Main Report

ENTSO-E 2025, 2030, 2040
Network Development Plan 2018

Connecting Europe: Electricity

2025 - 2030 - 2040

Final version after consultation and ACER opinion - October 2019

entsoe
Reliable Sustainable Connected

Contents

ENTSO-E Reports 2018

As an improvement to the TYNDP 2018 package, the Insight Reports have been categorised in order to help readers navigate through the document and focus on what readers might find of interest. The category of reports are:

— Executive Report – Contains the key insights of the whole TYNDP package through its two-year cycle.

— Regional Reports – Based on the four projects of common interest (PCI) regions, the reports focus on the regional challenges of the energy transition.

— Communication – These reports communicate how we have interacted with our stakeholders and improved the TYNDP package from 2016 to 2018.

— Technical – These reports give a deeper insight into the technical subjects, including how we use our data, and the technical challenges of energy transition.

We hope this guide is of benefit to all stakeholders.

Main Report

Regional Reports
- North-South Interconnections East
- North-South Interconnections West
- Northern Seas Offshore Grid
- Nordic & Baltics

Communication
- Stakeholder Engagement
- Improvements to TYNDP 2018

Technical
- Data and Expertise
- Technologies for
- Transmission
- Viability of the Energy Mix
- CBA Technical

Adequacy
- Mid-Term Adequacy Forecast

Foreword

The 2018 Ten Year Network Development Plan was adopted by ENTSO-E and publicly released on 19 November 2018 after a public consultation that ended on 21 September 2018. It was subsequently submitted to the Agency for the Cooperation of Energy Regulators according to Regulation (EC) No 714/2009. The Plan comes at a pivotal time in the delivery of the European policy objective of achieving a clean future for the power system by 2050 in a cost-efficient way while maintaining system security.

A clean energy future keeping Europe competitive means better integration of renewable energy sources through closer links between the power, heating and transportation sectors, and between the electricity and gas systems. For the first time, this Plan is built on future scenarios that are based on inputs from the industry, consumers and NGOs, which have been jointly elaborated with ENTSOG, thereby capturing the major interlinks between the gas and electricity sectors.

A clean energy future also means changes in the way everyone uses electricity. This Plan recognises this by focusing on the consumer. New tools and methods were developed to better understand how electricity demand will evolve and become a central part of the solution. One of the three scenarios is dedicated to exploring a future in which small renewable generation, home storage and demand response are widespread across Europe.

Our understanding of the future power system evolves as this energy transition unfolds. The TYNDP provides a plan for Europeans that takes into account their most likely needs economically, politically and societally. It must also take into account the uncertainties in the future development of infrastructure, which often depend on unpredictable factors such as public acceptance or financing. Even the impact of future weather patterns on network reliability must be accounted for.

Given the role of the Plan in informing investment decisions and policy support through Regulation (EC) 347/2013, the cost benefit analysis (CBA) methodology used in assessing projects has been significantly improved. These improvements seek to bring greater confidence in the results, and provide investors and policy makers with reliable information on the value of power infrastructure. The Plan thus represents a truly European approach in planning the future infrastructure, examining the interdependencies of the investment decision factors and complementing national and regional exercises.

With this TYNDP, ENTSO-E, in reflecting its TSO membership, is committed to supporting a secure, market-based and cost-efficient energy transition.

Dimitrios Chaniotis
Chairman of the ENTSO-E System Development Committee

Laurent Schmitt
ENTSO-E Secretary General

Section 1

TYNDP in numbers

2030

48 to 58%

of the demand covered by renewables in TYNDP 2030 scenarios

166

Transmission Projects proposed:

Consisting of 357 Investments
201 Overhead Lines 67 Subsea
23 Underground Cables

20

Storage Projects proposed:

17 Hydro Pumped Storage
3 Compressed Air

65 to 75%

CO_2 emissions reduction in TYNDP 2030 scenarios compared to the 1990 levels

€114bn

proposed investments by 2030

€2bn to 5bn

annual savings in generation costs due to TYNDP projects

2040

Numbers obtained by simulating TYNDP 2040 scenarios with the optimal 2040 grid, and comparing results with a no-action scenario (see section 5)

65 to 81%

of the demand covered by renewables in TYNDP 2040 scenarios

80 to 90%

CO_2 emissions reduction in TYNDP 2040 scenarios compared to the 1990 levels

3 to 14€/MWh

reduction in marginal costs of electricity generation with optimal grid

58 to 156 TWh

avoided dumped renewable energy with optimal grid

Section 2

TYNDP: key questions

Why does Europe need a plan for electricity infrastructure?

Europe has engaged on an ambitious path towards decarbonisation. The major change here is the rapid replacement of fossil-fuel generation by renewable energy sources. Europe will only reach its decarbonisation objective and the successful deployment of variable renewables if:

1. the costs of transforming the system are kept as low as possible (by an appropriate set of investments enabling better market integration and leading to competitive power prices), and
2. the continuous secure access to electricity is guaranteed to all Europeans (security of supply).

Achieving this requires a coordinated, pan-European approach to electricity system planning.

ENTSO-E's 10-year network development plan (TYNDP) is the European infrastructure development plan. It links, enables and complements national grid development plans. It looks at the future power system in its entirety and how power links and storage can be used to make the energy transition happen in a cost-effective and secure way. The TYNDP is essential to the timely and effective development of transmission infrastructure to deliver long-term European policy and aspirations.
It describes a series of possible energy futures jointly built with our gas counterpart, ENTSOG, and co-constructed with environment and consumer associations, the industry and any interested parties. The TYNDP uses an approved range of European indicators to compare how electricity infrastructure projects help to deliver the European climate targets, market integration and security of supply. The TYNDP, its objectives and contents are presented in section 3 of this document.

Are transmission or storage projects presented in the TYNDP the only solution?

Absolutely not. A successful energy transition requires a multitude of solutions coming from all energy professionals and users. The TYNDP scenarios already assume some of these will be in place. A regulatory and market framework enabling the smart handling of peak demand, new roles and behaviours for consumers and demand-side participation, better interlinkage of the gas, electricity and transport sectors, and better integration of renewable energy sources are all considered as starting points for the scenarios.

The TYNDP, and especially the study on identifying system needs, looks at how power lines and storage projects can contribute. However, all the findings can be extrapolated to identify other technological solutions solving interconnection barriers on either side of the border (including demand response, generation, storage, power to gas, etc.).

What will the future electricity system look like in 2025, 2030 or 2040? Why do projects need to be assessed according to multiple scenarios?

Predicting the future with certainty is not possible. Climate goals, renewable integration, technology breakthroughs, e.g. in mobility, batteries, heating and cooling or "Power to gas" as well as digitalisation are real game changers in the energy sector.

We can see strong differences among TYNDP 2018 scenarios, even though all are realistic paths towards European targets, co-designed by the whole electricity sector, consumers and NGOs. For instance, It is not possible to know with certainty how many of the European countries will be big or small importers or exporters of electricity by 2030.

Using a series of plausible scenarios helps investors and policy makers to limit the risks linked to the building of new interconnections (no regret options). Developing a plan with a portfolio of projects that will be robust for a range of scenarios is an absolute necessity – a transmission network is relatively cost efficient for society to build, but very expensive for it to do without.

Can the rising need for real-time system operation services become a game changer?

Renewable energy sources are a win-win in terms of security of fuel supply and climate action, but make a system more challenging to operate in real time. Growing demand for the system services (such as frequency and voltage stability) will shape new markets, which are expected to become a major part of the future electricity system.

New responsibilities for market participants and new value streams for existing or new assets (storage, traditional plants, interconnectors, etc.) will emerge in Europe.

This TYNDP presents, for the first time, an introduction to these questions. A better understanding of how many of these services will be needed, by whom they might be performed (complementing traditional generating plants), and how much of the future cost of electricity they will represent will require further studies.

Are the proposed grid investments insufficient, fit for purpose or oversized?

The added value of projects in the TYNDP is illustrated primarily through the CBA indicators. The interpretation of these indicators must take into account the full framework of the planning analysis as this is laid out exhaustively in the TYNDP package, and in particular by juxtaposing them to the system needs assessments for the 2030 and 2040 horizons. Only by considering the full framework can robust conclusions be drawn on the contribution of each individual project to the overall objectives.

The CBA indicators capture the bulk of a project's benefits and costs given the structural characteristics of the power system today. However, the TYNDP demonstrates that these characteristics evolve and consequently the CBA evolves both in scope and in methodology. In this TYNDP, an extended analysis of benefits not included in the CBA is presented (see section 6.2). These benefits are shown in the project sheets and have been calculated by individual project promoters according to the guidelines proposed by ENTSO-E. The methodologies used have yet to reach the level of maturity necessary to be endorsed, computed, and analysed by ENTSO-E and subsequently integrated in the CBA Guidelines. Nevertheless, they illustrate the potential areas where ENTSO-E will continue to work and innovate in order to provide the most comprehensive assessment of project benefits and costs.

It is also important to note that the project CBA depend largely on the scenarios used in the TYNDP.

They are therefore a function of the trends that prevail at the time when the scenarios are constructed. Recognising that the scenarios reflect the impact of policy initiatives, market dynamics, technology advancements, etc. means that the CBA study should also take into account the underlying trends and subscribe to a more dynamic interpretation from one TYNDP to another.

Similarly, the CBA depends on the hypotheses concerning the future development of the transmission network. A full-blown analysis of all plausible network configurations for analysing a given project is impossible at the scale of the TYNDP. An approximation is therefore made taking the form of the "reference grid" (see section 6.2) representing the most objective view of ENTSO-E on the state of the network at the time a given project is commissioned. The unavoidable impact of this approximation on the absolute values of the cost/benefits thus computed is compensated by the fact that all projects are assessed on a level playing field in a transparent way that allows for further analyses when needed.

Given all the above, the TYNDP aims to present all those projects that have either reached a sufficient level of maturity with a demonstrable positive impact on the overall planning objectives or represent the solutions with the highest potential to address needs in the long term alongside other alternatives (such as actions on generation/demand, digitalisation, etc.) and for which the continuation and support for further work is imperative.

Should all the projects progress?

The value of a long-term plan is that it is not a commitment to construct all projects, but rather to ensure that those that need to be developed at this stage are progressed.

Overall, the portfolio of projects is relatively stable between TYNDPs, indicating that the collection of European development projects is progressing towards maturity. Progress is slow but steady.

The costs of analysing potential future projects is small compared to the costs of building them, justifying to some extent the analysis of diverse solutions for uncertain needs. This is why several TYNDP projects that remain years away from starting construction may still be explored by project promoters, even though the benefits, as assessed in the TYNDP, have yet to be shown.

On the contrary, it is unlikely that a construction decision would be taken by promoters or allowed by regulators if the project cannot prove its benefits in the near future. It is also expected that the future needs analysis of the TYNDP, and the CBA results would lead some promoters to reconsider the scope or timing of their projects.

The TYNDP provides a solid basis to compare European projects through a series of indicators. Like any other development plan, it cannot however claim to provide a full and exact value of future investments which will eventually depend, for instance, on the actual energy mix, on local acceptability or on future market designs.

Section 3

TYNDP: about Europe's plan for reaching its targets

Europe needs more secure, affordable and sustainable energy. To meet this need, the EU launched the Energy Union strategy based on: (i) energy efficiency, (ii) diversification of energy sources and stronger cooperation between European countries, (iii) a fully integrated internal energy market enabling the free flow of energy through the EU, (iv) decarbonisation of the economy and development of renewable energy sources, and (v) research and innovation to drive the energy transition and improve competitiveness.

Europe's strategy is ambitious and requires significant effort in almost all areas of human activity. Optimal use of the existing electricity networks, creating links between wholesale and retail to leverage distributed energy sources, increase sector coupling notably through digitisation and updating the market design to bring more flexibility to the system are all part of the equation.

However, updating the market and network does not prevent Europeans from investing in extending and reinforcing the current grid. The Ten Year Network Development Plan (TYNDP) takes into account all the technological, market and policy evolutions and proposes a portfolio of projects that are supporting socio-economic welfare and helping Europe to meet its climate targets.

The TYNDP is a long-term plan on how the electricity transmission grid should evolve in Europe to implement the Energy Union strategy. It is based on extensive data collection and analysis, and is flexible enough to accomodate shifting policy landscapes, macroeconomic trends, and technological evolutions.

The TYNDP has included the consideration and appropriate inclusion of national development plans and promoter projects, in conjunction with publically consulted future scenarios. The scale of this work is unprecedented and cutting edge, defining what is achievable with analysis of this complexity and scale. Over 6000 system configurations (changing scenarios of generation and demand, grid configuration, climate conditions) modelled for each hour of the year in 38 countries.

3.1
How is the TYNDP developed?

At the heart of the TYNDP lays a collection of scenarios indicating how the European power system might look in the future. ENTSO-E and its gas counterpart ENTSOG have developed the scenarios together with a wide scope of stakeholders. Each scenario's impacts on energy markets and networks are analysed with the help of tailored modelling tools. Thanks to the models, ENTSO-E can explore various energy market needs and the corresponding power-grid configurations. In this way, we can understand which parts of the network infrastructure are working well, and where it needs to be stronger.

The main role of TYNDP is therefore to identify where investment in the electricity system would help deliver the Energy Union and, by so doing, benefit all Europeans. This has been done in two stages:
– starting with a theoretical overview of the optimal set-up allowing for the decarbonisation of the EU power system at the lowest cost (system needs analysis);
– a call for transmission and storage projects (under different stages of development) across Europe and complemented by an analysis of their performance under the different scenarios.

In addition, in response to new challenges, TYNDP started exploring real-time system operation needs (voltage and frequency control). These needs are expected to grow in the future as a result of the changing energy generation mix and increasingly responsive energy demand. As 2030 has been the focus of the 2016 study, this TYNDP also looked to the 2040 horizon which is a pivotal point in achieving the EU's long-term climate and energy goals. Studies on the 2030 scenarios and the socio-economic welfare gains related to capacity growth at the main boundaries complete this analysis.

TYNDP is a unique forecast as it underpins the scenario building, need identification, and modelling with a collection and assessment of specific grid infrastructure projects. A European-wide call for projects led to TYNDP 2018 featuring 166 transmission and 20 storage projects. ENTSO-E analysed each of the TYNDP projects and worked with their promoters to develop detailed information sheets. The results can be consulted on the TYNDP 2018 online portal.

