power quality and network losses management; • Improve power quality (reduction of voltage asymmetry between phases) with a focus on system inertia impacting frequency control,, i.e. distribution grids where all generation units (and a significant part of the loads) are connected through power-electronics devices (flicker and harmonics);

<table>
<tr><td></td><td>Specific tasks
Upgrading of the network
• New tools for network planning and design including the simulation of active components, RES and control algorithms so as to study cost-effective solutions to increase the hosting capacity of existing grids, deferring reinforcements.
• Training of dispatchers so as to adapt to the new environment (new Energy Management platforms).
Power system flexibility
• Network management platforms (with the associated monitoring and control systems) able to interact with all market players (and TSOs if necessary) and with embedded functionalities such as self-healing capabilities for fault management and voltage control.
• Grid support capabilities of smart PV inverters (e.g. voltage regulation, curtailment using reactive/active power control) adapted to distribution network requirements and needs (possibility of centralized direct -and possibly locally automated- communications between DSOs and grid-connected inverters).
• Grid losses reduction through reactive power compensation provided by DER.
• Fault ride-through support through DER, including islanding operations.
Power system reliability
• Develop models and associated simulation software for the study of distribution grids with very low (no) inertia, able to mimic the altered power quality, the modified dynamic behavior of the power system, the possible interactions between the controllers of PE-interfaced generation units (and load).
• Use the developed models and software to better manage and understand harmonic distortion and power oscillations.
• New actuators (e.g. switches) and new sensors (e.g. fault detectors, voltage and current sensors) allowing new protection and control strategies.
ICT and digitalization
• Network monitoring systems and related ICT infrastructure supporting monitoring and control of DER.
• Standardization in data exchange protocols/interfaces between the DSOs and the TSOs, market players, especially generators.
Market design
• Recommendations for valuation of ancillary services brought by DER (e.g. voltage control, active and reactive power control, etc.).
• New market rules (replacing feed-in tariffs) for the deployment of renewables with propositions for new remuneration schemes.
DSO regulatory involvement
• Networks codes for DSOs defining the allowed interactions with the different market players during operations.</td></tr>
<tr><td>Expected benefits</td><td>The main expected benefit is the increase of the hosting capacity for distributed (intermittent) generation in the MV networks (cf. KPIs). Other benefits will be:
• the development of energy management platforms allowing the full use of the monitoring and control devices to be rolled out as well as secure connections and data exchange with all market players and the TSOs;
• the development of energy management platforms improving MV network operating conditions and indirectly asset management.</td></tr>
<tr><td>KPIs</td><td>• Reduction in cost of DG integration [%]
  ◦ Reduction in costs to stay within network capacity limits [%]
  ◦ Reduction in costs to stay within PQ limits [%]
• Reduction in energy not supplied from DER [%]</td></tr>
</table>

Partners involved	Equipment manufacturers, ICT and system architecture companies, R&D institutes, market players (retailers, generators, consumers and prosumers), DSOs, regulators, TPG stakeholders.	
Expected projects	Typical projects in D4 include enabling methods and technologies as well as large scale demonstrations for the industrialization and pan-European roll out of Energy Management platforms allowing DSOs to monitor and control the network as well as to interact with all market players and TSOs. Indeed, projects should focus on the roles of the different market players, and the necessary market mechanisms for the participation of DER in systems services, including potential changes in the regulations and the market rules. Projects should also include the tests of new technologies for voltage monitoring, voltage control and congestion management.	
Budget	79 million Euros	
Time line		
Expected impacts: Energy Union	**Energy security, solidarity and trust**	Maximizing the potential for renewable electricity production in Europe contributes the energy security endeavor of the EC.
	A fully integrated European energy market	The Energy Management platforms to be developed and deployed will give market players the technical means to create new businesses, especially to find profitable business models related to system services from renewables.
	Energy efficiency contributing to moderation of demand	The Energy management platforms to be developed, allowing communication and data exchange with all market players, will ease the possibilities for proposing energy efficiency services, including demand response, to the customers connected to MV networks.
	Decarbonising the economy	Maximizing the integration of electricity production from renewables will decrease the CO_2 content of the delivered kWh and therefore will decrease the footprint of all grid users.
Expected impacts : SET Plan	**Technology leadership**	The equipment to be developed, both by power system component manufacturers and ICT manufacturers, will bring new business opportunities. This should result in technological leadership in a sector where European players address global markets.
	Technology affordability	The development of power system components will drive the cost reduction of e.g. power electronics components for power plant control (inverters for example).
	New technologies and services to consumers	The energy management platform(s) will allow market players to offer new services (and the associated technologies) to customers connected to the MV network.
	Resilience and security of energy system	The contribution of DER to system services will improve the resilience of the electricity networks by offering more degrees of freedom to DSOs when operating the distribution grid close to its physical limits.

<table>
<tr><th>D5</th><th>Integration of storage in network management</th></tr>
<tr><td>Contents</td><td>
Challenges
The fast evolving environment of distribution networks, i.e. distributed generation (part of it being stochastic, interfaced through power electronics) and new load profiles (e.g. penetration of EVs and electrofuels,, new uses of electricity in buildings and heat pumps), has resulted in a series of challenges for network management related to generation-load balancing, power quality, congestion management and network losses. Most of the research activities of the DSOs have focused on finding and assessing the best sets of flexibility options depending on several criteria such as network topology, generation portfolio, etc. to cope with these challenges. Storage is one flexibility option among others (for instance flexible generation with fast turbines, grid reinforcements, FACTS, demand management, connection with other energy networks, distributed generators control, etc.) which must be assessed depending on the technologies and the foreseen functionalities. Many projects, both at national and EU level, have already investigated the added value which could be brought by storage in distribution networks (mainly for BESS -Battery Energy Storage Systems-). Yet there are still many open issues related to the lifespan of the storage technologies depending on their integration strategy (cycling profiles for instance), the valuation of the added value brought by storage for system services, the ownership and operations of storage devices by regulated players, the optimal spatial distribution (i.e. centralized versus decentralized storage) for a given objective function, etc. As a consequence, there is still a need for demonstration projects so as to assess the numerous questions to be answered related to the optimal deployment of storage in distribution networks (network flexibility and reliability, associated ICT infrastructures, market rules, and regulatory frameworks).
Objectives
The main objective of D5 is to specify, simulate and set up real-life demonstrations that will help market players and network operators better appraise the real added-value (technical and economic) brought by storage in the operations of the power system (flexibility and system services). These demonstrations will include specific work on innovative business models and recommendations regarding the necessary regulatory framework to be put in place.
Scope
The foreseen research activities should focus on:

The system services and the flexibility options that can be brought by the integration of different storage technologies in distribution networks (with CBA analyses assessing their economic performances compared to other flexibility options);
The need to assess the regulatory framework for storage operations and the associated valuation and remuneration for the provision of system services;
The need to consider storage in an integrated energy system, i.e. electricity can be stored at very large scale in buildings (thermal mass of buildings and individual hot water tanks with typical time scales of the order of magnitude of dozens of hours. Thermal storage in heating and cooling systems and the gas grids is addressed in D7.

Specific tasks
Upgrading of the network

Make sure that all tools used by network operators (operation, asset management, planning) account for the possibilities offered by storage, e.g. dynamic network simulation tools embedding the simulation of storage systems with active control algorithms, or planning tools accounting for the possibilities offered by storage when extending and/or refurbishing the network (e.g. deferred investments).

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	Power system flexibility • Study the added value brought by storage in MV/LV networks for the control of power flows, voltage profiles, power quality, as well as islanding and micro-grid applications, including black start capabilities. • Study the optimal spatial distribution of storage systems (especially for BESS systems) accounting for all constraints of the power system. • Study the integration of hybrid storage devices so as to have a Virtual Storage Power Plant (VSPP) fulfilling different functionalities. For instance, hybrid systems such as a flywheel-BESS-supercapacitor could help to cover wider ranges of functionalities. • Study the use of automated local thermal energy storage devices and local automated BESS (consumer level) by market players (aggregators, retailers) so as to provide system services for network operators. • At building level, investigate the inertia of thermal loads so as to better grasp the dynamics of the coupled energy system (electricity-heat-buildings). • Investigate new innovative control strategies to better control PV and storage systems so as to locally optimise balancing (LV networks). • Demonstrations of integrated design of the storage devices, e.g. joint design between battery manufacturers and power electronics providers, in order to optimise costs with the maximum coverage in terms of functionalities. • Storage in electricity networks for transportation (e.g. tramways) located in substations to provide system services to DSOs. • Study on the integration of hybrid storage devices and multi-BESS systems. • Further study the use of “second-life” automotive battery for stationary applications: battery pack selection, BMS as well as costs of BoS to be considered. • Study large scale centralized energy storage (e.g. thermal or chemical) for energy supply security over weeks to months. • Increase the integration of storage in cogeneration units in order to improve their flexibility. **Power system reliability** • Simulation tools to better appraise the cycling profiles associated to the envisaged applications and business models, which in turn, allow to estimate accurately the lifespan (and the failure modes) of the storage device. • Duty cycle standards so as to give undisputed performance certifications for market players using storage devices to provide system services. • R&I activities to understand the complex system dynamics of power systems with large power electronics penetration (power electronics interfaces for storage integration). • Study the development of self-consumption policies involving local storage so as to better control its effects on the stability of the power system. **ICT and digitalization** • ICT infrastructure for connecting (monitoring and possibly remote controlling by different actors) all storage devices to the network and/or energy and/or customers management platforms of the different actors (DSOs, retailers, aggregators, etc.). • Standardized communication protocols between storage devices and inverters, but also between storage devices and remote storage management platforms to meet requirements from network operators, retailers and aggregators (including cybersecurity). **Market design** • Develop a common coordination mechanism/platform/interface between storage providers and grid operators (allowing aggregation) in order to better control the power system and maximise social welfare.