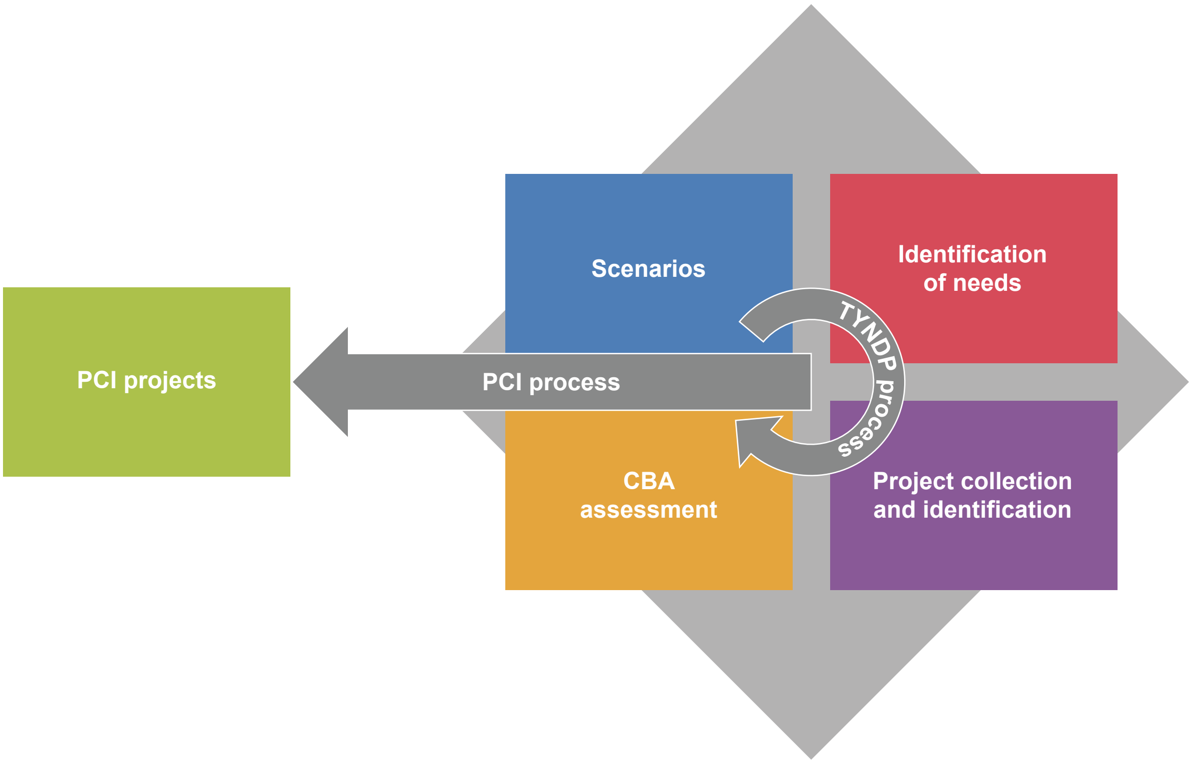
3.2

What is the role of the TYNDP in the Energy Union?

The call for projects, and ENTSO-E's overall remit, is in line with Regulation (EC) 714/2009, and Regulation (EU) 347/2013. The legal base indicates that the TYNDP should help identify those infrastructure projects that are key to the EU achieving its climate and energy objectives. Such projects, known as projects of common interest (PCI), have been selected from the TYNDP overall list of transmission and storage projects. Every two years, the European Commission utilises the information in the latest TYNDP, notably on individual projects, as part of its selection and adoption of a new biannual list of PCIs. From the moment a TYNDP project becomes a PCI it may benefit from favourable treatment such as accelerated planning and permit granting. Therefore, the PCIs have a special status among the TYNDP projects.

The TYNDP, through its unique access to data, stakeholder involvement, and analytical capabilities, provides a transparent picture of the European electricity transmission network. In this way, we support informed decision-making leading to strategic investment at regional and European level. We also offer unique data-sets and sound analysis that can be reused by other risk-averse industries.

Figure 3.1: Inputs to the PCI process



3.3
How are the projects assessed?

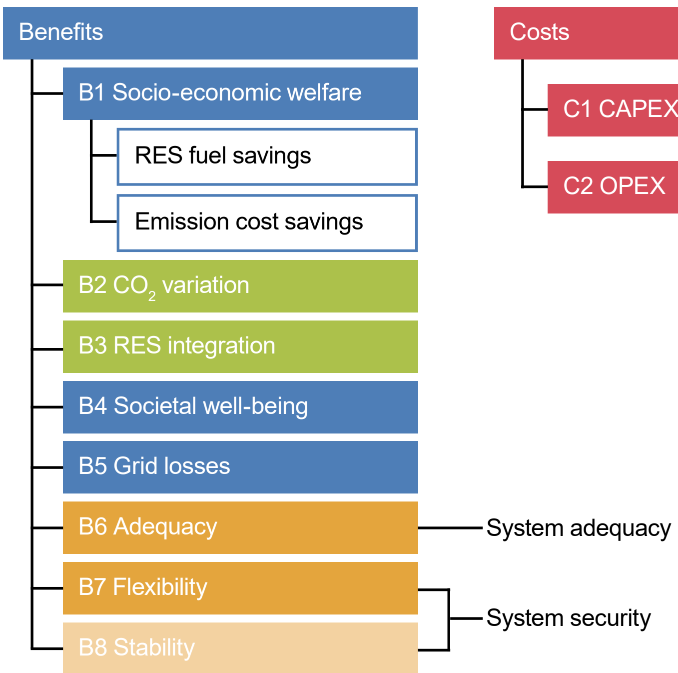
Transmission projects are by nature multi-purpose. Originally, the main goal of cross-border electricity interconnections was to contribute to security of supply. Interconnectors were built to provide mutual support in case of supply disruptions, thereby ensuring the reliability of electricity supply. Their role in improving socio-economic welfare has received growing attention over the last 20 years. More recently, and given the EU's ambitious renewable-energy and CO_2 targets of the EU, the integration of electricity from RES and CO_2 mitigation appear as new motives for transmission projects. The majority of TYNDP projects contribute to all these objectives, proving this multi-purpose characteristic of transmission projects.

Each project included in the TYNDP is assessed using the pan-European CBA methodology. This methodology sets out the criteria for the assessment of costs and benefits of transmission and storage projects, all of which stem from European policies on market integration, security of supply and sustainability. As such, each TYNDP project is assessed against eight benefit indicators, two cost indicators and three indicators for residual impact. A benefit can also be 'negative', for example – an increase in CO_2 emissions or higher grid losses.

The scheme below shows the main category groups of indicators used to assess the impact of projects.

Some projects will provide all the benefit categories, whereas others will only contribute significantly to one or two of them. Other benefits, such as benefits for competition, also exist. These are more difficult to model and are not explicitly taken into account. The CBA methodology is prepared by ENTSO-E in coordination with stakeholders, subject to an opinion from Agency for the Cooperation of Energy Regulators (ACER) and the European Commission, and should finally become a published document by the European Commission.

Figure 3.2: Project assessment

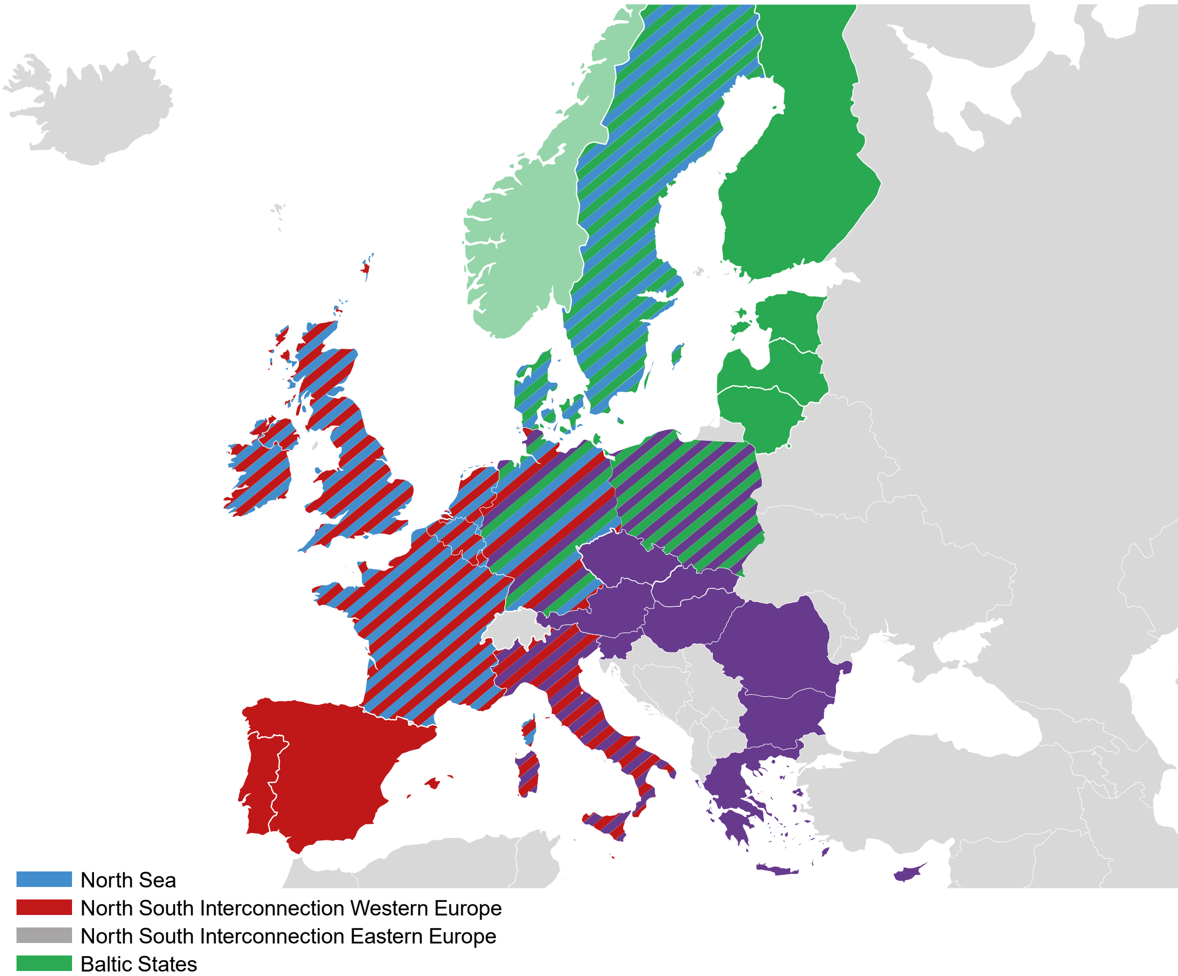


3.4
How is the TYNDP produced?

From start to final publication, the delivery of the TYNDP (including the preparation of scenarios) takes over two years and involves over a hundred experts from all across Europe. Stakeholders play a significant constructive role throughout the process through consultations on the different parts of the TYNDP, public workshops and the permanent Network Development Stakeholder Group which gathers European associations representing the industry, consumers and non-governmental organisations (NGOs).

The TSO experts prepare tools and methodologies, collect and consolidate data, run market and network models simulations and analyse the results. The project is managed centrally from ENTSO-E secretariat in Brussels. Pan-European teams of experts are involved with the methodologies, computations and general analysis. They are complemented by Regional Groups who bring the necessary local expertise and analysis to understand the challenges of tomorrow's grid. This structure ensures that the plan benefits from a real European direction, while reflecting the diversity of European electricity systems.

Figure 3.3: Trans-European Networks for Energy (TEN-E) electricity priority corridors - Regional Groups



3.5
What is in the TYNDP package?

This Executive Report presents the key findings, analysis and methodological elements which are further described in the TYNDP 2018 reports or presented in the project sheets.

A full presentation of elements composing the TYNDP package, explanations on project sheets elements, summarised methodologies, and an introduction to innovative approaches which we tested over the last two years are presented in the Annex to this document. Each section in this Executive Report concludes with a TYNDP Portal (https://tyndp.entsoe.eu/tyndp2018/), guiding the readers who want to further explore each topic through the TYNDP 2018 package.

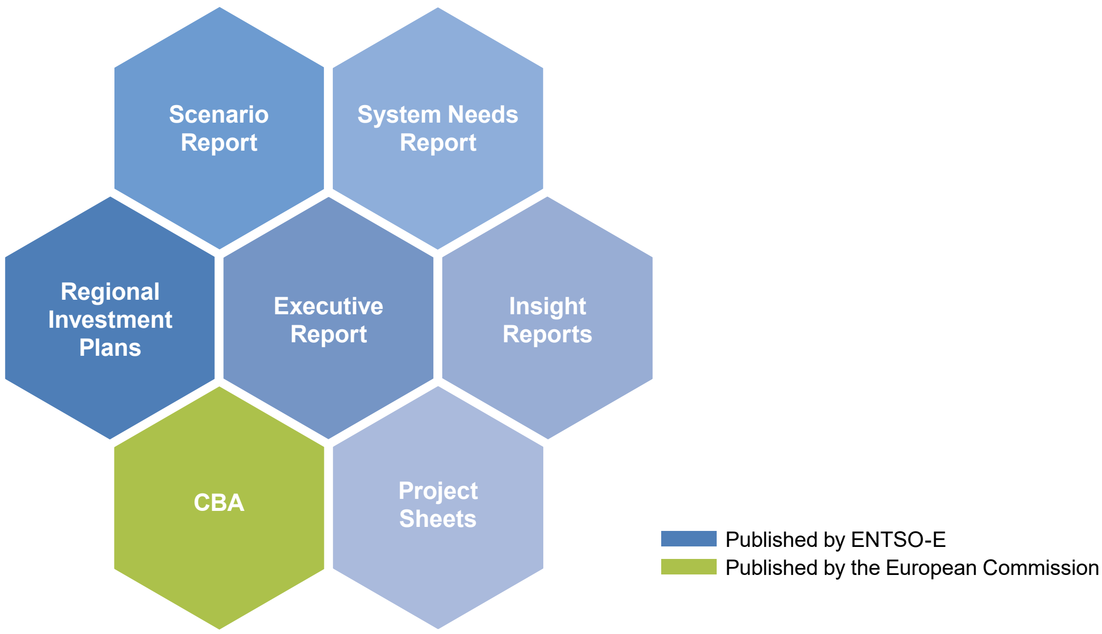
The scenarios and system needs packages were released in 2017 and 2018 for consultation. They were updated following the comments and advice we received from stakeholders, and are now in their final form, ready to be delivered to the ACER for their opinion with the rest of the TYNDP package in autumn 2018.

The present report corresponds to the last stage of the TYNDP: the release of the final analysis of the electricity system and transmission and storage projects which were submitted by promoters:

- This Executive Report
- The TYNDP project sheets for transmission and storage projects include maps, description analysis of relevant system needs, CBA results and other information. Accessible through an online portal (https://tyndp.entsoe.eu/tyndp2018/projects/).
- A collection of eight Insight Reports, presenting further analysis on the future system and insight on TYNDP approaches and results:
  - Data and expertise as key ingredients
  - Improvements to TYNDP 2018
  - Available technologies report review
  - Stakeholder engagement
  - Four Regional Insight Reports covering all Europe, providing a regional focus on the development needs and current development projects, their impact and effectiveness to meet regional and EU targets and policy.

While summarised methodologies are presented in this report, or in those reports where study results are presented, the full detailed methodologies which we followed through the TYNDP are also available on the TYNDP website. Complete data-sets (list in the Annex) are also available, as we hope many will find in the scenarios or other analysis a basis for their own future studies.

Figure 3.4: TYNDP 2018 documents



Section 4

Scenarios: growing uncertainty towards ambitious targets

The solution for tomorrow's challenges will be the parallel development of all possible solutions, including the role of prosumers and historic generators, and the development of new interconnections.

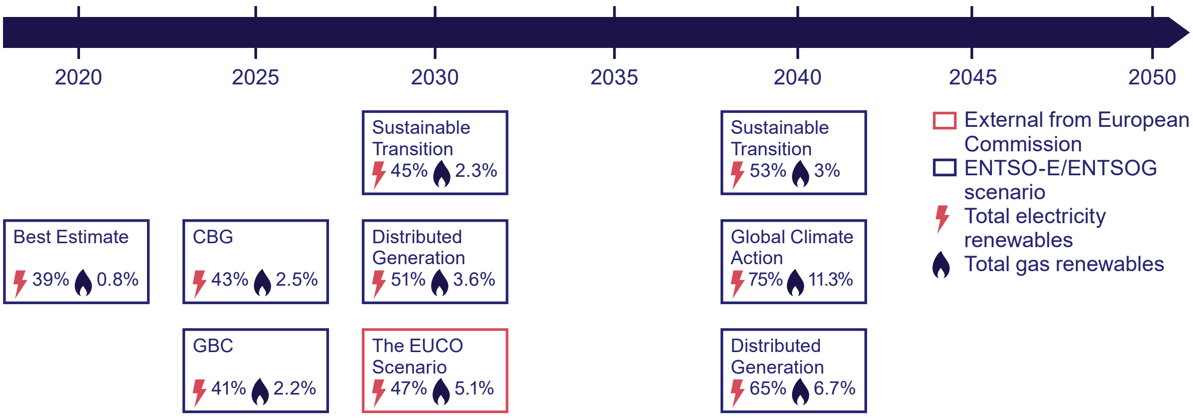
For the first time, ENTSO-E and the Association of European gas Transmission System Operators (TSOs), ENTSOG, have jointly built their TYNDP scenarios, so that they scenarios to reflect European and national energy policies, consistent across the sectors and technically sound. The scenarios are built through close engagement with stakeholders; they are based on forward-looking policies, whilst also being ambitious in nature and aiming at reducing emissions by 80 to 95% in line with EU targets for 2050.

Such a change at this scale will progressively, but increasingly, impact on all grid users and the network required to meet their changing needs. The speed of this change In some cases, the speed of this change can be predicted, for example through national and European targets. However, for Europeans to understand the value of developing their infrastructure, the need for development in an uncertain future needs to be provided.

ENTSOs scenarios provide a range of predictions of how the industry and its users might develop to meet the 2030 EU decarbonisation targets. The variety of the proposed scenarios, both in terms of storylines and approaches to build them, allows them to be used to assess a network adequate to meet the most likely sets of future needs.

The TYNDP scenarios and the full data-sets are publicly available and can provide a sound basis for any party wishing to perform their own analysis of future energy policies, market designs or technologies.

Figure 4.1: 2020 to 2030 scenario-building framework for TYNDP 2018



Scenario storylines
The TYNDP 2018 scenarios cover 2020 to 2040. 2020 and 2025 are labelled as best-estimate scenarios due to a lower level of uncertainty. As uncertainty increases over longer time horizons, the 2030 and 2040 scenarios have been designed with European 2050 targets as an objective, recognising the work done in the e-Highway 2050 project.

Why build joint electricity and gas scenarios?

Joint electricity and gas scenarios are necessary for future investment decisions in Europe to be based on comparable analysis between the sectors. Additionally, the construction of the scenarios heavily relies on the input provided by dozens of representatives from all sides of the energy sector, consumer and environmental associations and governments.

This approach, and the expertise of gas and electricity TSOs, also ensures that the scenarios are ambitious, correspond to the latest available analysis, and are broadly technically feasible; for instance, making it possible to maintain the energy balance at all times in each country.

The scenarios for 2030 and 2040 follow these storylines:

Figure 4.2: The scenarios for 2030 and 2040

Sustainable Transition (ST)
Targets reached through national regulation, emission trading schemes and subsidies, maximising the use of existing infrastructure.

Distributed Generation (DG)
Prosumers at the centre – small-scale generation, batteries and fuel-switching society engaged and empowered.

Global Climate Action (GCA)
Full-speed global decarbonisation, large-scale renewables development in both electricity and gas sectors.

External Scenario: Based on EUCO 30 (EUCO)
EUCO 30 is a core policy scenario produced by the European Commission. It models the scenario models the achievement of the 2030 climate and energy targets as agreed by the European Council in 2014 and thus does not take into account the most recent technical and political developments, but includes an energy-efficiency target of 30%. The ENTSOs welcome both this new collaboration with the European Commission and further cooperation.

Figure 4.3: European map – annual generation and demand evolution in European countries – **2025**

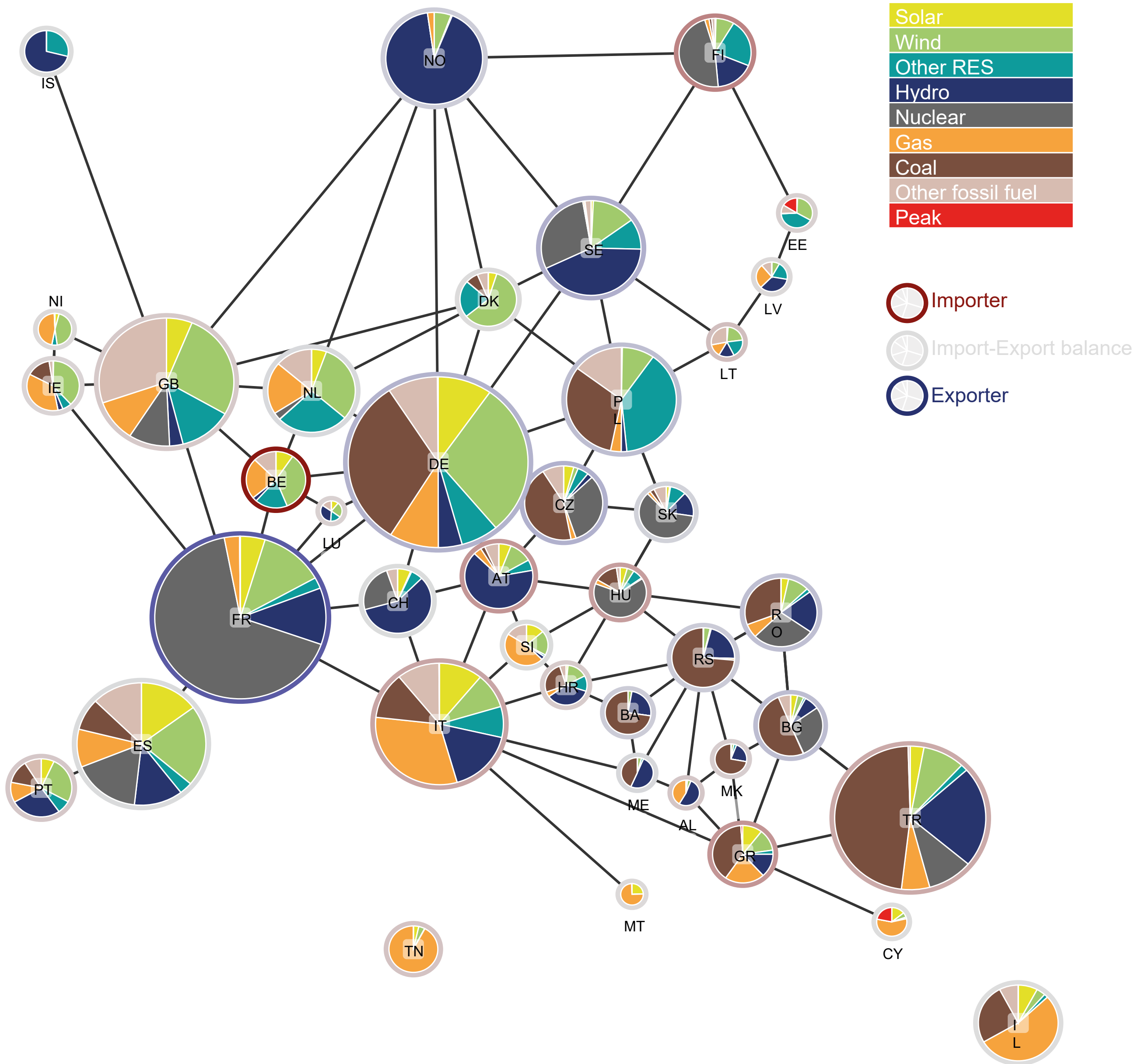


Figure 4.4: European map – annual generation and demand evolution in European countries – **ST 2030 Generation Mix**

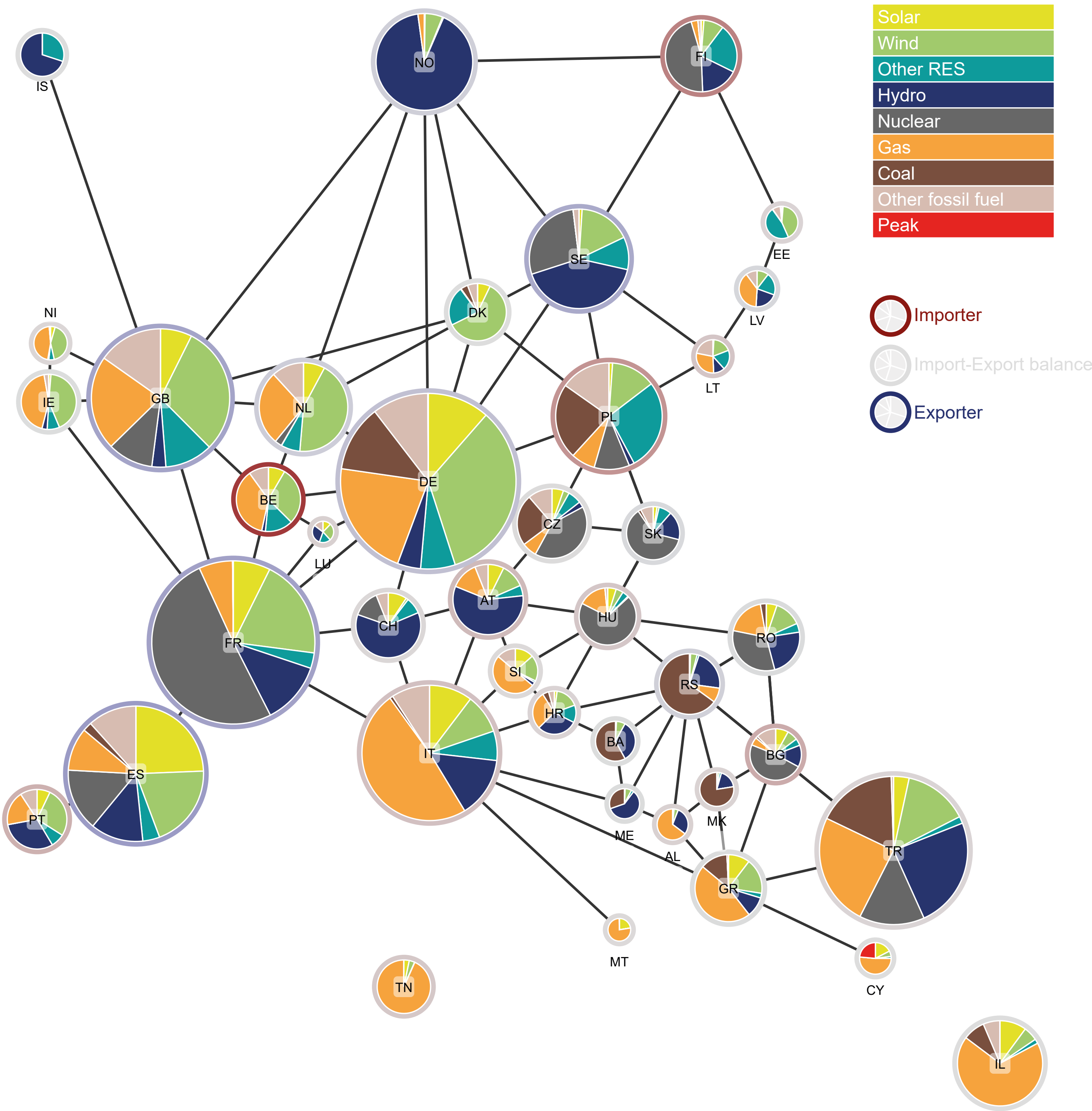


Figure 4.5: European map – annual generation and demand evolution in European countries – **DG 2030 Generation Mix**

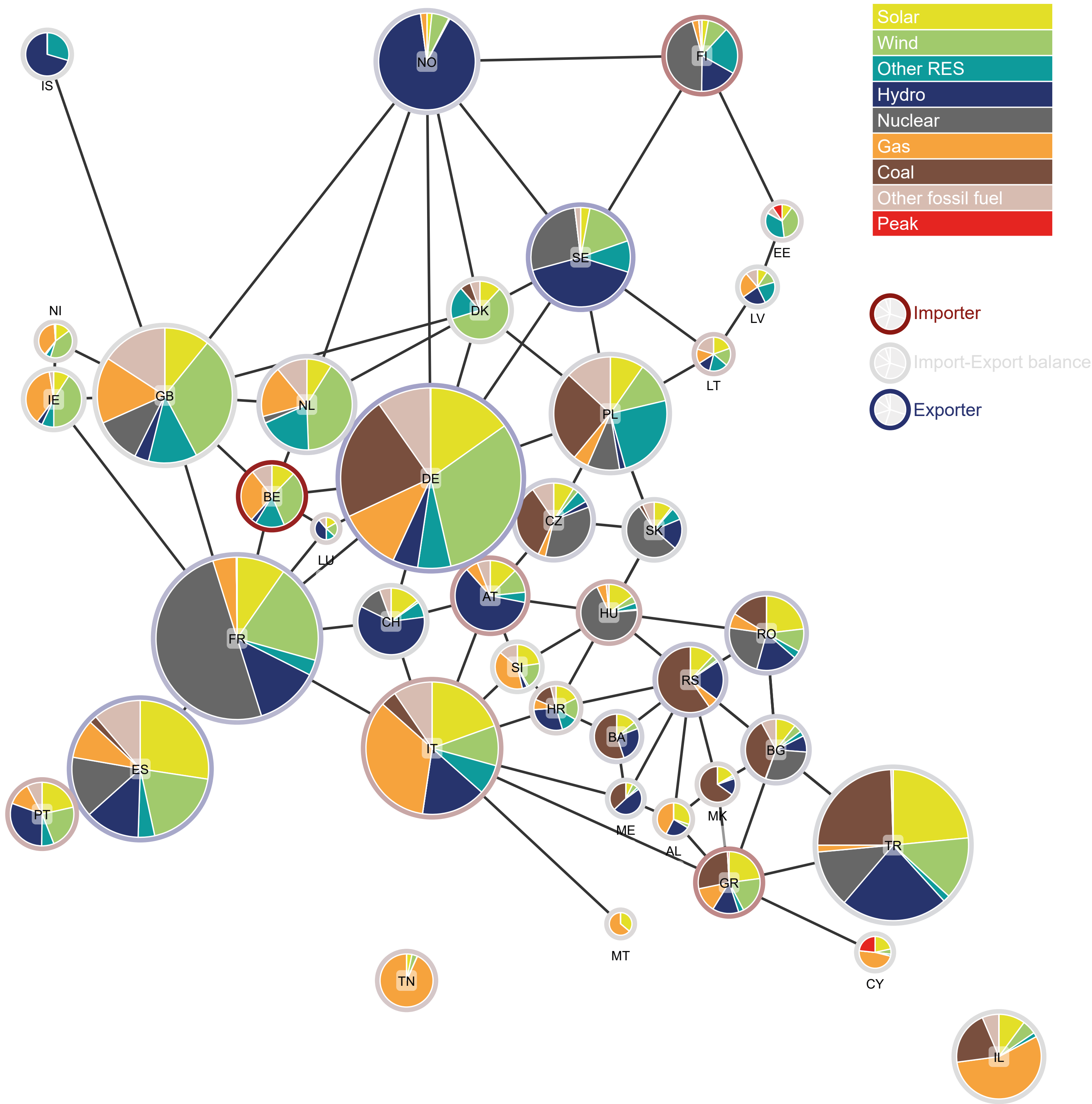
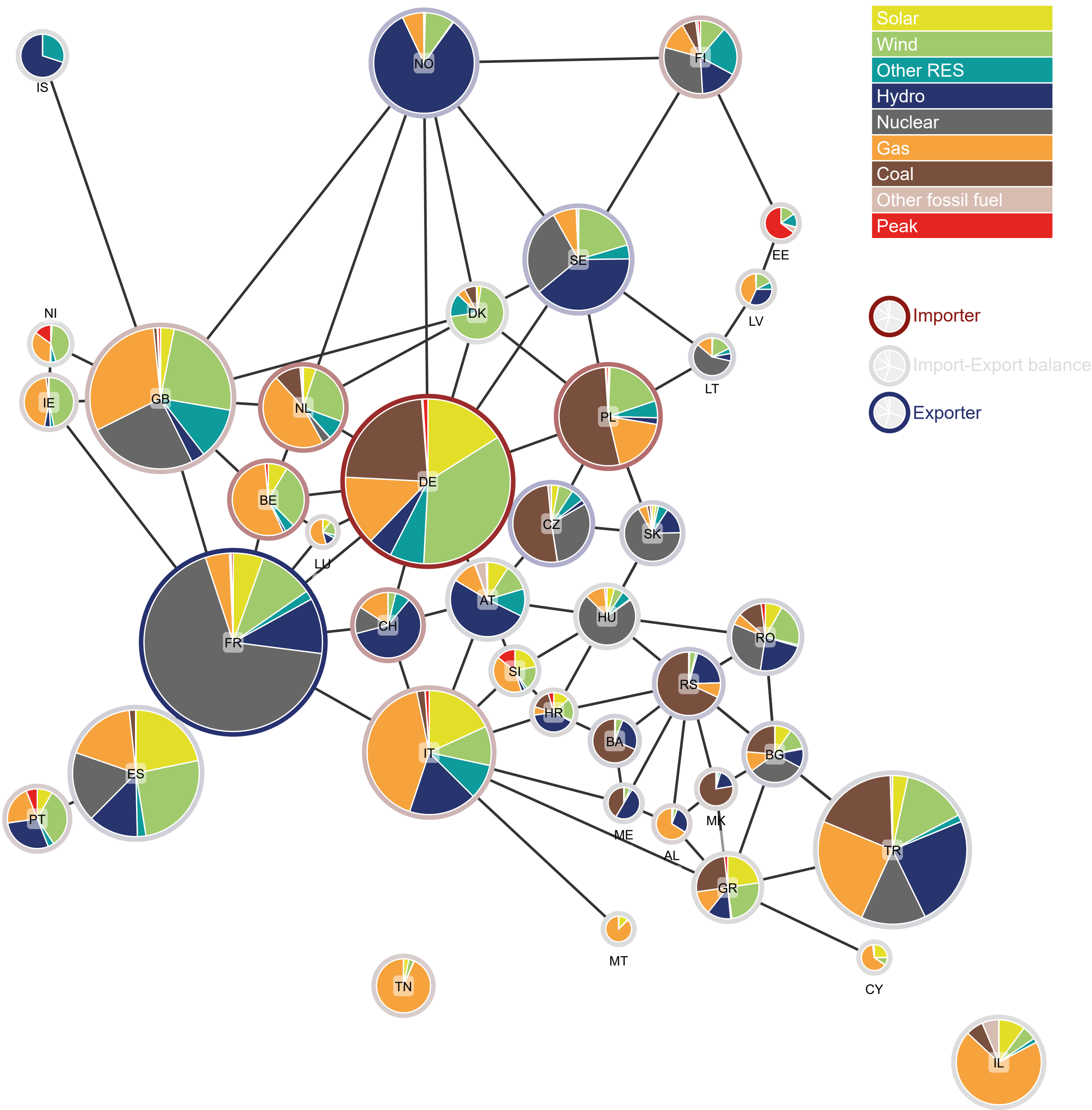