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<tr><td colspan="3">• CBA tools to compare storage with other flexibility means (network reinforcements and new lines, demand management, connections with other energy networks, flexible generation, etc.) including environmental and social aspects (LCA).
• Multiservice business models for storage integration with a focus on the valuation and remuneration schemes of the system services brought by storage (regulations and market mechanisms to be studied and implemented).
• Investigate the use of dynamic pricing as a tool to trigger participation of storage in flexibility markets.
• Study and demonstrate the integration of Power2heat solutions for balancing and storage; with a focus on dynamic compensation between heat and electricity.
• Study the social acceptance of storage related to potential security and environmental impacts.
DSO regulatory involvement
• Investigate the needs for new regulatory mechanisms addressing storage ownership and operations for markets players and DSOs.</td></tr>
<tr><td>**Expected benefits**</td><td colspan="2">There are many benefits brought by storage since storage devices can bring a wide range of system services. Storage integration in the power system will
• increase in the grid hosting capacity for distributed generation resources (network availability and power quality, reduction of curtailment),
• improve the network operations (voltage control, reduction in network losses, power flow optimization, balancing, peak load reduction) and security (e.g. black start capability, islanded operation)
• optimize the use of existing network assets.</td></tr>
<tr><td>**KPIs**</td><td colspan="2">• Reduction in cost of DG integration [%]
◦ Reduction in costs to stay within network capacity limits [%]
◦ Reduction in costs to stay within PQ limits [%]
• Increased system flexibility at acceptable cost [%]
• Reduction in energy not supplied from DER [%]</td></tr>
<tr><td>**Partners involved**</td><td colspan="2">Storage equipment manufacturers, storage management software developers, power electronics manufacturers, ICT and system architecture companies, R&D institutes, DSOs, regulators, market players (retailers, aggregators, generators, etc.), TPG stakeholders.</td></tr>
<tr><td>**Expected projects**</td><td colspan="2">The expected projects in D5 must all include real-life demonstrations that will help market players and network operators better appraise the real added-value (technical and economic) brought by storage in the operations of the power system (for well-defined market mechanisms).</td></tr>
<tr><td>**Budget**</td><td colspan="2">100 million Euros</td></tr>
<tr><td>**Time line**</td><td colspan="2"></td></tr>
<tr><td rowspan="3">**Expected impacts: Energy Union**</td><td>**Energy security, solidarity and trust**</td><td>The large-scale deployment and integration of storage in distribution networks will ease the integration of PV and wind power, therefore participating in the security of electricity supply at the pan-European level.</td></tr>
<tr><td>**A fully integrated European energy market**</td><td>The advent of new market players (i.e. storage operators) or the use of storage devices in the portfolio of existing market players will create new business activities and offers in the electricity markets.</td></tr>
<tr><td>**Energy efficiency contributing to moderation of demand**</td><td>The use of storage can contribute to energy efficiency by promoting self-consumption, peak-load reduction, and load shifting capabilities.</td></tr>
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	Decarbonising the economy	Maximizing the integration of electricity production from renewables will decrease the CO_2 content of the delivered kWh and therefore will decrease the carbon footprint of all grid users.
Expected impacts : SET Plan	**Technology leadership**	The equipment to be developed, both by storage equipment and power electronics manufacturers as well as ICT manufacturers, will bring new business opportunities. This should help European storage manufacturers to address new markets in the world for stationary and mobile storage applications.
	Technology affordability	The research and innovation activities to be carried out should help lower the cost of storage integration through the promotion of standards and the economies of scale.
	New technologies and services to consumers	Local storage devices will be used by market players to offer new services to the end consumers.
	Resilience and security of energy system	All system services that can be brought by storage devices, when deployed, will help improving the resilience of the electricity system.

D6	**Infrastructure to host EV/PHEV – Electrification of transport**
Contents	**Challenges** Electro-mobility for private end-users still remains very limited even though major car manufacturers propose today plug-in hybrid vehicles (PHEVs) and full-electric vehicles (EVs). So far, the main development of electro-mobility has been observed in cities where market players propose new services to citizens (electric bicycles and cars for instance) and where local authorities promote tramways and hybrid buses for public transportation. In case of a massive roll-out of EVs, impacts on the distribution grids (and as a result on transmission networks) must be carefully evaluated. For DSOs, the mitigation of impacts generated by the different charging options at LV (slow charging, fast charging, etc.) will be key when experiencing possible overloads and power quality problems. For EV owners, the main issue is the availability of a pan-European network of charging points with standardized solutions (plugs, billing, etc.). **Objectives** The main objective of D6 is the evaluation of the impacts of electrification of transport (mainly EVs) may have on the European distribution grids from the perspective of planning, operation and market design. The massive integration of EVs and electric transport in cities could allow load control (load shaping) and system services (from distributed storage with V2G -vehicle-to-grid- applications), but could also result in overloads and power quality issues (voltage profiles and harmonics). **Scope** Most of the relevant activities for D6 have already been partially addressed by projects both at national and EC level, e.g. concepts such as EV control and aggregation as VPP (virtual power plants, i.e. V2G applications with EV batteries as decentralized storage devices), or tools to assess the steady state and dynamic impact of a large roll-out of EVs on the distribution grids. However, there is still a lack of knowledge regarding the techno-economic feasibility of a large-scale electrification of transport. Further R&D activities are needed to quantify, monitor and control the EV-grid interactions, viz. (similar R&D activities are also needed to better appraise the impact of the development of public transportation on the distribution grids of medium to large cities in Europe) : • Novel control techniques for charging technologies (smart EV charging management) in order to optimise the integration of volatile power from renewable sources (solar and to some extent wind) by aggregating the EV power demand;

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Smart load management approaches accounting for individual patterns of mobility for each user, specific vehicle characteristics and the ICT infrastructure to be deployed;
Smart EV charging solutions, such as the centralized management of electric vehicle recharge stations from grid secondary substations;
Tools to study at all spatial and time scales possible overloads and power quality issues (such as harmonics, voltage profiles) coming from EV charging;
Validation and certification of electro-mobility systems.

Specific tasks
Upgrading of the network

Network modelling and optimization tools for planning and asset management in the presence of massive integration of EVs (short-, medium- and long-term scenarios for the implementation of the adequate recharge infrastructures are needed for the assessment).
Simulation tools to assess the steady state and dynamic impacts in operation (especially power quality and voltage profiles) of a large roll-out of EVs on the distribution grids.

Power system flexibility

Energy management in transport electricity network located with storage solutions in substations (connecting with the local DSO) to provide system services to DSOs (e.g. with a storage device recuperating the braking energy of tramways).
Development of smart (and controllable) EV charging/battery swapping infrastructures accounting for energy availability, network constraints and electricity prices.
Further develop V2G technology solutions and assess the true costs of implementation and the benefits.
To ensure interoperability with the future EVs (with a focus fast, very fast, and inductive recharge technologies);

Power system reliability

Optimization tools for power flow calculation able to simulate the power electronics embedded in charging station (recharge) and EVs (V2G application), including the control systems (both hardware and software).
Forecasting tools accounting for customer behavior so as to predict EV charging loads.

ICT and digitalization

Development of centralized/distributed remote management systems enabling smart grids integration of EV charging infrastructures, supporting business-to-customers and business-to-business relationships and ensuring easy and secure payments for customers.
Interface the remote management system with the Energy management platforms (cf. D4 for instance).
Creation of a common marketplace in order to provide roaming services for EV charging services.

Market design

Tariff schemes and incentives to promote optimized charging and facilitate customer engagement.
Demand response: market mechanisms for V2G applications.

DSO regulatory involvement

Regulatory issues regarding market design and network regulation to efficiently integrate electric vehicles in electricity grids (system services).

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<tr><td>Expected benefits</td><td>The massive integration of EVs and electric transport in cities will allow load control (load shaping) and system services (from distributed storage with V2G -vehicle-to-grid-</td></tr>
</table>

	applications). The improved modelling and optimisation tools will enable DSO to better plan and operate the network, i.e. overloads and power quality issues related to EV charging.	
KPIs	• Increased network hosting capacity for EVs [%]	
Partners involved	DSOs, TSOs, ICT companies, manufacturers (cars, power system components, power electronics, charging stations, etc.), market players (retailers, aggregators, ESCOs), R&D institutes, regulators.	
Expected projects	Project in D6 should aim at both implementing methods and tools to analyse the effects of the massive roll out of EVs on the network and demonstrate at significant scales new solutions (remote management system, smart charging stations, etc.) and market mechanisms.	
Budget	100 million Euros	
Time line		
Expected impacts: Energy Union	**Energy security, solidarity and trust**	The massive roll-out of EVs (together with the ever increasing penetration of green electricity) will reduce Europe's dependence on imports of fossil fuels for the transport sector, and ensure secure energy (fuel) supplies.
	A fully integrated European energy market	The roll-out of EVs should participate in the construction of an integrated energy market by providing new electricity-based services (vehicle-to-grid applications enabling grid services provision, smart charging stations allowing customers to respond to specific tariffs, etc.).
	Energy efficiency contributing to moderation of demand	The electrification of transports should result in better energy efficiency at the European energy system level since increasing the well-to-wheel efficiency for vehicles and public transportation (when using green electricity).
	Decarbonising the economy	The roll-out of EVs and in general the electrification of transports will allow to reduce CO_2 emissions from the transport sector when the electric kWh has a low CO_2 content (green electricity).
Expected impacts : SET Plan	**Technology leadership**	New business opportunities for the stakeholders of the value chain: car manufacturers (e.g. support to electric vehicle market growth), market players, technology providers.
	Technology affordability	The massive roll-out of EVs should help manufacturers all along the value chain to drive down the costs (power system components, charging stations, ICT infrastructure, and vehicles) by learning effects.
	New technologies and services to consumers	New smart standardized charging technologies and EVs as well as the associated billing services will be proposed to the European consumer.
	Resilience and security of energy system	Smart charging stations together with load forecasting as well as ICT infrastructures and power system components will allow the usage of the power demand of EVs as a flexibility option for DSOs.