Figure 4.6: European map – annual generation and demand evolution in European countries – **EUCO 2030 Generation Mix**



4.1
Scenarios responding to energy transition

All scenarios represent different pathways to meeting 2030 decarbonisation targets in the EU. Each of them sees lower CO_2 emissions compared to 2020.

The scenarios highlight that consumers will be central to achieving decarbonisation, through an evolution of behaviour, a fit-for-purpose regulatory framework and reliance on renewable energy through new usages. This will be particularly the case for the transport and heating sectors, where clear complementarities and synergies appear between electricity and gas. In this context, smart integration of the electricity, gas and transport systems and smart approaches to handling peak demand will be key in the future energy landscape.

Decarbonisation should be smart, efficient and secure. Therefore, for the first time, together both ENTSOs examine possible renewable generation, the development of renewable gases, and the uptake of a wide range of technologies, among which smart grid technologies, centralised or smaller-scale electricity storage, power-to-gas or CCS/CCU still deserve to be further explored.

Between 2025, 2030 and 2040, all scenarios show a steady reduction in fossil fuel, a strong increase in wind and solar, and a decrease in nuclear (except for the EUCO 2030 scenario where levels are similar to the 2025 scenarios). In addition, the levels of hydro and pumped storage generation slightly increase with biomass and other RES (such as biomass) remaining relatively constant throughout.

Because of new electricity uses, and despite energy-efficiency measures, the demand slightly increases by the 2030 time horizon in all but 1 scenario, the EUCO 2030 scenario, where the demand is mainly consistent with the best-estimate 2025 scenario.

What's new? New technologies and uses, climate conditions

As the role of prosumers grows, ENTSO-E has entirely reviewed for this TYNDP the way new behaviours are considered in the scenarios (including demand response, electric vehicles, heat pumps and home storage). To adapt to the growing importance of electric heating, we have also developed a new approach to better represent the impact of temperature variations on electricity demand.

As renewable generation develops, the weather plays a bigger role in determining when and where electricity is produced. The TYNDP 2018 is the first to consider several climate conditions. The electricity mix in each scenario is assessed using three different climate situations: a wet year, a dry year and a normal year. By using multiple climate years, the future system is assessed by taking into account a wider range of potential future operating scenarios.

Figure 4.7: CO_2 emissions evolution in the four priority corridors

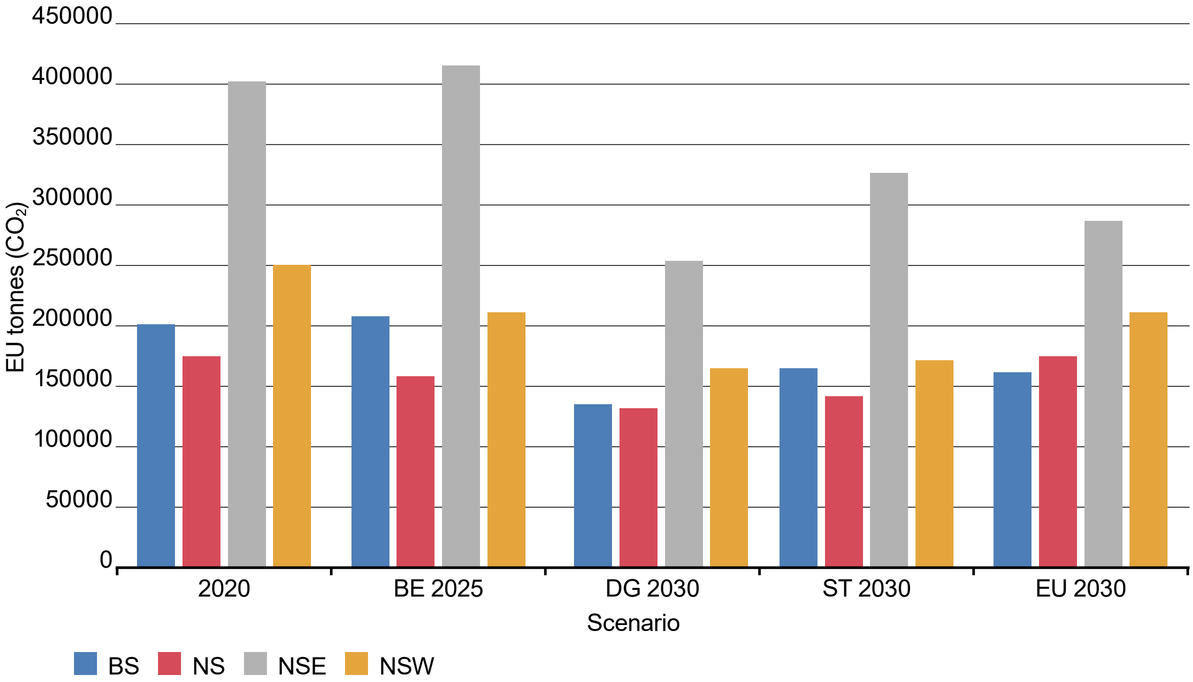
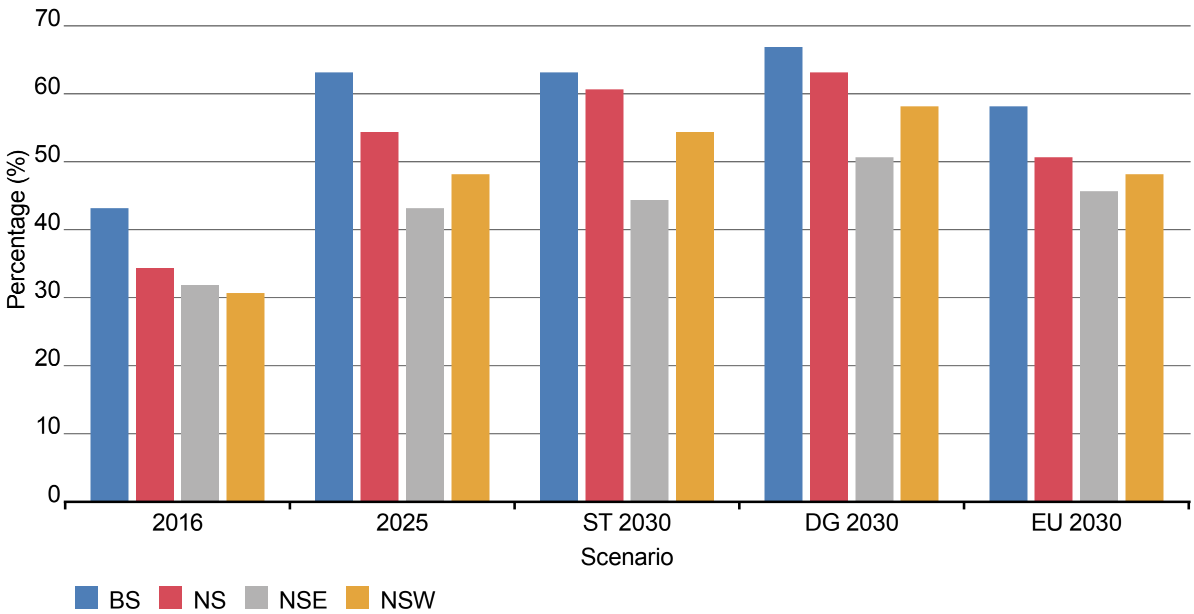


Figure 4.8: Demand covered by RES in the four priority corridors



4.2

Volatile future exchanges and prices highlight need for multiple-scenarios approach

A diverse approach, both in terms of storylines and scenario-building techniques, enables a better understanding of which factors will be subject to high uncertainity and, conversely, which evolutions can be forecast with greater certainty.

For the 2030 scenarios, some important trends, such as the import export balance of each country or the average electricity price, show high volatility between the scenarios. This indicates that these elements cannot be known with any certainty.

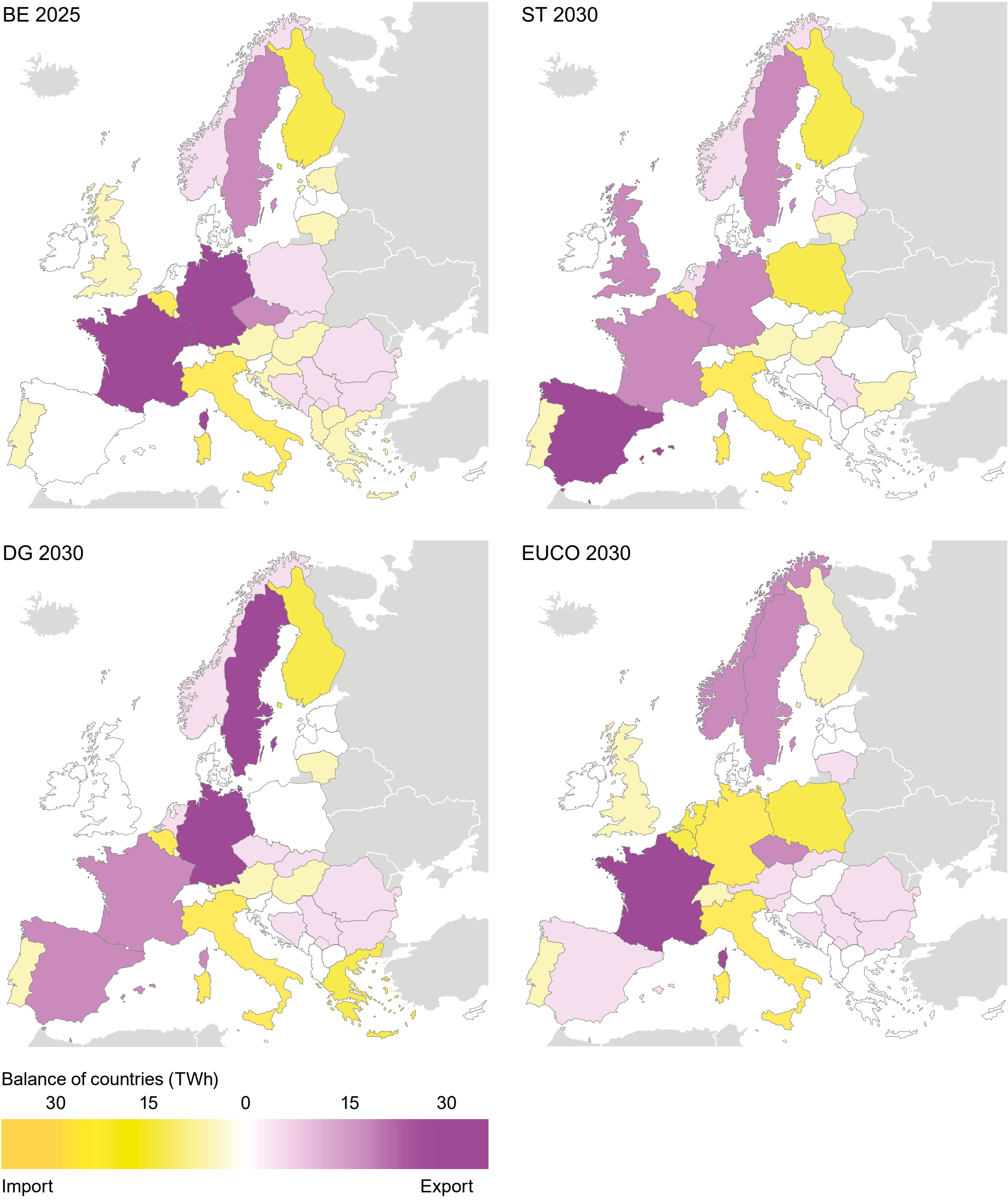
To guarantee the stability of the system and control of its costs, the risks and benefits of potential significant investments should be assessed against all of these likely situations.

Varied approaches to scenario building

ENTSO-E, like other recognised entities producing scenarios, uses diverse approaches in its analysis. For instance, 2025 and one 2030 scenario are built using a bottom-up approach: the data (generation, technologies, demand) corresponding to the storyline are collected for each country and consolidated centrally. Other scenarios are built with a top-down approach: scenario indicators described in the storylines, such as the share of demand covered by RES, dictate the generation and type of demand.

Likewise, the future geographic repartition of wind, solar and thermal units is determined using different calculation approaches, some optimising the generation portfolio and others conforming more to national political contexts.

Figure 4.9: Import/Export balances for the TYNDP 2018 scenarios



More on scenarios in the TYNDP package

Scenario Report
The Scenario Report provides a developed overview of the scenarios. This includes the storylines and key assumptions of these scenarios (section 2) that lead into the scenario results (section 3) in terms of demand, supply and EU climate targets. The stakeholder engagement process (section 4) has been fundamental in selecting which scenarios to consider and giving them their framework. The significant changes in the scenario-building process that have taken place compared to the latest TYNDP editions are summarised in the scenario-development methodology (section 5). This intensive scenario-development process is the starting point towards TYNDPs' next steps for electricity and gas (section 6).