<table>
<tr><th>D7</th><th>Integration with other energy networks (heating and cooling, gas, etc.)</th></tr>
<tr><td>Contents</td><td>
Challenges
The EU has set very ambitious targets in terms of greenhouse gas emissions reduction and energy production from renewable energy sources. For the electricity sector, these targets imply a massive integration of wind and PV power, thus resulting in the need for flexibility options so as to ensure balancing. There are many flexibility options, e.g. demand management and demand response, flexible RES and thermal generation, network (PE, reinforcement, etc.), etc. and storage. In order to provide further options, the structure of the energy system as a whole must evolve: these additional flexibility options can be provided through large scale thermal and chemical energy storage by coupling electricity distribution networks with heating and cooling networks (thermal storage) and with gas networks (chemical storage). The typical timescales for these flexibility options can be very large, e.g. days for thermal storage and months for chemical storage. In urban areas other couplings can be achieved with networks relying on electricity (water network, transport, etc.). The flexibility option brought by the coupling of the distribution grid with heat and cooling networks can already be achieved with existing technologies, however, the coupling of the distribution grid with the gas grid is still in the pilot phase with power to gas technologies (electricity to hydrogen with electrolysis and then methane from hydrogen with the Sabatier process). There is therefore a major challenge for network operators to study and demonstrate that new flexibility options for balancing can be brought by coupling the electricity distribution grids with other local (e.g. in urban areas) energy networks.
Objectives
The main objective of D7 is to demonstrate that the flexibility options brought by the coupling of the electricity distribution grid with other energy networks can help DSOs better operate the network with very high penetration of intermittent generation.
Scope
The main research and innovation activities to be conducted in D7 are the following:

Thermal storage: quantify and demonstrate the flexibility brought by coupling electricity distribution networks and heating (and cooling) networks.
Chemical storage: quantify and demonstrate the flexibility brought by coupling electricity distribution networks and gas networks.
Load management: quantify and demonstrate the flexibility brought by coupling electricity distribution networks and other network in urban areas (drinking water network and waste water networks for instance).
Provide a systemic analysis of the integration of storage into different multi-energy coupling concepts or tri-generation (e.g. electricity to district heating network with heat pump and thermal storage or electricity to gas to electricity and heat with combined heat and power generation units). The impact of a large fleet of residential electrical water tanks on the power system flexibility may also be addressed, especially within the scenarios with very high penetration of wind and solar generation.

Specific tasks
Upgrading of the network

Methods and simulation tools to provide a coupled analysis of the dynamics (including steady state analysis) of the coupled system (heat and cooling, gas, electricity networks with an extension to water -waste and drinking- and public transport networks in urban areas).
Large-scale demonstrations of successful integration of power to gas technologies in the energy system (including coupling with local fuel supply).

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	• Develop methodologies and tools for joint planning and operation of different energy systems (electricity, gas, heat). **Power system flexibility** • System services (balancing) brought by heating (and cooling) network operators in case of low (or negative) residual loads when producing and storing thermal energy. • System services (balancing) brought by gas network operators in case of low (or negative) residual loads when producing and storing chemical energy; • System services (balancing) brought by drinking water and network operators in case of low (or negative) residual loads; • System services (balancing) brought by individual electrical boiler in case of low (or negative) residual loads when producing and storing thermal energy; • Optimise the connection, control and management of CHPs connected to district heating networks, including those coordinated as "virtual power plants", so as to provide flexibility. **Power system reliability** • Security assessment for the whole energy system in case of outages in the electricity network (e.g. electric pumps in the district heating and cooling networks, or in the drinking and waste water networks, as well as electric compressors and control equipment in the gas network). **ICT and digitalization** • Specify and assess the costs of the ICT infrastructure needed to connect all market and regulated players of the energy system. **Market design** • Demonstrate the business case for producing: ◦ heat when residual loads are low with e.g. large-scale heat pumps (green electricity) or individual electrical boiler (green electricity); ◦ electricity (gas-fired or biomass fired CHP units) when residual loads are high. • Market simulators coupling the electricity, gas and heat markets, building upon flow-based methods and simulation tools. • Market design (and the associated regulatory framework) for e.g. thermal storage for participation in electricity and heating markets. ***DSO regulatory involvement***
Expected benefits	The main impact of the research and innovation activities to be carried out in D7 should be the overall optimisation (efficiency and costs) of the energy systems. For DSOs, the expected benefit is the demonstration that additional flexibility option can be found (at affordable costs) by coupling the distribution grids with e.g. district heating systems and distribution gas grids.
KPIs	• Reduction in energy not supplied from DER [%] • Reduction in cost of DG integration [%] ◦ Reduction in costs to stay within network capacity limits [%] ◦ Reduction in costs to stay within PQ limits [%]
Partners involved	DSOs, heating and cooling network operators, gas network operators, water network operators storage equipment manufacturers (including power to gas technologies), power electronics manufacturers, ICT and system architecture companies, R&D institutes, regulators, market players (retailers, aggregators, generators, etc.) for gas, electricity and heat, city planners, TPG stakeholders.
Expected projects	The expected projects in D7 must assess the overall benefits of the coupling between the electricity distribution networks and other energy distribution networks (gas, heat and to some extent transport and water in urban areas). These assessments must be both technical and economic. For some projects, where technologies are already available, real-life demonstrations that will help market players and network operators

	better appraise the real added-value (technical and economic) brought by these couplings are expected.	
Budget	150 million Euros	
Time line		
Expected impacts: Energy Union	**Energy security, solidarity and trust**	The coupling of the distribution electricity grid with other (energy) distribution networks should help optimize the hosting capacity of DER, and therefore participate in the security of supply.
	A fully integrated European energy market	The coupling of the distribution electricity grid with other (energy) distribution networks should help integrate the different energy markets (e.g. electricity, gas and heat).
	Energy efficiency contributing to moderation of demand	
	Decarbonising the economy	Maximizing the integration of electricity production from renewables will decrease the CO_2 content of the delivered kWh and therefore will decrease the carbon footprint of all grid users.
Expected impacts : SET Plan	**Technology leadership**	
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	The large-scale (thermal and chemical) storage options brought by the coupling of the networks will improve the resilience of the energy system in case of outages.

D8	**Monitoring and control of LV networks**
Contents	**Challenges** Currently, large European DSOs are developing and rolling out advanced monitoring and automation technologies in order to better monitor and operate their distribution LV networks. The monitoring of the low voltage (LV) network is key regarding load-flow optimization at local level, fault detection, power quality (voltage and harmonics) and optimization of maintenance operations within a fast evolving environment (growing share of distributed generation such as PV, distributed storage and new uses such as heat pumps and EVs that modify the load profiles). Some EU-funded and national projects have allowed DSOs to test for example LV supervision systems (monitoring and control) for secondary substations (including circuit breakers), self-healing equipment, and new AMR/AMI and AMM solutions. Yet, the modernization of the LV distribution grids in member states is an ongoing process that currently requires further development such as cost effective new management methodologies and control methods. Despite the effort of major European DSOs, the European LV networks are still often managed with a coarse-grained monitoring of power and voltage in MV/LV transformers, a rather poor knowledge of topology, and few tools for decision-making support. **Objectives** Some major DSOs have started to equip and test their distribution LV networks with

	some TSO and MV-like monitoring and control equipment: however, there is still a need to demonstrate under real operating conditions and at a large scale, an integrated set of new solutions to improve LV network monitoring and control for all distribution grids in Europe, at affordable costs. **Scope** • Data collection and exchange of information between DSOs and the different service providers (retailers, aggregators, etc.) with the corresponding market rules (remuneration of system services) and network regulatory schemes (e.g. ownership of data). • Optimal management and activation of local flexibilities thanks to the information exchange and the new market/regulatory frameworks (generation and load control). • Modeling of generation and loads at a fine-grained spatial scale so as to better appraise production and consumption (accuracy). • In case of an outage: faster fault localization, isolation times, and recovery of healthy sections (self-healing and/or automatic islanding) for improved outage management. • Protection systems that can cope with the increasing penetration of power electronics generating harmonics (fault detection) and two-way power flows. • Improve reliability and quality of power supply by finding the right level of automation. **Specific tasks** ***Upgrading of the network*** • Develop protection schemes as well as remote control systems for two-way power flows (communication with smart PV inverters) and network switches. • Study automatic control concepts and determine the most cost-effective automation level (semi-automated versus fully automated LV network) with data protection and cyber security approaches, adapted protection schemes and use of decentralized storage. **Power system flexibility** • Operational scheduling tools for optimal grid configuration based on day-ahead forecasting and real network data to maximize (DER penetration, EV penetration, etc.) or minimize (network congestions, network losses, reverse power flows to TSO, etc.) given objective functions. • LV and MV monitoring combined with forecast algorithms to display the actual availability of network capacity with respect to its standard value, providing a clear knowledge of the network performance, facilitating the calculation of the set points for their controls and also providing a clear view of grid assets loading. • Definitions of information to be exchanged between the MV and LV levels regarding coordinated reactive power management. • Investigate and evaluate how the communication structure for AMM could be used as an information channel and for load control. Load control can be used to inform certain loads, on the basis of network capacity, when it is appropriate to increase or decrease consumption. This could also involve pricing. • New control architecture for optimized operation • New algorithms to identify system topology **ICT and digitalization** • Information model aggregation (using IEC 61850). • Data protection and cyber security methodologies. • Communication infrastructure supporting integration. • Communication interfaces on secondary substation level. • Develop accurate frequency and voltage measurement devices (with a focus on the costs and the ease of integration). • Use AMM as an operational component in the automation architecture.