Methodologies
There is a full methodology document available on the TYNDP 2018 website which gives a comprehensive explanation of how each assumption was made. This includes assumptions for fuel and carbon prices, reference grid, demand, electric vehicles, heat pumps and the scenario-building process.

Data-sets
Complete data-sets are available for download, making the TYNDP scenarios a possible basis for any analysis on the future electricity system, and giving third parties the opportunity to replicate TYNDP projects assessment calculations. ENTSO-E will be happy to respond to anyone showing an interest in the use of the scenarios.

Data and expertise Insight Report
The data and models Insight Report outlines many of the inputs required to build and run scenarios.

Improvements of TYNDP 2018 Insight Report
ENTSO-E continues to evolve in its processes and procedures. The improvements to TYNDP 2018 outline some of the ways ENTSO-E has improved in moving from the 2016 edition to the current TYNDP 2018.

Section 5

New barriers across Europe: needs, costs and solutions

What new developments are needed by 2030 or 2040 to create maximum value for Europeans, ensure continuous access to electricity throughout Europe and to deliver on the climatic agenda?

How can new developments in grid infrastructure contribute to these objectives?

What would be the cost of not having the right system by 2030 or 2040?

What future challenges will be created by the new progress of small, variable, distributed renewable generation units?

The 2025, 2030 and 2040, TYNDP scenarios provide a detailed picture of the electricity system situation in each European country. They show how much renewable capacity each country will need to integrate into its system, the market integration barriers which still persist and contribute to increasing the cost of the electricity system for Europeans, and how each country would manage their peak demand and ensure continuous access to electricity.

Starting from the situations described in the scenarios, the TYNDP examines through various European or regional plans how further developments in the grid could contribute to further decarbonising, optimising and securing the electricity system.

This section of the TYNDP presents the key conclusions of the different analyses developed in detail in the TYNDP package:

2030 and 2040: the cost of no action
The costs of developing the right system are far smaller than the economic, security of supply and environmental costs we would experience if we did not increase capacity on the transmission grid.

2030: main boundaries for electricity exchange and interconnection targets
Many projects able to solve system needs by 2030 are already being planned, and are submitted in the TYNDP. While generation or demand evolution contributions are represented in the various scenarios, is the current collection of projects appropriate for 2030 needs? Are there areas where it is lacking or oversized?

2040: completing the map
Beyond the portfolio of projects of the previous TYNDP, a greater integration of markets through new interconnectors is needed and could provide benefits in terms of financing, the environment and security of supply.

New challenges in real-time system operations
The changing environment radically transforms the way real-time operation of the system will be done, leading to new technical needs and future value for system investments.

System needs or transmission needs?

The different studies performed in the TYNDP and presented in this section focus on the development of interconnection levels, which corresponds to the models, data and expertise available for the creation of the TYNDP.

However, all these findings can be extrapolated to identify specific projects aimed at solving interconnection barriers through other technologies (including demand response, generation, storage, etc.).

ENTSO-E expects that the solution to tomorrow's challenges will be the parallel development of all possible solutions, including the role of prosumers and historic generators, and the development of new interconnections.

How needs analysis influences the identification and life cycle of projects

The cost to society of an inadequate network is dramatic. This is because of the central role that dependable and reliable energy supply plays in our personal and professional lives.

The combination of growing (already long) lead times for transmission projects, and the normality of needs beyond that of purely increasing transmission capacity, means that the new needs assessment will be a vital and evolving tool to guide and manage increasing uncertainty due to the carbon-free energy transition. In fact, ENTSO-E expects to see a rapid rise in projects that are not driven by transmission capacity issues, but rather changes to the generation, storage and demand portfolios.

ENTSO-E intends that future updates of the needs assessment in the TYNDP will allow the needs behind projects to be monitored in future years so that as and when needs change, projects can also evolve. This evolution will require, and in the past has required, modifications to the scope of some projects and in some instances their termination.

5.1

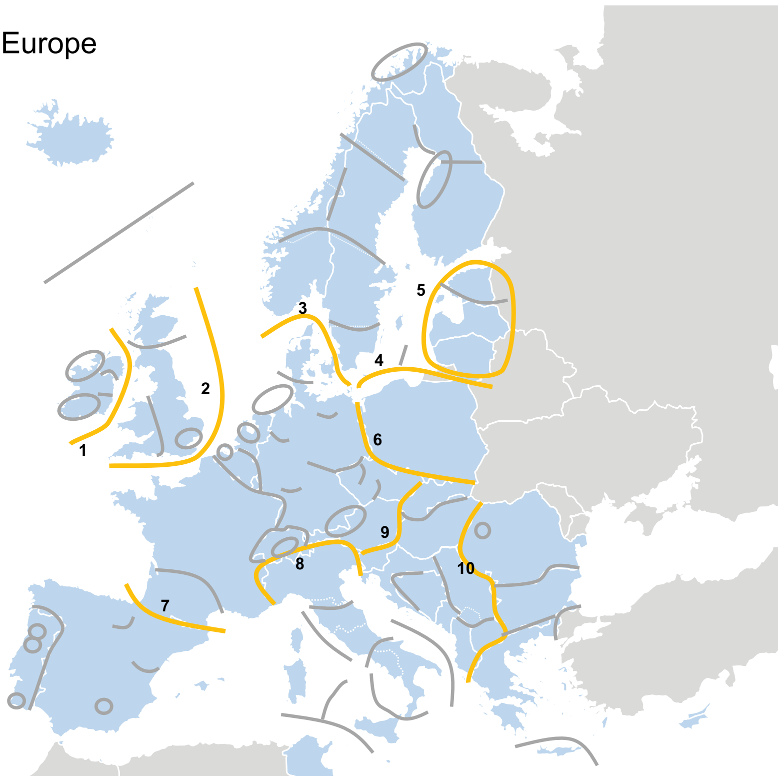
2030: main boundaries for electricity exchange and interconnection targets

For 2030, the analysis of the way the development of the grid can address future system needs focuses on main European boundaries. A boundary is identified every time this is a major barrier preventing optimal power exchanges between countries or market nodes from occurring.

The main boundaries each consist of a collection of land or maritime borders between European countries. There are many main barriers to power exchanges.

They obey a globally radial pattern: tensions on the grid occur between regions in Europe where potential for RES is high (hydro and wind in Scandinavia; wind in Scotland, Ireland, to Spain and Italy; solar in Mediterranean countries) and with densely populated, power-consuming areas in-between. These barriers appear mostly where geography has set natural barriers: seas and mountain ranges, which are more difficult to cross.

Figure 5.1: Main boundaries in the TYNDP 2018



As in TYNDP 2016, we have identified and analysed the following main boundaries:

1. Ireland – Great Britain and Continental Europe
2. Great-Britain – Continental Europe and Nordics
3. Nordics – Continental West Europe
4. Nordic/Baltic to Continental East Europe
5. Baltic integration
6. Central East integration
7. Iberian Peninsula integration
8. Italian Peninsula integration
9. South-East integration
10. Eastern Balkan

Boundaries

Main boundaries

Other important boundaries

How we identify and analyse the main boundaries

ENTSO-E experts identify main boundaries using the following considerations:

- Ireland, Great Britain, the Iberian Peninsula, Italy and the Baltic States being isolated and weakly connected peninsulas in the European network;
- Extensive increases in production from RES and hence increased restriction on the ability of the existing network to be able to transmit this energy;
- Even higher integration of hydro countries which could provide storage capacities for electrical energy if that energy can be transferred;
- High price differences between countries indicating the inability to be able to transfer and trade energy between these countries to reduce these differences;
- Increased local fluctuations of power in-feeds causes higher European flows which require the stronger integration of power systems.

For each of the main boundaries, we have tested how the market prices react to different levels of new interconnections. The results are curves showing for each main boundary the evolution of the average market price, starting with the 2020 level of interconnection up until new capacity stops bringing sufficient increases.

Figure 5.2: Marginal cost differences for the three 2030 scenarios with reference grid (2027)

Avg. hourly marginal cost differences (€/MWh)

- From 0 to 2
- From 2 to 5
- From 5 to 10
- From 10 to 15
- More than 15

5.2
Unlocking 2030 barriers

The following figures represent the overall diminution of wholesale market volume (gains in socio-economic welfare) when the total transmission capacity across the boundary increases from the current situation (first point of the curve[1]).

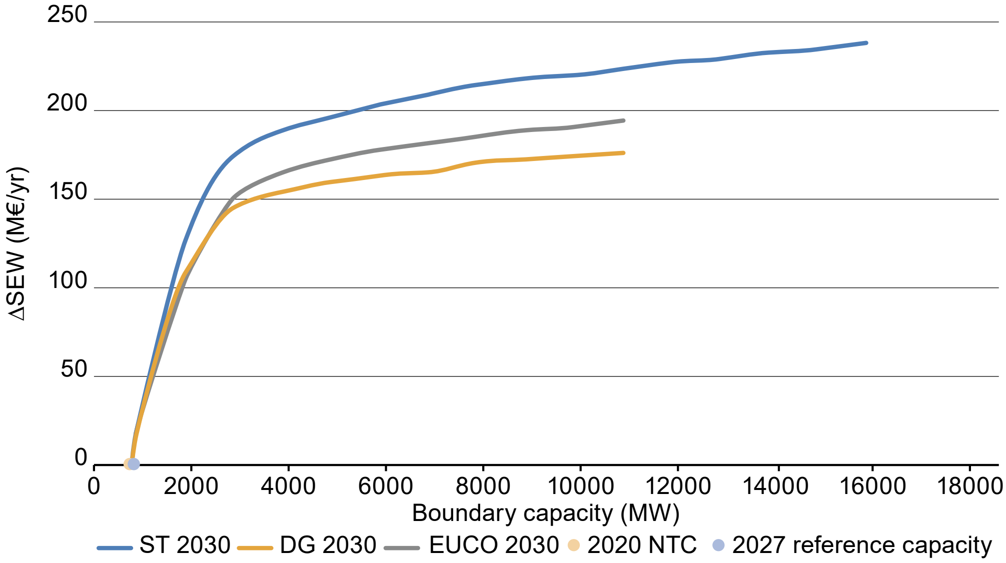
Steep curves indicate high needs for further integration of the markets across the boundaries.

Although this analysis is performed through the international electricity exchanges perspective, the needs it enables us to identify can also be addressed by other technological solutions deployed for that purpose (generation, storage, demand side technologies).

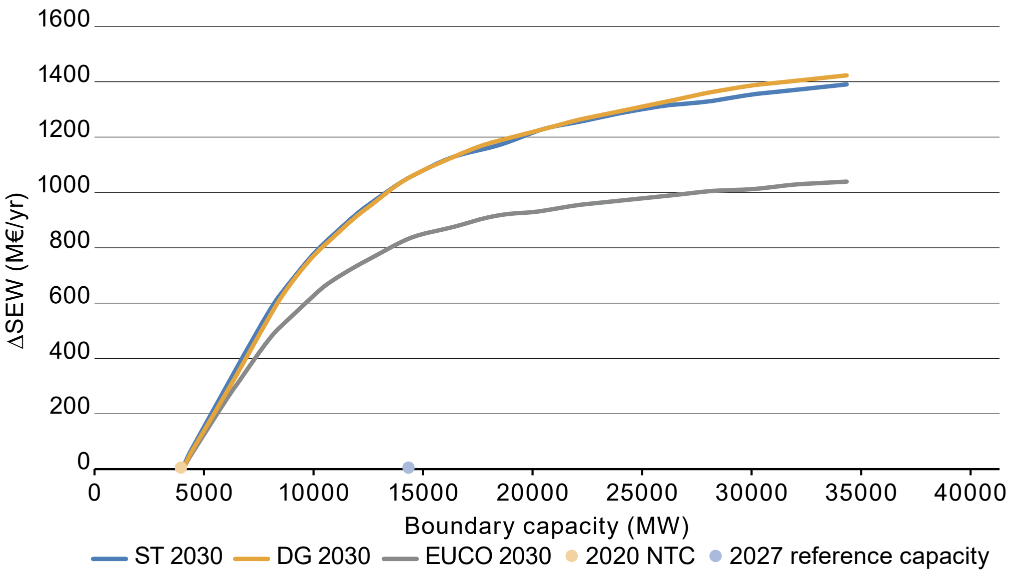
The analysis, the methodology of which is presented in the Annex to this report, was performed on the ENTSO-E 2030 scenarios using market-modelling tools. Each point in the curve corresponds to the results of a simulation of one scenario, for several climate conditions, with the indicated transmission capacity for the boundary and other grid set to the 2027 base case. Standard costs for capacity increases at each boundary were used in the analysis.

Figure 5.3: SEW/Capacity diagrams for TYNDP 2018 2030 boundaries

SEW/Boundary capacity diagram, Ireland – Great Britain and Continental Europe

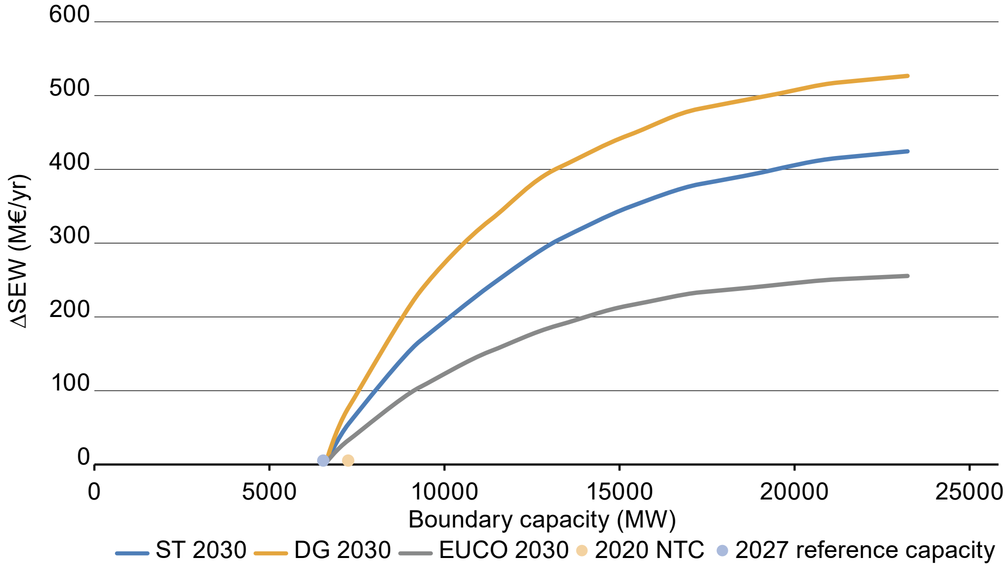


SEW/Boundary capacity diagram, Great Britain – Continental Europe and Nordics

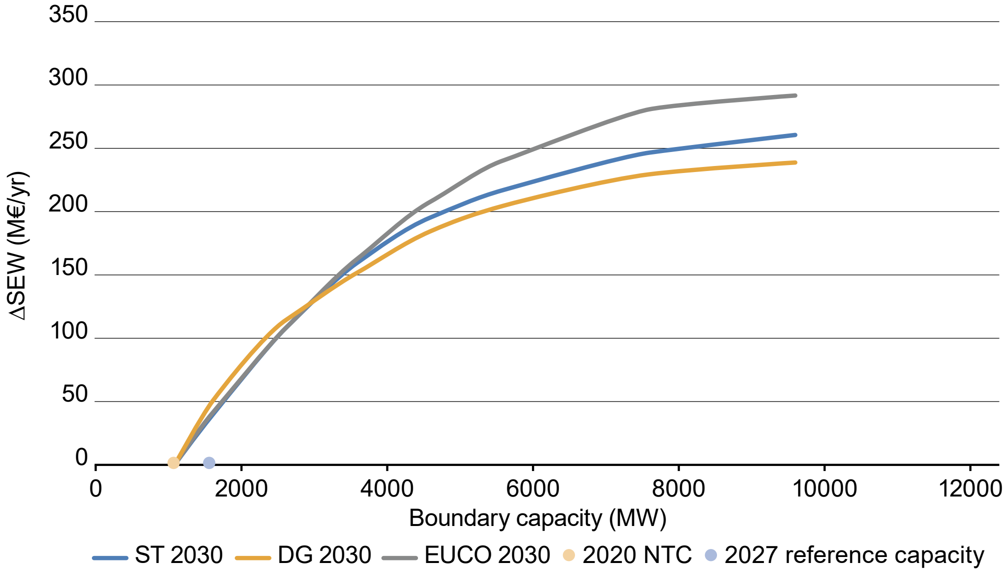


[1] Standard increase/decrease capacity is 1000 MW. If there are four borders crossing the boundary, all of which are increased by 250 MW in each step.