<table>
<tr><td></td><td colspan="2">• Use new systems to operate and monitor LV networks, optimizing and identifying network congestions, network losses, reverse power flows to TSO and act in a preventive and prescriptive way, in order to minimize and optimize human intervention.
Market design
• Recommendations on market rules and mechanisms for provision of ancillary services, islanding modes of operation.
• Coordination between technical grid control and market based power balancing (e.g. technical virtual power plants vs. market based virtual power plant)
DSO regulatory involvement</td></tr>
<tr><td>**Expected benefits**</td><td colspan="2">These developments will lead to full distribution system flexibility to integrate distributed RES and ensure enhanced demand response (supported by new actors such as storage operators or others), and will allow risk reduction when managing distribution grids.
• Improved observability of the LV network.
• Improved network operations: continuity of supply, power quality, reduction of network losses.
• New opportunities for market players providing system services (for instance voltage control and reactive power provision).</td></tr>
<tr><td>**KPIs**</td><td colspan="2">• Reduction in energy losses [%]
• Reduction in cost of DG integration [%]
  ◦ Reduction in costs to stay within network capacity limits [%]
  ◦ Reduction in costs to stay within PQ limits [%]
• Improving Quality of Service (SAIDI, SAIFI)
• Time reduction for awareness, localisation and isolation of grid fault [%]
• Reduction in energy not supplied from DER [%]</td></tr>
<tr><td>**Partners involved**</td><td colspan="2">Equipment manufacturers, ICT and system architecture companies, R&D institutes, DSOs, market players and regulators</td></tr>
<tr><td>**Expected projects**</td><td colspan="2">Projects proposing new methodologies as well as hardware and software components are expected. All projects should include large-scale (in real LV networks) demonstrations as proof of concepts and address the associated market, regulation and social issues.</td></tr>
<tr><td>**Budget**</td><td colspan="2">142 million Euros</td></tr>
<tr><td>**Time line**</td><td colspan="2"></td></tr>
<tr><td rowspan="4">**Expected impacts: Energy Union**</td><td>**Energy security, solidarity and trust**</td><td>By improving the control and monitoring of the LV networks, more local DER (mainly PV) will be integrated to the European grids, thus contributing to the security of supply at pan-European level.</td></tr>
<tr><td>**A fully integrated European energy market**</td><td>The developments will boost the retail markets by facilitating the exchanges between the different market players and the DSOs while maintaining the reliability of European LV network at affordable costs.</td></tr>
<tr><td>**Energy efficiency contributing to moderation of demand**</td><td>The automation and communication systems to be developed will allow market players and DSOs to control loads.</td></tr>
<tr><td>**Decarbonising the economy**</td><td>The automation and communication systems to be developed will allow DSOs to increase the hosting capacity of DER (mainly PV) at LV level.</td></tr>
<tr><td></td><td>**Technology leadership**</td><td>The developments will create new business opportunities for European manufacturers (control systems, protection systems, inverters, AMI/AMR, etc.) and engineering companies</td></tr>
</table>

		(forecasting tools, optimization tools, etc.), and as a consequence reinforce their leading position.
	Technology affordability	
Expected impacts : SET Plan	**New technologies and services to consumers**	The development of the new control and monitoring environment together with the associated communication infrastructure will allow market players to bring new services to the consumers while maintaining the reliability of the LV networks.
	Resilience and security of energy system	The development of improved control systems (automation, protection, etc.) will increase the resilience of the LV network under stringent conditions due to the variability of DER and loads and unforeseen events (faults due to lightning, etc.)

D9	Automation and control of MV network
Contents	**Challenges** Medium Voltage (MV) network monitoring, automation and control equipment, (including new robotic systems) as well as appropriated dispatching control software, are becoming available. Recently, some efforts towards autonomous intelligence (grid automation and control solutions) have been made to locally manage the MV grid in some EU-funded and national projects. In the meantime, however, several EU member states have connected large amounts of intermittent renewable generation (especially solar PV and wind) on their MV networks, which like in LV networks (cf. D8), has resulted in an increased volatility of electricity production, directly impacting power quality. Moreover, today, some of the existing assets of MV networks are ageing and need to be upgraded with control and communication capabilities. There is a still a major challenge for European DSOs to fully equip MV networks with advanced monitoring, automation and control technologies in order to better monitor and operate their distribution MV grids. The automation and control of the MV networks is key regarding power flow and voltage control, faults detection, power quality as well as optimization of maintenance operations. **Objectives** Major DSOs have equipped and tested their distribution MV networks with advanced monitoring and control equipment: however, there is still a need to demonstrate under real operating conditions and at a large scale, an integrated set of new solutions to improve MV network automation and control for operation and maintenance of all distribution grids in Europe in order to better integrate renewables and new loads. **Scope** • Accelerate the large scale deployment and validation of advanced automation and control solutions with the associated protection schemes and ICT infrastructures, and • Facilitate the increased participation of grid users in MV network operation and energy markets thanks to data collection and exchange of information between DSOs and the different service providers (retailers, aggregators, etc.) with the corresponding market rules (remuneration of system services) and network regulatory schemes (e.g. ownership of data). **Specific tasks** ***Upgrading of the network*** • Integrated voltage control and congestion management in distribution networks by means of smart transformers. • Middleware layers (with multi-agent systems) as a possible alternative for the management of MV networks hosting large share of renewables (including storage). • New actuators (e.g. switches) and new sensors (e.g. fault detectors, voltage and current sensors) for MV network.

	• Develop protection schemes as well as remote control systems for two-way power flows (communication with power electronics of generation and storage) and network switches. **Power system flexibility** • Large scale deployment of smart substations under the IEC standards (61850 and 61970/61968 CIM). • New tools (with advanced algorithms) taking advantage of the increased monitoring so as to optimise topology (as a flexibility option in the operations). • Operational scheduling tools for optimal grid configuration based on day-ahead forecasting and real network data to maximize (DER penetration) or minimize (network congestions, network losses, reverse power flows to TSO, etc.) given objective functions. • Interactions between TSOs and DSOs: increase observability of the distribution system for transmission network management and controllability with better forecasting and data flow. • Optimal management and activation of local flexibilities thanks to the information exchange and the new market/regulatory frameworks (active and reactive power management techniques for generators and loads). **Power system reliability** • New equipment and associated software for faster fault detection and isolation times. • Validation of self-healing network solutions using smart controllers in smart secondary substations. • New tools for MV power system stability analysis with a high penetration of power electronics. • Automatic fault clearing procedures with automatic power restoration. **ICT and digitalization** • Active management and control using communication infrastructures at MV level restricted in bandwidth. • Communication interfaces at smart substation level with the associated data protection and cyber security methodologies. • Design and optimise (costs) dedicated ICT infrastructures for MV network management. • Finding the right level of grid automation and the relevant parameters depending on the characteristics of the different grid architectures in Europe. **Market design** • Recommendations on market rules and mechanisms for provision of ancillary services (e.g. reactive power provision) provided through the MV network. **DSO regulatory involvement**
Expected benefits	These developments will lead to full MV distribution network flexibility to integrate distributed RES and will allow risk reduction when managing distribution grids. In addition, they will result in new business opportunities related to the provision of ancillary services for the MV network.
KPIs	• Reduction in energy losses [%] • Reduction in cost of DG integration [%] ◦ Reduction in costs to stay within network capacity limits [%] ◦ Reduction in costs to stay within PQ limits [%] • Improving Quality of Service (SAIDI, SAIFI) • Reduction in time needed for awareness, localization and isolation of grid fault [%] • Reduction in energy not supplied from DER [%]
Partners involved	Equipment manufacturers, ICT and system architecture companies, R&D institutes, DSOs, TSOs and regulators.

Expected projects	Projects proposing new methodologies as well as hardware and software components are expected. All projects should include large-scale (in real MV networks) demonstrations as proof of concepts and address the associated market, regulation and social issues.	
Budget	100 million Euros	
Time line		
Expected impacts: Energy Union	Energy security, solidarity and trust	By improving the automation and control of the MV networks, more wind and PV power will be integrated in the European grids, thus contributing to the security of supply at pan-European level.
	A fully integrated European energy market	The developments will facilitate new offers in the electricity markets for the provision of ancillary services, while ensuring the reliability of European MV network at affordable costs.
	Energy efficiency contributing to moderation of demand	The automation and communication systems to be developed will allow market players and DSOs to control loads.
	Decarbonising the economy	The automation and communication systems to be developed will allow DSOs to increase the hosting capacity of DER at MV level, which will lead to decreasing CO_2 emissions
Expected impacts : SET Plan	Technology leadership	The developments will create new business opportunities for European manufacturers (control systems, protection systems, smart substations, etc.) and engineering companies, and as a consequence reinforce their leading position.
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	The development of improved control systems (automation, protection, etc.) will increase the resilience of the MV network under stringent conditions due to the variability of DER and loads and unforeseen events.

D10	Smart metering data processing and other big data applications
Contents	**Challenges** In addition to the roll out of smart meters (to be completed in 2022, Directive 2009/72/EC), the increased monitoring and information exchange needs in distribution grids are going to generate large-scale databases (big data) to be managed, in some applications close to real time, while ensuring data privacy and security. As matters stand, contrarily to the banking or telecommunication sectors, there is no significant experience in big data applications in the electricity sector. The challenge posed by the growing volume, velocity and variety of data has to be met. Large volumes and velocities of data generated by short-interval reads of smart meter data, for instance; could overwhelm existing IT infrastructures. The resulting data storage costs could be very high due to increased data volumes and retention requirements with traditional database technologies. Big data applications and the associated data mining algorithm will contribute to the optimisation of the distribution grids and the implementation of the smart distribution grids so as to connect and manage new variable loads (EVS, heat

pumps, etc.) with intermittent production (mainly PV and wind power) while ensuring a transparent and non-discriminatory access for all market players (prosumers, retailers, aggregators, ESCOs, etc.).

Objectives

Scalable solutions to address large-scale data management issues in the electric distribution systems must be developed, which implies the standardisation of data models, methods and tools for data storage, data mining techniques, and data editing solutions. The availability of such solutions is key to develop data mining algorithms for all stakeholders of the distribution system. For DSOs, data management solutions associated to modern data mining techniques will allow the optimisation of the grids (power flow optimisation, faults detection, power quality, DER hosting capacity, asset management). For other market players, it will create new business opportunities.