SEW/Boundary capacity diagram, Nordics – Continental West Europe



SEW/Boundary capacity diagram, Nordic/Baltic – Continental East Europe



SEW/Boundary capacity diagram, Baltic integration

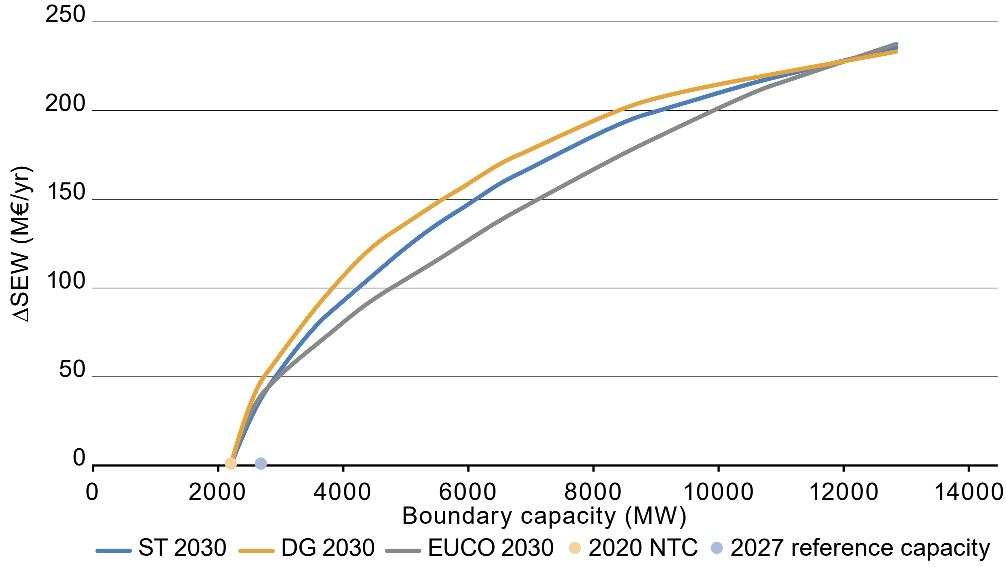
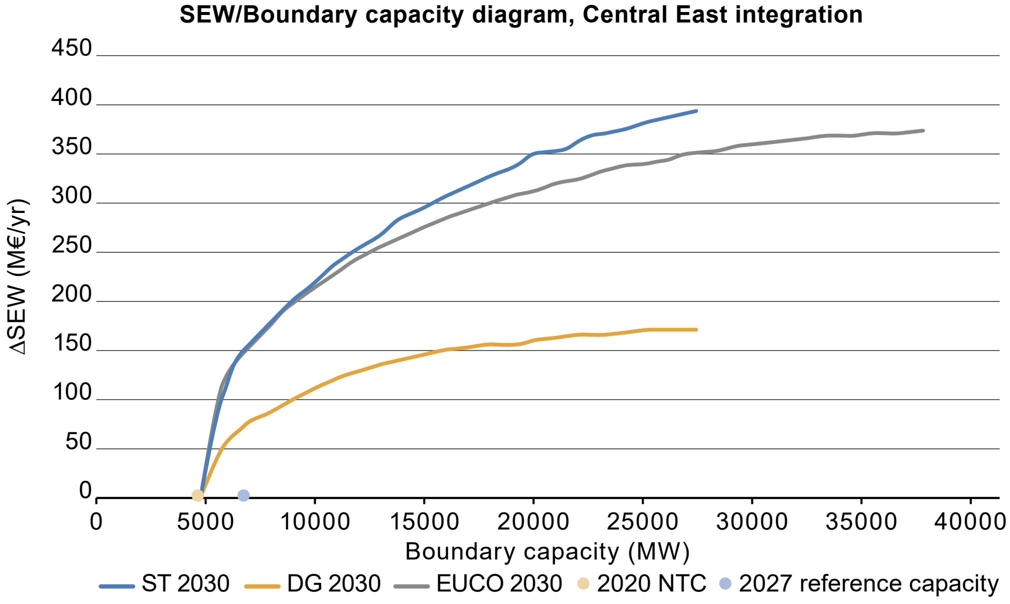
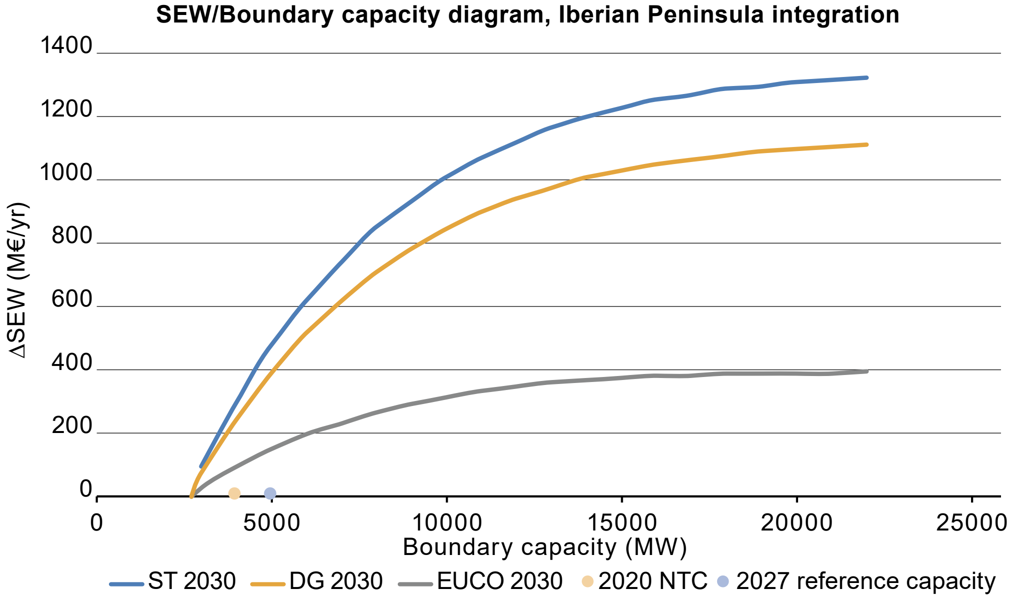
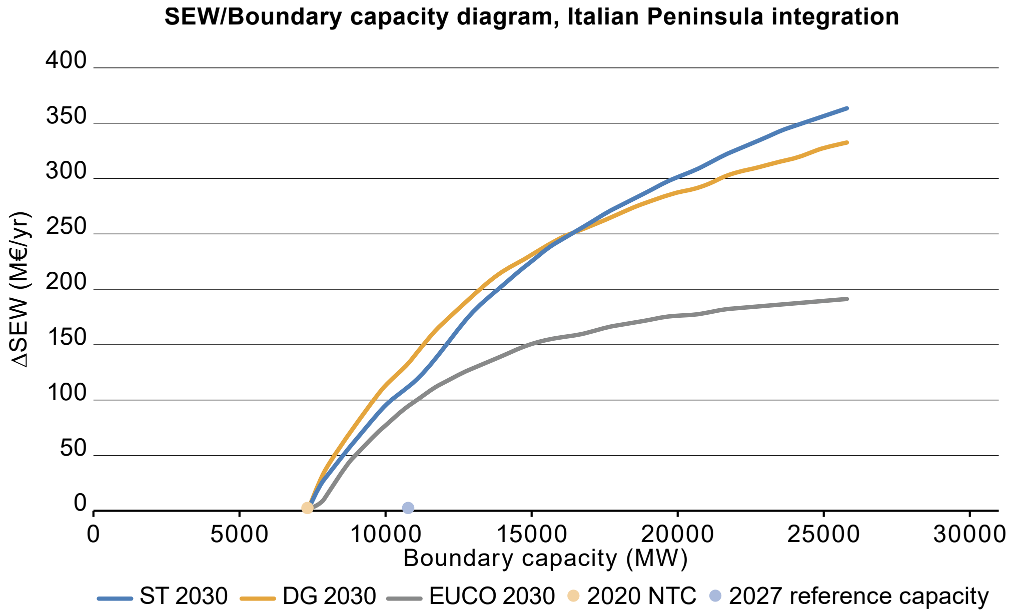


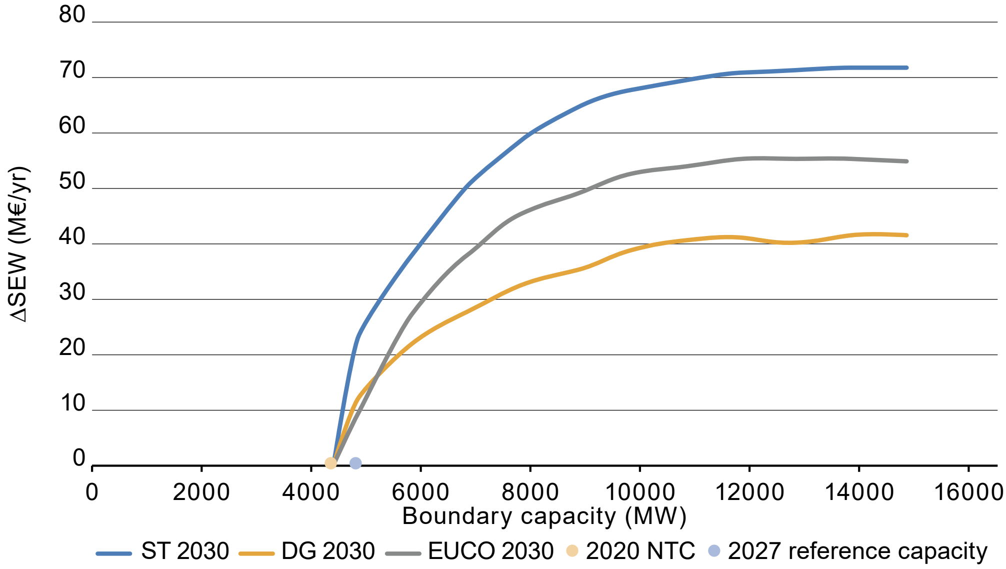
Figure 5.3 continued:







SEW/Boundary capacity diagram, South-East integration



SEW/Boundary capacity diagram, Eastern Balkan

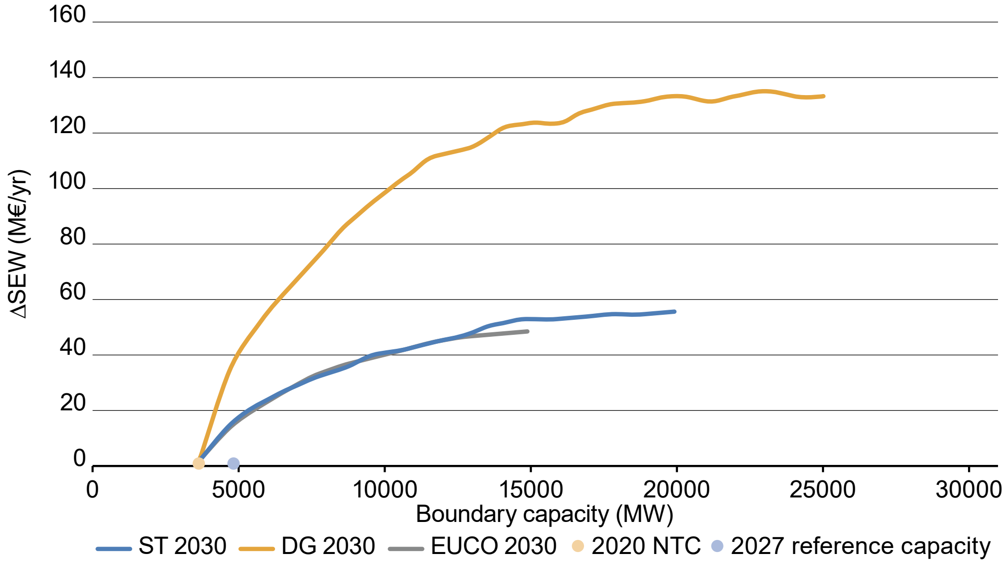
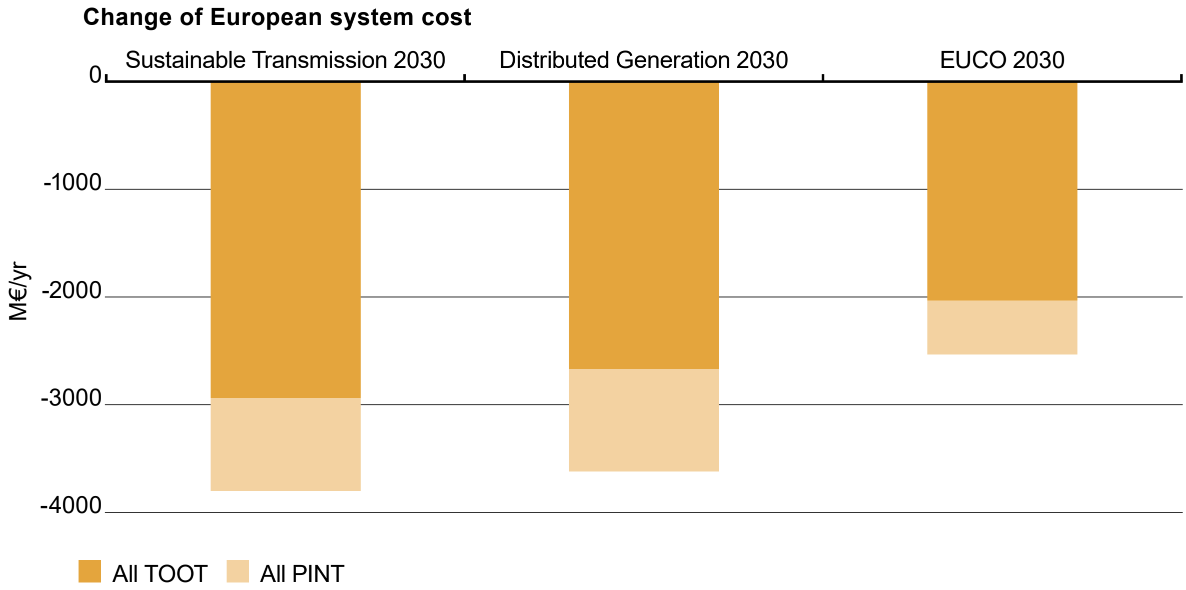
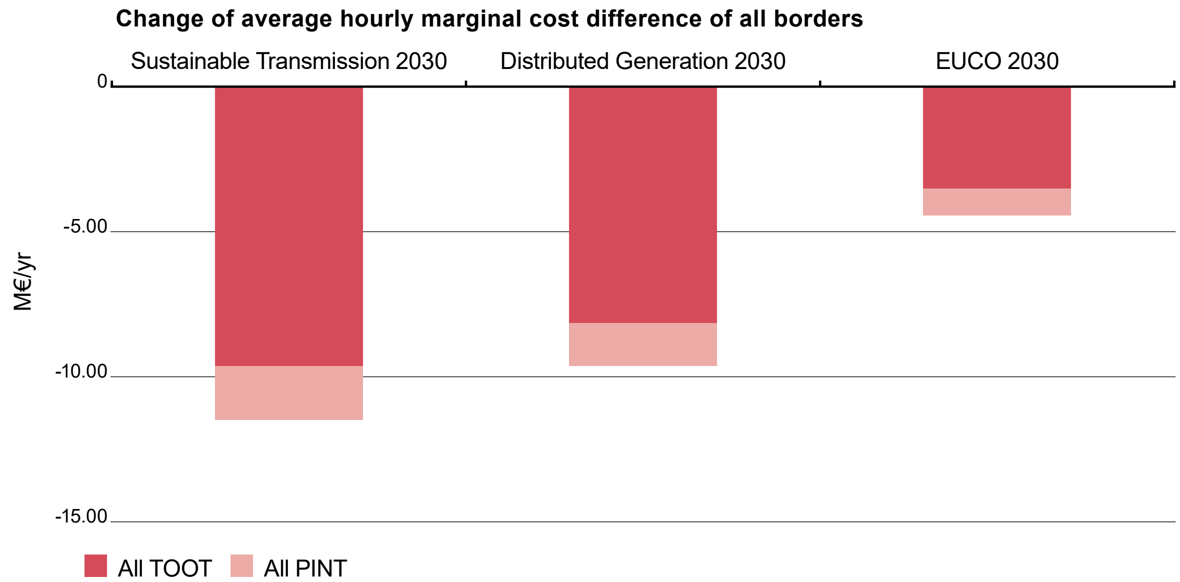
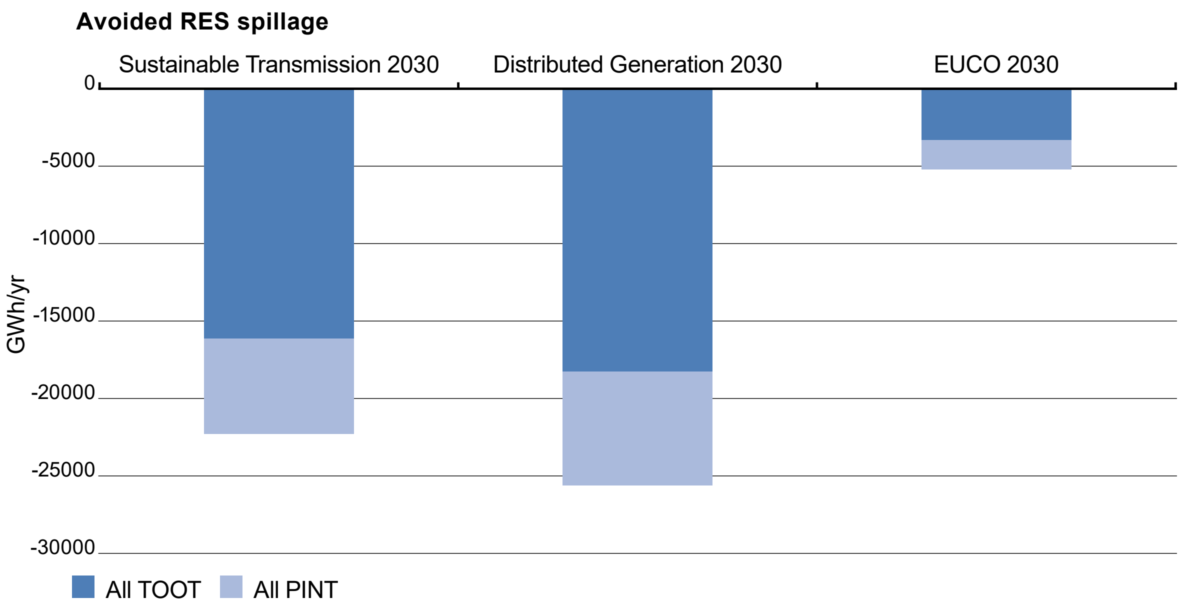
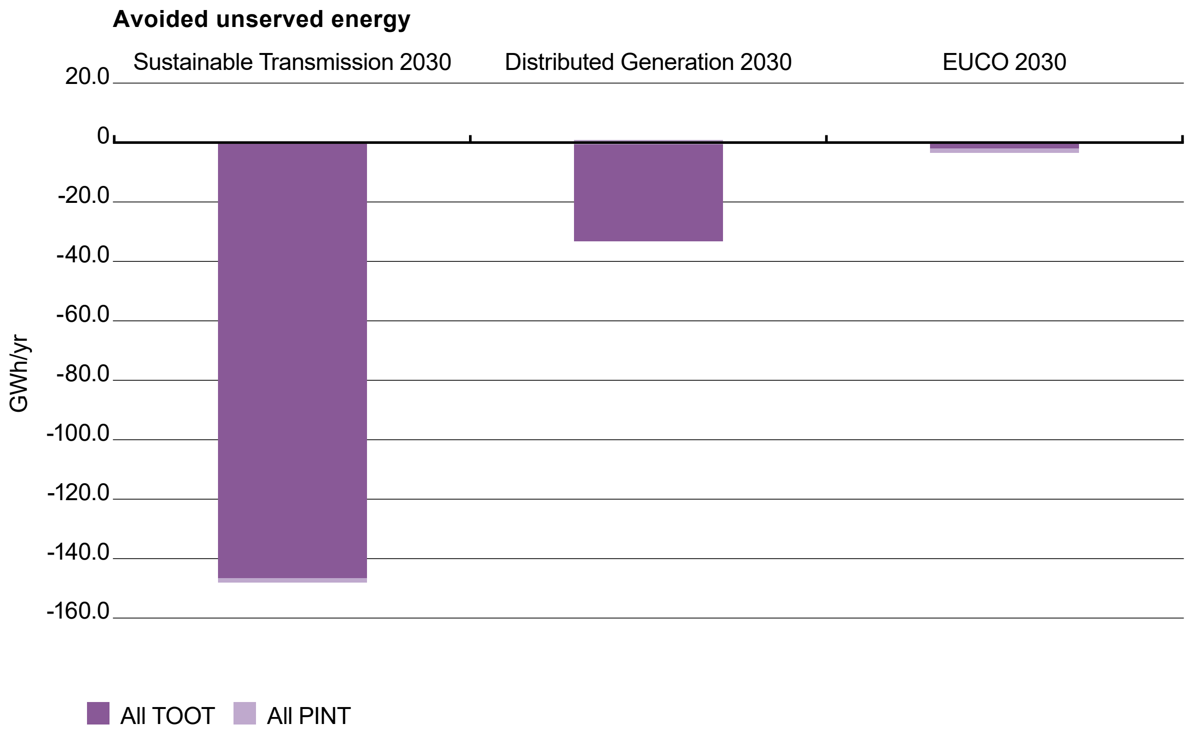


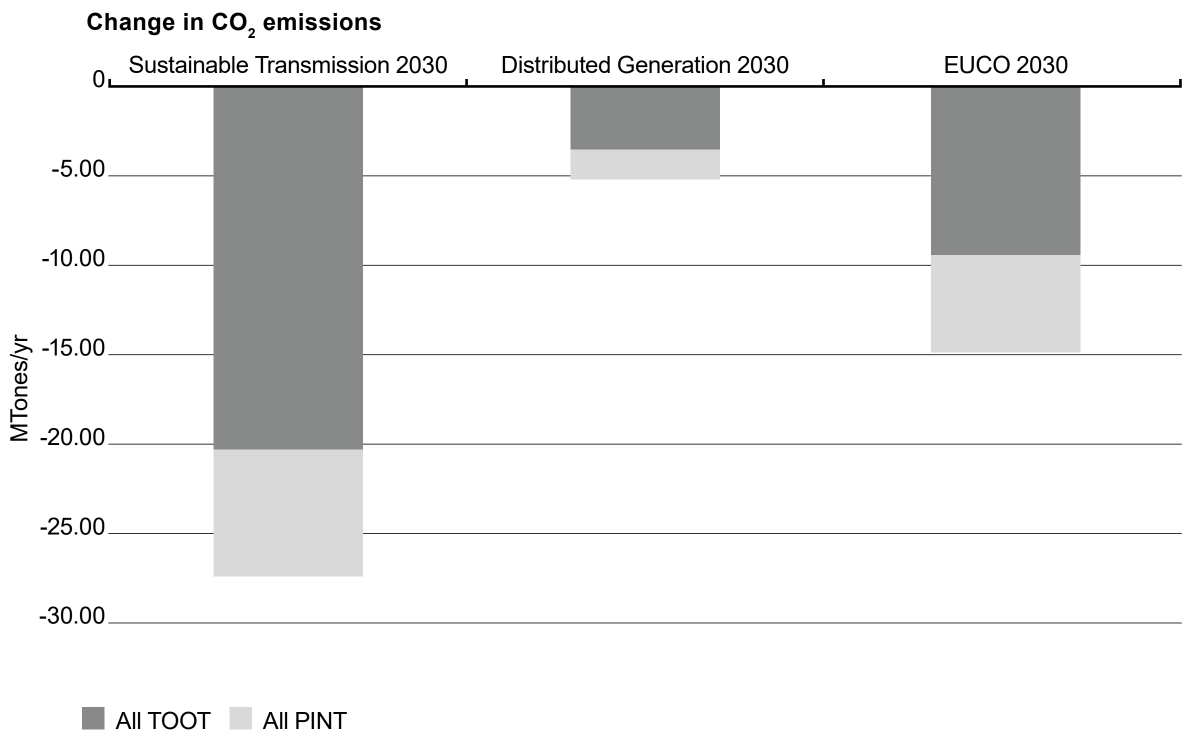
Figure 5.4: Impact of implementing full project portfolio on system cost, CO_2 emissions, RES spillage, unserved energy and average hourly price differences (average of all borders)[2]







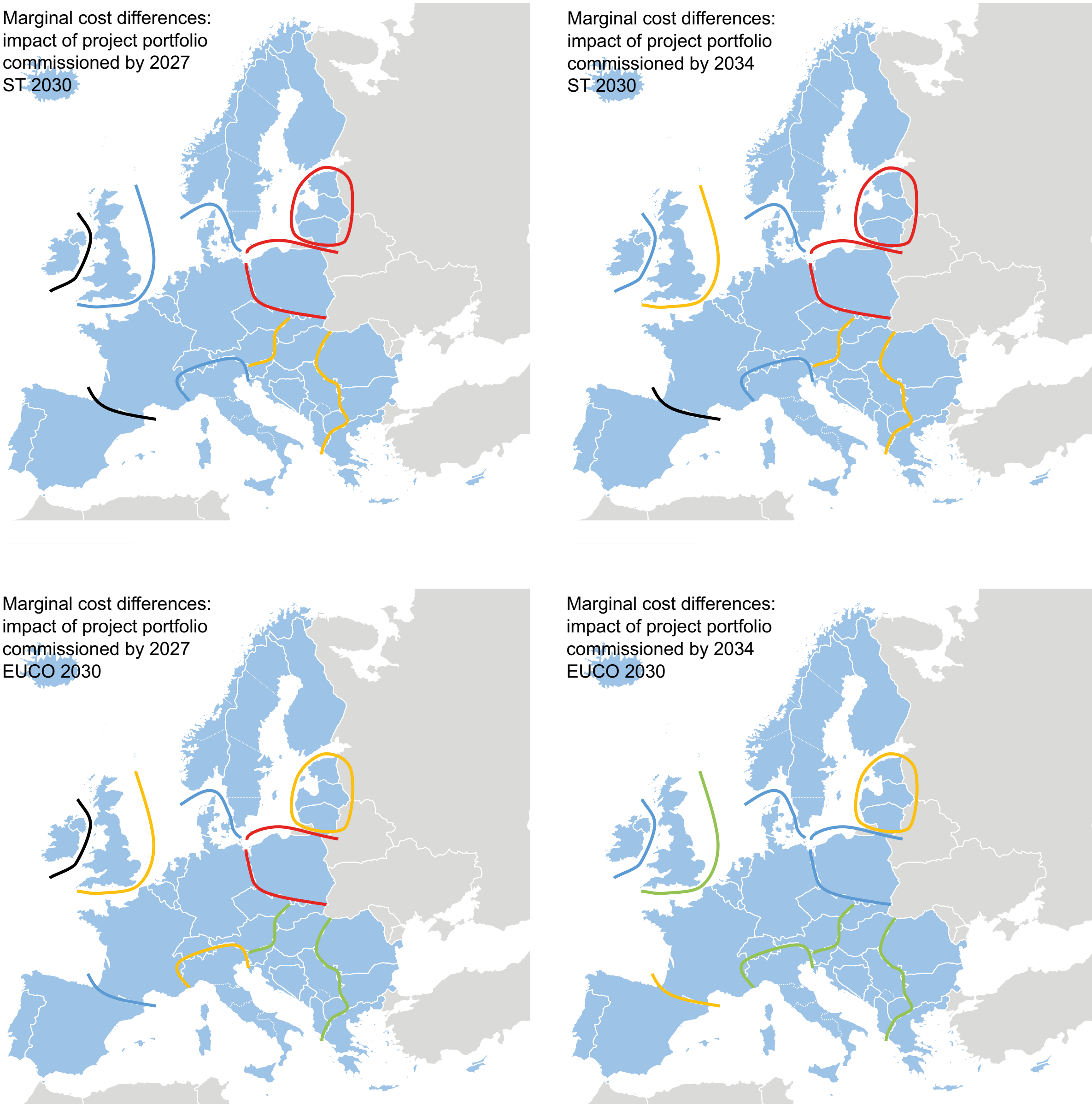




[2] This figure does not differentiate between the status or time horizon of projects nor does it make assumptions on the feasibility of competing projects.

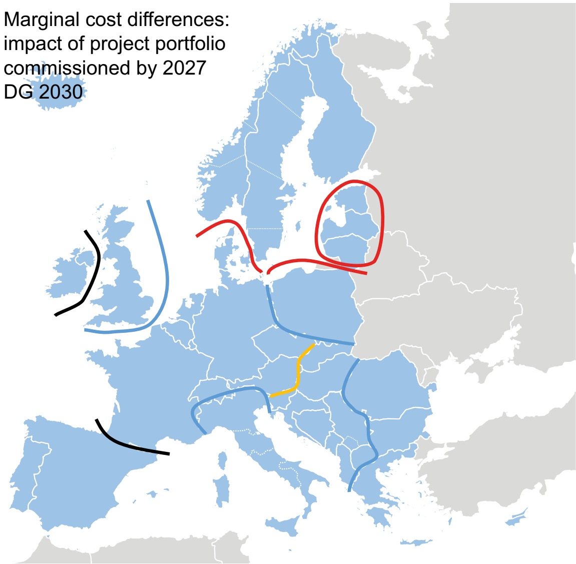
The impact of the project portfolio on the marginal cost differences across main boundaries is presented in Figure 5.5 for each scenario. These maps might be compared with similar maps shown in Figure 5.8. The first set of maps presents the marginal cost differences when all TOOT projects (projects with commissioning date by 2027) are commissioned and the second set of maps illustrates the same results when all TOOT and PINT projects (projects with a commissioning date before 2035) are commissioned.