Scope

- Standardization and interoperability of system architecture, protocols and data models.
- Efficient data mining algorithms for DSOs for various applications ranging from generation/load forecast to consumer behavior but also failure/ageing models for network components.
- Efficient data mining algorithms for market players (prosumers, retailers, aggregators, ESCOs, traders, etc.) to boost retail electricity markets and create new business opportunities, in connection with the DSOs.
- Addressing data privacy concerns (while considering cyber security issues, cf. D11), while ensuring a transparent and non-discriminatory access to the data for all market players.
- Ways and means to reduce the CAPEX of the ICT infrastructures and the associated O&M costs, for instance transaction costs for active demand operations.
- Develop standard systems for editing smart meter data with different customer interfaces (e.g. PC, TV, custom displays, etc.) and connected to smart appliances in order to enable the provision of energy efficiency services.

Specific tasks

Upgrading of the network

- Develop highly-distributed, low-cost sensors for the optimal management of the network (power flow optimisation, fault detection, power quality, hosting capacity for DG or EV, demand response, etc.).

Power system flexibility

- Development of mathematical approaches to describe consumption behavior from data mining techniques (load forecast, aggregation of consumer profiles) while ensuring the availability of the data for market players and customers.
- Development of mathematical approaches to forecast generation from PV and wind power with data mining techniques, while ensuring availability of the data for market players and customers.

Power system reliability

- Development of mathematical approaches to predict ageing and lifespans of network component (e.g. transformers, switches, breakers, etc.) including the associated ICT infrastructure (sensors, communication infrastructures) and smart meters.
- Novel data mining and data processing techniques to improve the reliability of the power system.

ICT and digitalization

- Improve the efficiency of large data mining processes.
- Develop data protection tools (access, authentication, and encryption), data publishing systems and data storing systems (e.g. web dashboards for data management, etc.).
- Ensure the standardisation of data models (e.g. CIM).

<table>
<tr><td></td><td colspan="2">• New IT solutions to process large data streams (cooperation with the bank industry).
• Develop distributed online analytical data stream processing.
• Efficient systems to obtain information from different and disparate sources of data (standardization and interoperability, data privacy and cyber-security issues, etc.).
• Develop and test solutions based on smart metering information and other sources of big data in order to improve the operation of the grid or to reduce costs while maintaining the quality of service.
Market design
• Recommendations for data privacy and data use by the different stakeholders of the electric system, including customer acceptance.
• Recommendations for new regulations to provide personalized services and tariffs to individual customers.
• Business models for providing new energy services thanks to the availability of large-scale data bases and advanced data-mining techniques.
DSO regulatory involvement</td></tr>
<tr><td>Expected benefits</td><td colspan="2">The developments will allow DSOs to better operate their networks, viz.
• Improved and optimised operations, asset management and planning;
• Increased integration of new uses, penetration of distributed generation
and market players to find new business opportunities, e.g.
• New energy-efficiency tailor-made services for the end user (including demand response);
• Possibility to define power quality and rated power at the customer's site.</td></tr>
<tr><td>KPIs</td><td colspan="2"></td></tr>
<tr><td>Partners involved</td><td colspan="2">Equipment manufacturers, ICT and system architecture companies, software developers, R&D institutes, DSOs, market players and regulators.</td></tr>
<tr><td>Expected projects</td><td colspan="2">Projects proposed in D10 should include a demonstration and validation component to verify the scalability and the replicability of the proposed solutions, as well as market/regulatory analyses to make sure that the proposed exploitation of the results is in line with the current market rules and the regulatory framework of the targeted member states.</td></tr>
<tr><td>Budget</td><td colspan="2">100 million Euros</td></tr>
<tr><td>Time line</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Expected impacts: Energy Union</td><td>Energy security, solidarity and trust</td><td>By developing data mining algorithms improving generation forecast and the optimisation of the network, more DER will be integrated to the European LV (PV) and MV (wind and PV) grids, thus contributing to the security of supply at pan-European level.</td></tr>
<tr><td>A fully integrated European energy market</td><td>The developments will boost the retail markets by facilitating the access to data by all market players in a transparent and non-discriminatory way.</td></tr>
<tr><td>Energy efficiency contributing to moderation of demand</td><td>The developed data mining techniques will allow market players (retailers, aggregators, ESCOs) to fine tune their commercial offers, i.e. new tariffs based upon demand response scheme.</td></tr>
<tr><td>Decarbonising the economy</td><td>The deployed infrastructure and the associated data mining techniques will allow DSOs to increase the hosting capacity of DER both at LV and MV level.</td></tr>
<tr><td>Expected impacts : SET Plan</td><td>Technology leadership</td><td>The roll out of large-scale data management equipment (manufacturers, ICT and system architecture companies) and data mining techniques (software developers) will create new business opportunities for European companies and bring</td></tr>
</table>

		experience to address markets outside Europe (north America, China, Japan).
	Technology affordability	
	New technologies and services to consumers	New tariff-based services will be offered to the end consumers thanks to data access by all market players.
	Resilience and security of energy system	The development of improved control systems (automation, protection, etc.) will increase the resilience of the LV network under stringent conditions due to the variability of DER and loads and unforeseen events (faults due to lightning, etc.).

D11	Cyber security (system approach)
Contents	**Challenges** ICT infrastructures are ubiquitous in power networks. The full digitalization of the distribution network (digital substations, smart meters, monitoring systems, etc.) brings new opportunities, not only for operations, but also for asset management. However, it also brings new threats related to cyber security. Compared to transmission grids, the challenges associated to cybersecurity have an additional feature: the connection to smart meters (end-users) which brings threats in terms of data protection and possible access to the DSO ICT infrastructures through these connection points. Cybersecurity is therefore a major issue when considering security threats for the distribution electricity networks: here, cyber security includes the protection of all ICT systems in response to physical access and access through ICT infrastructures including network operation staff. **Objectives** The main objective of D11 is to map and appraise cyber-security issues for the distribution grid, and propose solutions to mitigate these risks, ideally in an integrated manner in order to solve the problem in a systematic way. **Scope** The main research and innovation activities to be considered in D11 are as follows: • Identify and define the cyber security issues (confidentiality, integrity, vulnerability and availability of information flow) by considering the different layers of the SGAM (Smart Grid Architecture Model); • Identify the existing security standards and the possible gaps so as to provide potential improvement for the specific case of the smart grids; • Explore possible cyber security R&D issues that should be addressed for the specific case of smart distribution grids (on top of the existing activities in other sectors such as the banking sector); • Provide support for the creation of a European ICS-CERT (The Industrial Control Systems Cyber Emergency Response Team) for the smart grid sector. • Develop and demonstrate an integrated solution for cyber-security. **Specific tasks** ***Upgrading of the network*** • Develop and demonstrate physical and cyber security protections to avoid fraudulent access through physical installations (primary and secondary substations, MV and LV lines, etc.) to ICT systems. • Develop recommendations to make the IT/OT structure of power systems resilient and less vulnerable by design (focusing on the functionalities). **Power system flexibility** **Power system reliability**

<table>
<tr><td></td><td colspan="2">• Engage a common work with TSOs since cybersecurity issues are common to both transmission and distribution system operators at inter-connected infrastructures.
ICT and digitalization
• Study the risks and vulnerabilities related to the use of public ICT infrastructure for smart grid purposes, e.g. connection with the customers through smart meters and energy boxes (for example for demand-response signal or metering).
• Study the risk and vulnerabilities related to the use of wireless communications at the customers' premises but also in critical infrastructures like substations.
• Study the risk and vulnerabilities related to SCADA systems as a means to provide remote supervisory and control (e.g. high connectivity of SCADA ICT networks with other ICT networks such as the corporate intranet or even the Internet).
• Authenticating and authorizing users (maintenance personnel for instance) to IEDs (Intelligent Electronic Devices) in substations or smart meters in such a way that access is specific to a user.
• Define models for encrypted and authenticated orders which could be common to all smart grid stakeholders.
• Develop and demonstrate an integrated solution covering cyber-security issues of all infrastructures involved so as to avoid specific solutions for each installed equipment.
Market design
DSO regulatory involvement</td></tr>
<tr><td>**Expected benefits**</td><td colspan="2">The expected benefits of the proposed activities are:
• An exhaustive appraisal of the potential threats, vulnerabilities and risks related to the digitalization of the power system, and more specifically the distribution grids;
• A set of best practices to mitigate those risks (including the improvement of existing standards).</td></tr>
<tr><td>**KPIs**</td><td colspan="2">• Improving Quality of Service (SAIDI, SAIFI)</td></tr>
<tr><td>**Partners involved**</td><td colspan="2">DSOs, TSOs, standard organizations (ISO, IEC, CENELEC, etc.), ICT hardware manufacturers and software providers, equipment manufacturers, regulators, market players, consumer associations.</td></tr>
<tr><td>**Expected projects**</td><td colspan="2">Projects in D11 should include studies on methodologies and technologies to mitigate the risks for cyber-attacks. Demonstrations (tested robustness) on key generic technologies should be envisaged.</td></tr>
<tr><td>**Budget**</td><td colspan="2">100 million Euros</td></tr>
<tr><td>**Time line**</td><td colspan="2"></td></tr>
<tr><td rowspan="4">**Expected impacts: Energy Union**</td><td>**Energy security, solidarity and trust**</td><td></td></tr>
<tr><td>**A fully integrated European energy market**</td><td></td></tr>
<tr><td>**Energy efficiency contributing to moderation of demand**</td><td></td></tr>
<tr><td>**Decarbonising the economy**</td><td></td></tr>
<tr><td>**Expected impacts : SET Plan**</td><td>**Technology leadership**</td><td>European ICT hardware and software providers will gain much experience and insight on the current and future cyber security challenges of the sector, as well as on the available techniques and controls to better address them. Thus, European power system equipment manufacturers, as world leaders, can embed</td></tr>
</table>

		cyber security functionalities in their future products, thus leading to a competitive advantage.
	Technology affordability	
	New technologies and services to consumers	Technologies provided to the end user such as smart meters, energy boxes, wireless monitoring and control devices (e.g. smart plugs) will all embed cyber-security functionalities, thus leading to a secured use of the home equipment for European end-users.
	Resilience and security of energy system	Cyber security has been identified as one of the major issues for the resilience and the security of the electricity system; the work to be conducted in D11 should help to find suitable solutions so as to mitigate these risks.

<table>
<tr><th>D12</th><th>New planning approaches and tools</th></tr>
<tr><td>Contents</td><td>Challenges
The fast evolving environment of power systems, and more especially distribution networks (intermittent distributed generation, new loads, new power electronics and ICT technologies, etc.) influences considerably the process of planning. As a consequence, new methods to support the decision-making process resulting in optimised capital investment, low operating costs, reduced power losses as well as improved reliability and power quality are needed. The problem of optimal planning of distribution network developments is a dynamic (because of the fast evolving environment) and multi-criteria task involving a large number of variables, most of them being uncertain (random variables). Therefore there is a need for advanced mathematical and computational algorithms (probabilistic methods). Tools already exist (methodologies and software) to model power flows in distribution networks together with network losses and reliability indices, and the optimised investments can be calculated with well-known algorithms. However, these tools are not able to take into account the increasing complexity mentioned above, for instance the degrees of freedom brought by power electronics, active demand, storage and possibly DC links. Therefore, new planning approaches are needed to integrate the full picture of distribution grids in the future, the market dimensions as well as the available data (cf. D10).
Objectives
The purpose of D12 is to develop the next generation of planning tools able to account for the fast evolving environment of distribution networks.
Scope
The functional objectives include the development of knowledge in the following issues:
• New planning approaches and simulation environments able to cope with the full complexity of the distribution system (distributed generation, new loads, storage, active demand, power electronics, dynamic rating, automation and control systems, etc.).
• Development of probabilistic tools where the joint probability density function can be determined from the available data (cf. data mining techniques in D10).
• CBA analyses accounting for all costs, e.g. ICT infrastructure needed to connect all market players as well as the monitoring, automation and control equipment.
• Interactions with spatial planners, especially city planners, so as to account for the permitting procedures when planning new lines.
Specific tasks
Upgrading of the network</td></tr>
</table>

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<tr><td></td><td colspan="2">

- The planning issues of the future power system must be considered by studying its integration in the whole energy system, i.e. by assessing the added value brought by the coupling between electricity, gas as well as heating and cooling networks (cf. D7).
- Study all alternatives (degrees of freedom) to network reinforcements and new lines/links e.g. by using energy storage, power electronics, etc.
- Develop advanced mathematical (probabilistic) and computational tools so as to scan the whole phase space (use of High-Performance Computing facilities).
- Methodologies and simulation packages allowing DSOs to determine where the connection of new generation units, loads and storage should be encouraged (signal to market players).
- Increased the level of robustness of the future network to face extreme events due to climate change (high temperatures, floods, etc.) and due to natural hazards (earthquakes, etc.)
- Methodologies to improve the environmental footprint and the social acceptance of new equipment.

Power system flexibility

- Using data coming from the field (smart meters, monitoring systems at all levels, fault detection, etc.) to improve the planning process and the associated tools, taking into account the potential flexibilities brought by grid extensions in specific areas.

Power system reliability

ICT and digitalization

Market design

- Optimise the permitting procedures by integrating all constraints imposed by spatial planners in the simulation tools.

DSO regulatory involvement
</td></tr>
<tr><td>Expected benefits</td><td colspan="2">The research and innovation work to be carried out in D12 should allow DSOs to control the risks when investing while ensuring the reliability of the network at affordable costs.</td></tr>
<tr><td>KPIs</td><td colspan="2">• Planning tools readiness
• Planning rules readiness</td></tr>
<tr><td>Partners involved</td><td colspan="2">DSOs, equipment manufacturers, public authorities (state and regional and city), city planners, consumer associations, regulators.</td></tr>
<tr><td>Expected projects</td><td colspan="2">Typical projects in D12 include the development of methodologies, algorithms, and simulation environments validated with real network topologies and data.</td></tr>
<tr><td>Budget</td><td colspan="2">100 million Euros</td></tr>
<tr><td>Time line</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Expected impacts: Energy Union</td><td>Energy security, solidarity and trust</td><td>New planning methods accounting for the dynamic development of distributed generation will help to maximize the future hosting of wind and PV power, thus participating in the security of electricity supply.</td></tr>
<tr><td>A fully integrated European energy market</td><td>New planning methods accounting for the constraints induced by the market players will help DSOs operating future networks as market makers.</td></tr>
<tr><td>Energy efficiency contributing to moderation of demand</td><td>New planning methods able to account for the flexibility options brought by demand response and energy efficiency will support policies promoting the moderation of demand.</td></tr>
<tr><td>Decarbonising the economy</td><td>Facilitating the future integration of PV and wind power in distribution networks will help decarbonizing the electricity mix.</td></tr>
</table>

Expected impacts : SET Plan	Technology leadership	
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	

D13	Asset management
Contents	**Challenges** The evolving environment of distribution system is going to change the cycling profiles of the current assets: new loads (e.g. energy storage, electrification of transport and new uses in buildings, cf. D6 and D2) and load control (e.g. demand response, cf. D1) as well as intermittent generation (i.e. wind and PV power, cf. D3 and D4) are going to modify the operating conditions of the assets, which were (for most of the installed ones) originally designed for rather steady and unidirectional power flows. Therefore, the role of asset management in the control of the DSO's expenditures becomes even more critical. Fortunately, the monitoring, control and automation evolution of the distribution grids (cf. D8 to D10) as well as data mining techniques bring solutions to DSOs so as to better estimate and optimise the lifespan of the equipment and move from planned maintenance to condition-based maintenance. This, in turn, will allow network operators to prioritize maintenance resources toward assets that carry the most risk (risk-based maintenance). However, the deployment of monitoring (sensors), remote control and automation (actuators) as well as ICT infrastructures also implies maintenance of these new assets, most of them having lifespans and maintenance requirements which strongly differ from power components. Few projects have addressed the above mentioned challenges: this calls for an intense R&I activity in the asset management field for the coming years. **Objectives** The main objective of D13 is to provide DSOs with methodologies and tools to optimise the yearly expenditures for operation and maintenance by moving from planned maintenance to condition-based and risk-based maintenance (both for the existing and the next generation of power components as well as for the new digital environment). therefore extending the lifespan of assets while reducing service interruption times and ensuring safety. **Scope** With the digitalization of the distribution grids, DSOs have the opportunity to completely review maintenance procedures when upgrading the distribution networks. New knowledge must be generated dealing with critical parameters that impact ageing of equipment and inspection methods relying on ICT techniques (completing the in-field inspection visits). The following activities should be conducted: • Observation of the real behaviour of equipment in the distribution network, combining new simulation techniques and new observation approaches (e.g. drones), with an on-site monitoring (sensors and robots for in-site observation); • Understanding equipment ageing by improving the feedback from existing pieces of equipment, specifying and performing laboratory tests to qualify their real-life reliability, modelling and simulating ageing laws (including forecasting equipment ageing due to extreme events which cannot be reproduced experimentally);

- Developing decision making tools to optimise asset management for three time scales:
  - operation, to take into account the probability of failure of the assets, and perform on-line the related risk analysis, but also to prepare their replacement without impacting network operation
  - maintenance, to optimize maintenance and intervention plans relying on new IT systems
  - network planning, to increase the lifespan of new pieces of equipment, without impacting the electric system safety
- Optimisation of the electric system by proposing evolutions for maintenance policies of equipment (hardware and software), using new doctrines that reinforce the coherence between system operation, asset management and network planning.
- Optimisation of investments in distribution grids taking into account different approaches, such as smart grid solutions and traditional network reinforcement at the same time as the reduction of the operational costs (OPEX).

Specific tasks

Upgrading of the network

- Insert results from research related to ageing models and condition/risk-based maintenance into planning tools so as to account for maintenance constraints (and flexibilities) when performing planning studies.
- Design, implement, and test in the field maintenance approaches based on new robotic systems in order to reduce the time for maintenance and mitigate the risks associated to service interruption, while increasing safety for field maintenance teams.
- Innovative modifications in elements or components of the electricity system to facilitate maintenance approaches based on new robotic systems.

Power system flexibility

- Develop and use tools providing SoH (State of Health) estimates and probabilities of failure as a flexibility option when operating the network close to its physical limits so as to optimize the time of maintenance and the impacts on operations.
- Develop software and hardware to improve remote maintenance operations (especially for the new digital environment).

Power system reliability

- Develop accurate ageing (and failure) models accounting for the new cycling profiles (including extreme events) both for the power component (lines, substations, etc.) and the ICT infrastructure, by using, among other, data mining techniques and probabilistic approaches.
- Develop accurate SoH estimation techniques as an input to predictive maintenance (e.g. components' wear, oil level in transformer oil pits, SF6 level in switchgear) to better estimate the probable distance (time) to failures (link with ageing and failure models).
- Specify and perform laboratory tests to qualify the modelling work on SoH, ageing laws, failure laws.
- Tools for new maintenance strategies, i.e. conditional maintenance (predictive maintenance) and risk-based maintenance based upon ageing models and optimization algorithms able to address different time scale (from operations to planning).
- Training of maintenance operators for their adaptation to the new digital environment (.e. man-machine interfaces) and new robotic solutions.

ICT and digitalization

- Optimise costs (accuracy, redundancy, etc.) of the ICT infrastructure collecting and processing data (both for the on-line monitoring of components and data storage) to feed the data mining algorithms for conditional and risk-based maintenance.

	Market design DSO regulatory involvement	
Expected benefits	The works to be conducted in D13 should help improve the economic efficiency of maintenance work and provide flexibility options to the DSOs at different time scales (from operations to planning activities). The wide-scale implementation of predictive maintenance should help DSOs to better manage reliability and fine tune their OPEX.	
KPIs	• Asset lifespan increase with acceptable CAPEX and OPEX • Reduced OPEX	
Partners involved	DSOs, equipment manufacturers, software and engineering companies, regulators.	
Expected projects	Projects in D13 include enabling methods and technologies as well as real-life demonstrations to validate the tools and methodologies as well as the developed equipment.	
Budget	48 million Euros	
Time line		
Expected impacts: Energy Union	Energy security, solidarity and trust	The optimization of the maintenance work, and the developments of new tools and methodologies to account for the new cycling profiles of the power components as well as the ICT infrastructures, will help increase the RES hosting capacity of distribution grids.
	A fully integrated European energy market	
	Energy efficiency contributing to moderation of demand	
	Decarbonising the economy	The improvement of advanced maintenance methodologies and tools will increase the life time of the assets thus reducing the carbon footprint of the network.
Expected impacts : SET Plan	Technology leadership	The development of advanced tools and methodologies as well as digital components will help European companies to strengthen their position on the market.
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	The improved knowledge of the assets' lifespan, SoH, failure modes, etc., will allow network operators to operate the distribution grids with better safety margins.

D14	Integration of Flexible decentralised thermal power generation
Contents	Challenges As specified in D3 (System integration of small DER) and D4 (System integration of medium DER), the massive integration and ever increasing penetration of intermittent and distributed generation impacts the operations of LV and MV networks mainly by causing voltage profile problems and issues associated with reverse power flows.

	Maintaining power quality (e.g. operating within voltage, harmonics distortion and power oscillations limits) has become a major challenge for DSOs which are deploying monitoring, automation and control solutions on their networks, cf. D8 (Monitoring and control of LV networks) and D9 (Automation and control of MV networks). In complement to the flexibility that can be brought by intermittent generation, by improving e.g. RES forecast, small to medium scale flexible thermal power generation units such as flexible engine power plants, industrial cogeneration and other CHPs can provide valuable flexibility options. For industrial cogeneration, the operations are often regulated by the demand for heat (usually steam) and this mitigates the availability to operate in a more flexible manner. The challenges are therefore to develop systems and technologies that can efficiently decouple heat and power and to develop clean multi-fuel offerings. For small (and micro) CHPs, addressing commercial and domestic consumer, their smart grid capabilities and peak shaving potential have not yet been fully demonstrated in practice. **Objectives** For thermal power plants (including industrial cogeneration units, small and micro CHP units, etc.), the main challenges are to further improve the flexibility and efficiency performance to back-up renewables, to better integrate the existing and future units in the grid/energy system, to develop technologies with high electrical efficiency that can use hydrogen, biomass and biofuels and to demonstrate their techno-economic performances in comparison to other flexibility solutions. **Scope** One of the main scopes of the R&I activities are relative to the improvement of the existing thermal power plants for their operational flexibility (ramp-up/shut-down, load capability, fuel flexibility and increased robustness of components). For industrial cogeneration, the main scope is to decouple heat and power and to develop multi-fuel offerings. For CHPs, the main scope is to test the integration of different technologies at different spatial scales. **Specific tasks** ***Power system flexibility*** • To further increase the rate at which a thermal generation unit can increase or decrease its output (load following capability). • To improve start-up/shut-down time and ramp rates. • To further reduce the minimum load at which a thermal generation unit can reliably operate. • To improve performances (efficiency and emissions) at partial loads. • To increase the clean fuel flexibility of thermal power plants, to be able to use different sources of fuels (mixing and switching). • To adapt waste heat recovery solutions (ORC, etc.) to the flexibility challenge so that energy efficiency improvements do not lead to a reduced flexibility. • To decouple the use of heat and power (e.g. via buffers, storage, power-to-heat, power-to-gas, power-to-fuel). • To better integrate existing and future units in the grid/energy system. • To demonstrate integration of technologies with high electrical efficiency that can use hydrogen, biomass and biofuels. • To optimise the connection, control and management of the units, including those coordinated as "virtual power plants", and providing flexibility to the power system. • To demonstrate contribution of small and micro-CHP to “virtual power plant” configurations.

	• To integrate small-scale and micro-CHPs, energy storage and demand response for optimal balancing of supply and demand, while maintaining high efficiency operation of the CHP system. • To demonstrate the complementarity between small- and micro-CHP installations and heat pumps at the district level.	
Expected benefits	The R&I activities to be conducted in D14 should help provide flexibility options to the DSOs at different time scales (from operations to planning activities). They will ensure that thermal power generation, including cogeneration, will provide the necessary flexibility so as to address the challenges in the future energy system.	
KPIs		
Partners involved	Manufacturers, research institutes and universities, ESCOs, utilities, aggregators, DSOs, TPG stakeholders.	
Expected projects	The projects should include all system stakeholders in demonstrations showing that decentralised thermal generation units can deliver the expected flexibility.	
Budget	125 M€	
Time line	2017-2026	
Expected impacts: Energy Union	**Energy security, solidarity and trust**	The flexibility provided by flexible thermal power generation will contribute to security of supply and stability of the grid.
	A fully integrated European energy market	
	Energy efficiency contributing to moderation of demand	Improvements in the identified areas will also contribute to the improvement of efficiency of thermal power plants. An improvement in efficiency, thus, will also mean better use of available resources and reduced CO2 emissions.
	Decarbonising the economy	Developments in the areas mentioned above will ensure that flexible thermal power generation is ready for the challenges in the future energy system, allowing an increased share of renewable energy sources to be integrated into the system and contributing to the decarbonisation of the energy system.
Expected impacts : SET Plan	**Technology leadership**	Technology leadership of turbomachinery and other power plants components is in Europe. These improvements will contribute to keep the technology's excellence in Europe, providing the most advanced technology worldwide.
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	The flexibility provided by thermal power generation will contribute to security of supply and stability of the grid.

9. APPENDIX 3: IMPACTS OF THE R&I ACTIVITIES PER CLUSTER

9.1 R&I ACTIVITIES FOR TRANSMISSION SYSTEMS

Table 20: impacts of the R&I activities relative to cluster 1 (modernization of the network).

Energy Union	**Energy security, solidarity and trust**	Through smart asset management the grid capacity will be increased while maintaining the same level of quality and security of supply. Through the public acceptance actions and through actions aimed to reduce the environmental impact of the infrastructure it is expected to improve the stakeholder engagement and trust.
	A fully integrated European energy market	Delivery planning tools for TSOs, DSO system development, accounting for a broad spectrum of novel technologies (generation, transmission, storage, demand side response and management) will enhance the development of an integrated energy market.
	Energy efficiency contributing to moderation of demand	The use of the new planning tools, new materials and power technologies will enable the increase of networks efficiency, will facilitate the development of more efficient electricity markets. It will also enable the development of Demand Response or the use of other technologies in the most cost effective manner.
	Decarbonising the economy	By enabling the increased use of RES through the development of new tools for grid planning, through the use of new materials with lower carbon footprint
SET Plan	**Technology leadership**	While the TSOs are not the developers of technologies the use of algorithms and tools which are placed in real environments, the use of new materials and technologies will support the technology leadership
	Technology affordability	By making use of optimal grid planning tools this cluster will allow the optimization of the network development and identification of the most cost effective technologies. Hence less investments are needed. Moreover the use of new technologies (new types of conductors, storage), new materials (nanotechnologies to increase the quality of services while optimizing the costs. The performance, extension of lifetime will bring efficiencies in the use of the components.
	New technologies and services to consumers	New technologies and new materials are expected to be developed in this cluster and together with new planning methodologies will allow the optimization of costs and costs reductions.
	Resilience and security of energy system	The use of new technologies and materials will enable more flexibility and capacity of the existing power grid. The energy security is expected to continue to be improved, the quality of the services to increase while the costs will be optimized.

Table 21: impacts of the R&I activities relative to cluster 2 (Security and System stability).

Energy Union	**Energy security, solidarity and trust**	Increase the system reliability and improve the quality of service through the use of expert systems, advanced automatic controls and effective decision making tools.
	A fully integrated European energy market	Grid controllability under the form of control procedures for system security and ancillary services will enhance the participation not only of central power plants but also Distributed Energy Resources, of storage, etc., in this type of services.
	Energy efficiency contributing to moderation of demand	The use of controllability of observability of the grid will provided the operation of the grid more efficient and therefore it will contribute the energy efficiency. The use of ancillary services will allowed to replace the load shedding through new provided services
	Decarbonising the economy	Grid controllability will maximize the use of RES and will contribute to the decarbonisation.
SET Plan	**Technology leadership**	European manufacturers of sensors, intelligent electronic devices, artificial intelligence, and sophisticated automatic control devices will strengthen the leadership position.
	Technology affordability	The deployment of the systems and application will enhance the technology affordability
	New technologies and services to consumers	By grid observability integration of sensors and integrated communications , combination of this information with data from DSOs and weather conditions will allow the pan European system to be more customer centric oriented by enabling more variable generation and flexible demand.
	Resilience and security of energy system	Through improved transmission system observability, the TSOs will be allowed to make appropriate decisions regarding system operational planning and real time operation. It will enhance security and stability of the pan European system with a high amount of variable RES. The use of improved defence and restauration plans will lessen the impact of power shortages for end users.

Table 22: impacts of the TSO R&I activities relative to cluster 3 (Power System Flexibility from generation, storage, demand and network).

Energy Union	**Energy security, solidarity and trust**	Maximizing the potential for renewable electricity production in Europe contributes the EU energy security in sense of les dependence on oil, gas.
	A fully integrated European energy market	The work to be carried out this cluster will provide the necessary environment to both end users and market players so as to have growing retail markets, by allowing commercial activities and business opportunities related to new services.
	Energy efficiency contributing to moderation of demand	Plan and operate the network in an efficient economical way through the use of Demand Response
	Decarbonising the economy	Enhance the deployment of low carbon technologies through the use of different flexibility means: storage, Demand Response, flexible thermal power generation, increase the grid hosting capacity, interaction of other energy networks.
SET Plan	**Technology leadership**	European manufacturers (ICT and network component) will benefit from participating in the projects by testing the market uptake of their new products, which is turn will strengthen their leading positions.
	Technology affordability	The research and innovation activities will help lower the cost of integration of technologies such as storage , or will avoid further investments in the grid through the enhanced utilization of the grid
	New technologies and services to consumers	Through the use of different flexibility means the environmental impact and the use of resources will be minimised. This will bring benefits to the customers and tariff payers through more cost effective operation in terms of capex and opex.
	Resilience and security of energy system	The contribution of different flexibility means to system services – storage, Demand Response, flexible thermal power generation, increase the grid hosting capacity, interaction of other energy networks – will improve the resilience of the electricity networks by offering more degrees of freedom to TSOs when operating the distribution grid close to its physical limits.

Table 23: impacts of the R&I activities relative to cluster 4 (Economic Efficiency of power system).

Energy Union	Energy security, solidarity and trust	Increase the cross border exchange through the market/grid operation integration
	A fully integrated European energy market	A more efficient Internal Energy Market that takes into account grid flexibility and the modelling of uncertainties to increase the cross border exchange
	Energy efficiency contributing to moderation of demand	Enabling the participation of customers through new market designs and therefore enhancing the moderation of demand
	Decarbonising the economy	Through improved and more flexible market design, the use of business models for RES which can facilitate the Res investment, enhance the further deployment of RES
SET Plan	Technology leadership	.
	Technology affordability	New mechanisms pushing towards an optimal investments needed through the development of the business models that take into account not only the model of the electricity sector but also the entire energy sector and the consideration of different actors
	New technologies and services to consumers	Development of market models which drive more cost effective investments into the power system
	Resilience and security of energy system	Ensuring through models and simulation tools the integration of RES into the power balancing and system services market. Design mechanisms that ensure both system adequacy and system security.

Table 24: impacts of the R&I activities relative to cluster 5 (Digitalisation of the power system).

Energy Union	**Energy security, solidarity and trust**	Cybersecurity Functional Objective will address the increased network security
	A fully integrated European energy market	The use of big data management platforms will enable the enhancement of European energy market
	Energy efficiency contributing to moderation of demand	The Internet of Things will contribute more customer participation
	Decarbonising the economy	New applications will enable the increase use of distributed energy resources.
SET Plan	**Technology leadership**	
	Technology affordability	By supporting the development of market platforms or tools to manage the big data from different sources, the long term cost reduction and more efficient use of existing electricity network will be enabled.
	New technologies and services to consumers	The use of Internet of Things in relation to the customers
	Resilience and security of energy system	The development of interfaces to intensify the use Internet of Things should bring also more security

9.2 R&I ACTIVITIES FOR DISTRIBUTION SYSTEMS

Table 25: impacts of the R&I activities relative to cluster 1 (Integration of smart customers and buildings).

Energy Union	**Energy security, solidarity and trust**	The wide adoption of energy efficiency solutions and AD response schemes will allow DSOs to host the new loads (EVs, heat pumps, etc.) and the increasing penetration of PV (at LV level) and wind power -and to some extent PV- at MV level.
	A fully integrated European energy market	The advent of AD response and energy efficiency will trigger new business opportunities for the (new) players of the retail and wholesale markets.
	Energy efficiency contributing to moderation of demand	The R&I activities of D1 and D2 contribute to the moderation of demand for end users all over Europe.
	Decarbonising the economy	Energy efficiency together with AD response will decrease the need for resorting to peaking unit emitting significant amounts of CO_2 thus reducing the CO_2 emissions of the electricity sector.
SET Plan	**Technology leadership**	European manufacturers (ICT and grid component) will benefit from participating in the projects by testing the market uptake of their new products, which in turn will strengthen their leading positions.
	Technology affordability	The wide deployment of energy efficiency in buildings and AD-response solutions to be deployed at the end end-user premises will help ICT manufacturers to improve the affordability of the in-home energy hardware and software solutions (economies of scale).
	New technologies and services to consumers	Products and services will be proposed to the European end-users so as to better control their electricity consumption and optimize their electricity bill.
	Resilience and security of energy system	The combination of energy efficiency services with the provision of AD-based system services will increase the number of degrees of freedom for DSOs when operating the distribution grids close to their physical limits.

Table 26: impacts of the R&I activities relative to cluster 2 (Integration of decentralised generation, demand, storage and networks).

Energy Union	**Energy security, solidarity and trust**	Maximizing the potential for renewable electricity production in Europe (D3 and D4), with the large-scale deployment and integration of storage in distribution networks (D5), contributes to the energy security endeavor of the EC. The coupling of the distribution electricity grid with other (energy) distribution networks should help optimize the hosting capacity of DER (D7) and the massive roll-out of EVs will reduce Europe's dependence on imports of fossil fuels (D6).
	A fully integrated European energy market	The Energy Management platforms to be developed and deployed (D3 and D4) will give market players (operating storage devices for instance, cf. D5) the technical means to create new businesses, especially to find profitable business models related to system services from renewables. The roll-out of EVs should also participate in the construction of an integrated energy market by providing new electricity-based services (D6). The coupling of the distribution electricity grid with other (energy) distribution networks should help integrate the different energy markets (D7).
	Energy efficiency contributing to moderation of demand	The Network Energy Management platforms to be developed, allowing communication and data exchange with all market players, will ease the possibilities for proposing energy efficiency services (possibly based on storage).
	Decarbonising the economy	Maximizing the integration of electricity production from renewables will decrease the CO_2 content of the delivered kWh and therefore will decrease the footprint of all grid users (including EVs).
SET Plan	**Technology leadership**	The equipment to be developed, by power system component manufacturers (including storage equipment and power electronics manufacturers) and ICT manufacturers, will bring new business opportunities. This should result in technological leadership in a sector where European players address global markets.
	Technology affordability	The development of power system components (including storage integration technologies and EV charging infrastructures) will drive the cost reduction of e.g. power electronics components for power plant control (inverters for example).
	New technologies and services to consumers	The energy management platform(s) will allow market players to offer new services (and the associated technologies). Local storage devices will be used by market players to offer new services to the end consumers.
	Resilience and security of energy system	The contribution of DER and storage to system services will improve the resilience of the electricity networks by offering more degrees of freedom to DSOs when operating the distribution grid close to its physical limits. The large-scale storage options brought by the coupling of the networks will improve the resilience of the energy system in case of outages.

Table 27: impacts of the R&I activities relative to cluster 3 (Network operations).

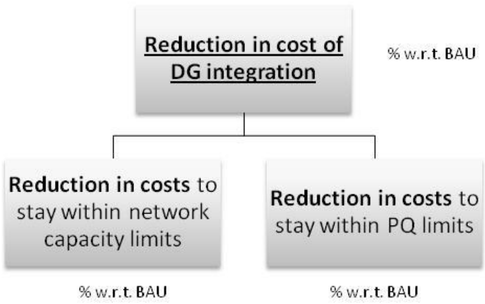
Energy Union	**Energy security, solidarity and trust**	By improving the control, automation and monitoring of the distribution networks as well as the generation forecasts (thanks to data mining algorithms), more wind and PV power will be integrated in the European distribution grids, thus contributing to the security of supply at pan-European level.
	A fully integrated European energy market	The developments of control, automation and monitoring solutions as well as the access to data by all market players in a transparent and non-discriminatory way will boost the retail markets by facilitating the exchanges between the different market players and the DSOs while maintaining the reliability of European distribution networks at affordable costs.
	Energy efficiency contributing to moderation of demand	The automation and communication systems as well as the data mining techniques to be developed will allow market players to fine tune their commercial offers and DSOs to control loads.
	Decarbonising the economy	The automation and communication systems to be developed will allow DSOs to increase the hosting capacity of DER, which will lead to decreasing CO_2 emissions.
SET Plan	**Technology leadership**	The technological developments will create new business opportunities for European manufacturers (control systems, protection systems, smart substations, etc.), engineering companies, ICT and system architecture companies, and software developers, and as a consequence reinforce their leading position.
	Technology affordability	
	New technologies and services to consumers	The development of the new control and monitoring environment together with the associated communication infrastructure will allow market players to bring new services to the consumers.
	Resilience and security of energy system	The development of improved control systems (automation, protection, etc.) will increase the resilience of the distribution network under stringent conditions due to the variability of DER and loads and unforeseen events (faults due to lightning, etc.).

Table 28: impacts of the R&I activities relative to cluster 4 (Planning and asset management).

Energy Union	**Energy security, solidarity and trust**	New planning methods accounting for the development of distributed generation will help to maximize the future hosting of wind and PV power, thus participating in the security of electricity supply.
	A fully integrated European energy market	New planning methods accounting for the constraints induced by the market players will help DSOs operating future networks as market makers.
	Energy efficiency contributing to moderation of demand	New planning methods able to account for the flexibility options brought by demand response and energy efficiency will support policies promoting the moderation of demand.
	Decarbonising the economy	Facilitating the future integration of PV and wind power in distribution networks by advanced planning methods will help decarbonizing the electricity mix.
SET Plan	**Technology leadership**	The development of advanced tools and methodologies as well as digital components will help European companies to strengthen their position on the market.
	Technology affordability	
	New technologies and services to consumers	
	Resilience and security of energy system	The improved knowledge of the assets' lifespan, SoH, failure modes, etc., will allow network operators to operate the distribution grids with better safety margins.

10. APPENDIX 4: NEW KPIS FOR THE DISTRIBUTION SYSTEMS

Hierarchy between KPIs for addressing DG integration:



Notes:

1) Time horizon could be related to network planning (e.g. 7 or 10 years)
2) Could be over a period of one year.
3) Percentage of generation could be ratio of generation / demand (e.g. for a given substation or even aggregated for an entire network or at national or European level)

KPI: Reduction in costs to stay within network capacity limits

E.g. KPI (%) = Costs to maintain operation within capacity limits due to required DG increase for given time horizon using novel solution (€)[1] / Costs to maintain operation within capacity limits due to required DG increase for given time horizon using BAU(€)[1]

KPI: Reduction in costs to stay within PQ limits

E.g. KPI (%) = Costs to maintain operation within PQ limits due to required DG increase for given time horizon using novel solution (€)[1] / Costs to maintain operation within PQ limits due to required DG increase for given time horizon using BAU(€)[1]

KPI: Reduction in cost of DG integration

E.g. KPI (%) = (Costs with Novel solution (CAPEX+OPEX) (€)[1] / Percentage of renewable generation (MWh)[2,3]) / (BAU costs (CAPEX+OPEX) (€)[1] / Percentage of renewable generation (MWh)[2,3])

ETIP SNET

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