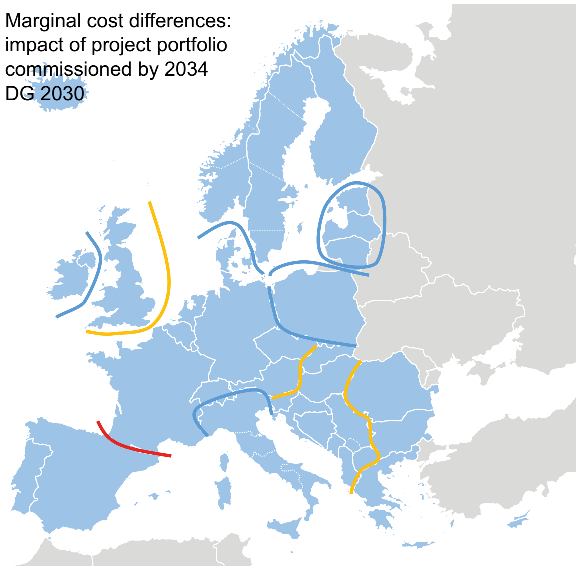
Figure 5.5: a Impact of the project portfolio on the average hourly marginal cost differences (€/MWh)



Avg. hourly marginal cost differences (€/MWh)

- From 0 to 2
- From 2 to 5
- From 5 to 10
- From 10 to 15
- More than 15





Appendix IV of the TYNDP 2018 Executive Report
Appendix shows the capacities of every border
in different time horizons and scenarios.

5.3
2030 interconnection targets

In 2017, an expert group (ITEG) proposed that the European Commission replace the 15% interconnection criteria for every country and electrified island with a new methodology developed collaboratively between the EC, ENTSOs, industry, universities and other experts. The methodology is based on the TYNDP CBA methodology and is based on three concepts:

- an efficient internal energy market should be interpreted by means of competitive electricity prices throughout the EU. Member States should aim at achieving yearly average of price differentials as low as possible. Additional interconnections should be prioritised if the price difference between relevant bidding zones, countries or regions exceeds 2€/MWh. More details about average hourly price differences between market nodes can be found in Appendix I of the TYNDP 2018 Executive Report Appendix.
- peak demand will be met through the combination of national capacity and imports for every Member State. In case the nominal transmission capacity of interconnectors is below 30% of their peak load, Member States should investigate options for additional interconnectors.
- the further integration of RES will not be a combination of national capacity and imports for every Member State. In case the nominal transmission capacity of interconnectors is below 30% of their peak load, Member States should investigate options for additional interconnectors.

The following maps show the results of the ITEG methodology applied for the TYNDP 2018 2030 scenarios, taking into account projects commissioned by 2030 and all projects commissioned by 2027 (Figure 5.6) that have already started the permitting process in 2018 (known as TOOT projects). The studies are based on a number of assumptions, including:

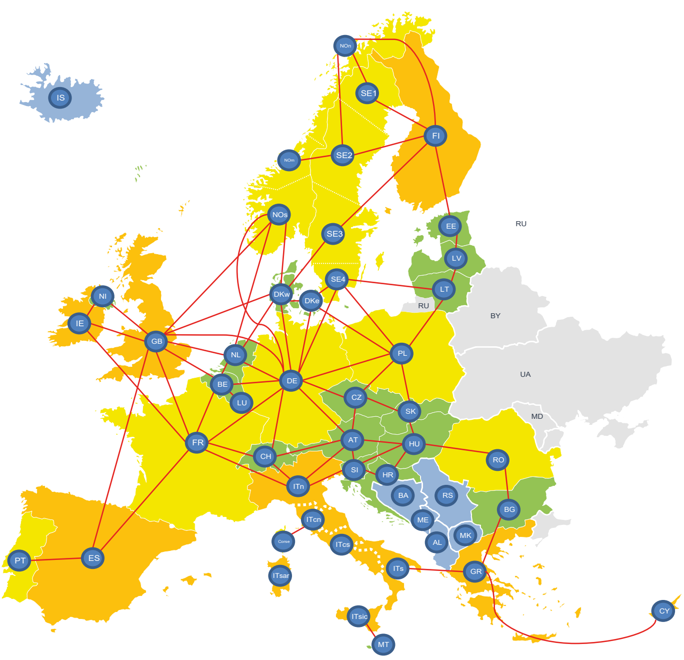
- that all scenarios are assumed adequate;
- the nominal cross-border capacity is based on the total physical capacities of all interconnectors, and does not include any restrictions based on system-security criteria (such as mitigating possible overloads resulting from N-1 contingencies); and
- price differentials between bidding zones are limited to those for which either an interconnector currently exists or for which projects have been assessed as part of the CBA phase of this TYNDP18. Therefore, they are not necessarily fully exhaustive.

Figure 5.7 shows that large marginal cost difference (>2 €/MWh) appears for all European borders in ST and DG scenarios and in the EUCO scenario, which might highlight the need for additional interconnection development apart from the existing interconnection grid (projects commissioned by 2020).

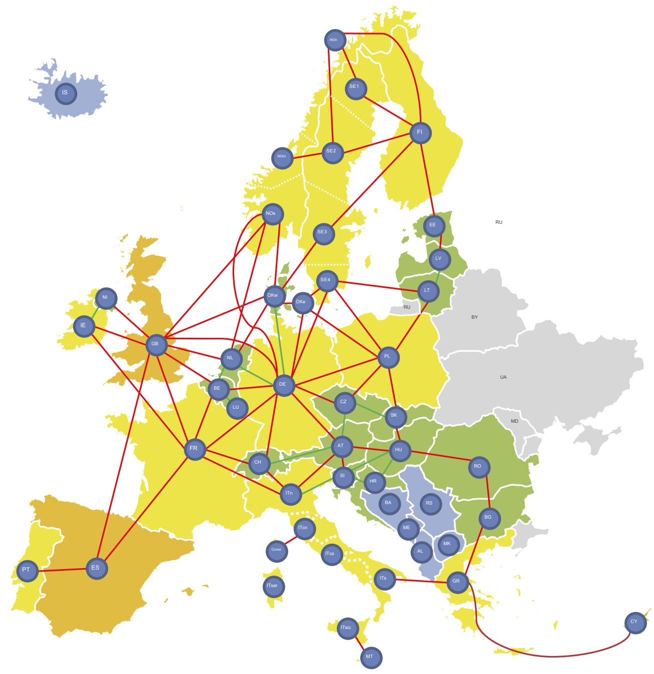
Regarding security of supply and RES integration criteria, the existing interconnection grid shows additional needs for interconnection development to be most urgent in Spain, Great Britain, Ireland, Italy, Greece and Finland in all scenarios and in France, Romania and Poland in the DG scenario.

Figure 5.6: Interconnection targets for 2030 scenarios

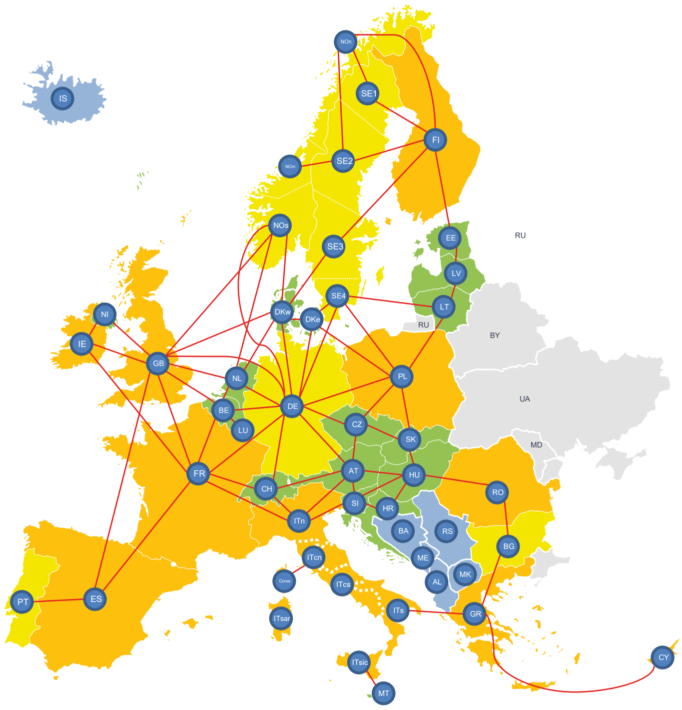
ITEG criteria ST 2030 2027 grid



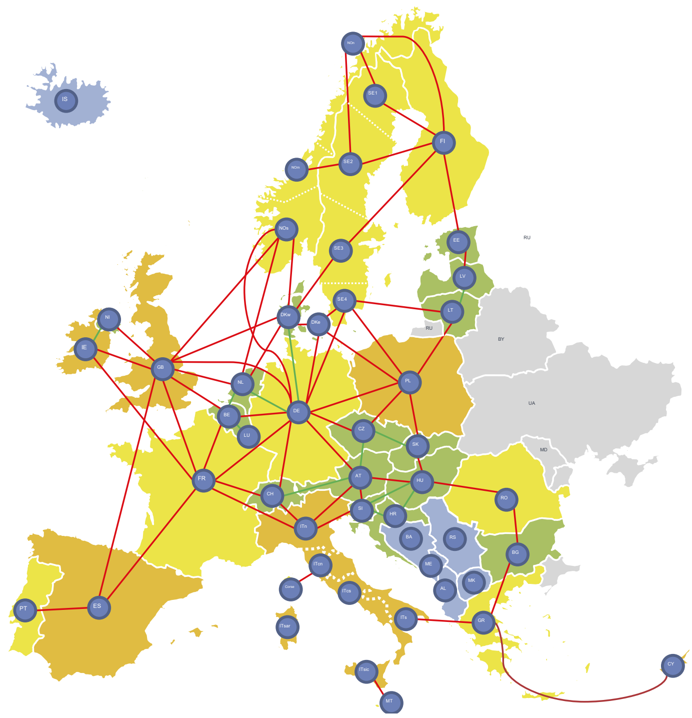
ITEG criteria ST 2030 2030 grid



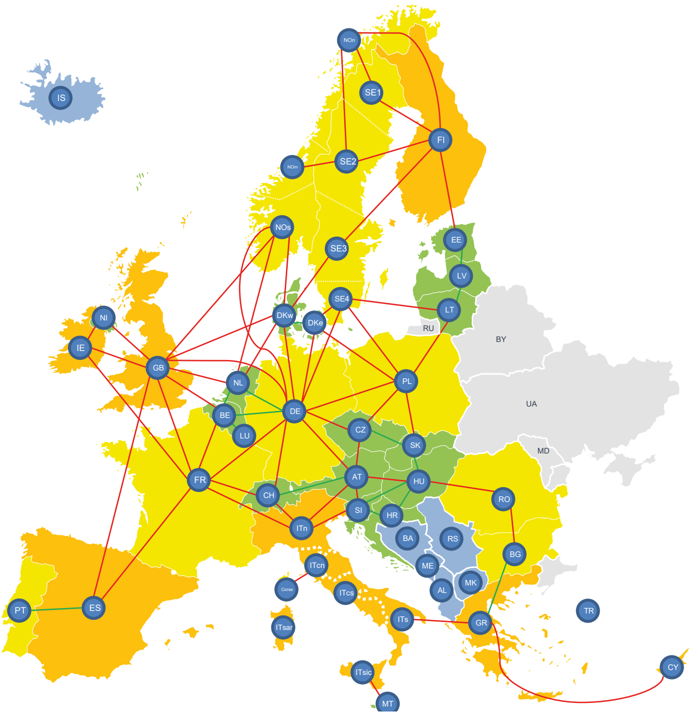
ITEG criteria DG 2030 2027 grid



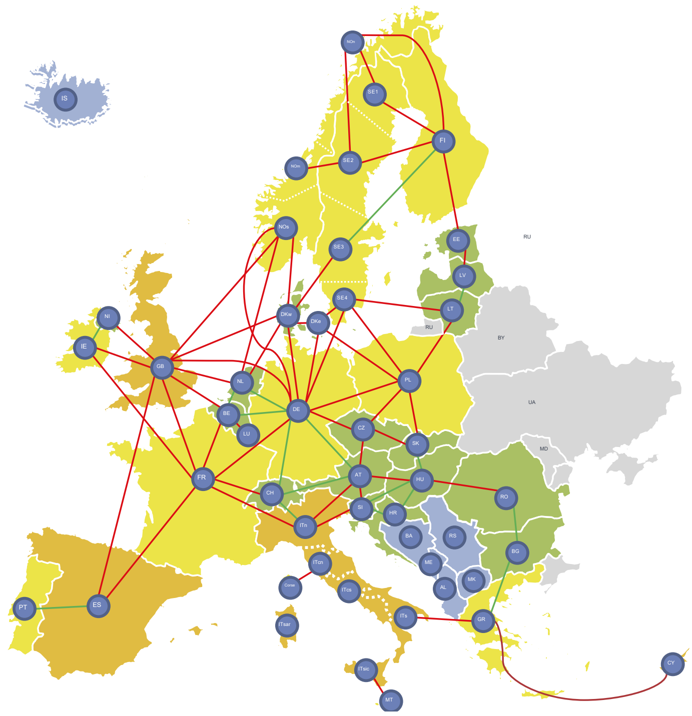
ITEG criteria DG 2030 2030 grid



ITEG criteria EUCO 2030 2027 grid



ITEG criteria EUCO 2030 2030 grid



- Yearly average marginal cost difference <2€MWh
- Yearly average marginal cost difference >2€MWh
- At least one of the 30% criteria show <30%
- At least one of the 30% criteria show >30% but <60%
- Both criterias show >60%
- No interconnection targets

Figure 5.8 shows that a large marginal cost difference still exists for most European borders in all scenarios, which might highlight the need for additional interconnection development apart from the project portfolio expected by 2027.

Regarding security of supply and RES integration criteria, the TYNDP 2018 project portfolio for 2027 shows additional needs for interconnection development to be most urgent in Spain and Great Britain in all scenarios, in Italy for DG and EUCO scenarios and in Poland for the DG scenario.

5.4

2030 and 2040: the cost of no action

- No new grid beyond 2020 would directly hit the European objective of a well-integrated European energy market.
- No action beyond 2020 would also have a tangible impact on the economy and quality of life of Europeans by putting at risk the reliability of access to electricity. If renewable energy sources and new electricity uses keep growing as foreseen, failure to deliver on transmission investments or other reinforcement solutions would lead to unacceptable and never before seen levels of business inoperability or even blackouts.
- In the no-grid scenarios, significant amounts of renewable energy would go to waste as they could not be exported because of the lack of cross-border capacity.

Methodology: The no-action scenarios

What would be the consequences of no (additional) grid for Europeans by 2040? To answer this question, we created no-grid versions for each of the 2030 and 2040 scenarios.

These scenarios keep the generation portfolio and the demand levels of the original scenarios but use a 2020 version of the grid (projects which will be operational by 2020 are in the final stages of their delivery and therefore are certain to happen).

Testing these scenarios and comparing the results to simulations of original scenarios (including a collection of projects considered mature, and also used as a reference to run the CBA) allows the reader to grasp concretely the value of the overall investment portfolio, rather than incremental benefits of additional capacity increases. In this section, average results for the three original and no-grid scenarios are presented in order to enhance readability. Simulations have been performed using three different sets of climatic conditions.

Failing to properly develop the European grid beyond 2020 would induce severe limitations in cross-border exchanges, coupled with a heterogeneous distribution of renewables across Europe. This would lead to important differences between regional market prices, with price differences at the borders going up by 600% in the worst cases by 2040. This means that the cohesion of the European single market would be harmed by vastly different electricity costs among neighbouring countries.

Bringing the electricity market differences to zero between neighbouring countries is not an objective in itself, as local conditions and grid development costs must be taken into account. However, in a less integrated market system, the power is less efficient, which means that it cannot flow from lower-cost areas to more expensive ones. Fragmented markets therefore lead to a rise in marginal prices, with a direct impact on consumers' electricity bills.

The enhanced grid leads to a much greater level of power transfer between countries as this network is used to trade power more efficiently. This is a good indicator that the additional grid is actually supportive of trade throughout Europe and the more efficient use of the generation portfolio.

Figure 5.7: The economic costs of no action by 2030 and 2040

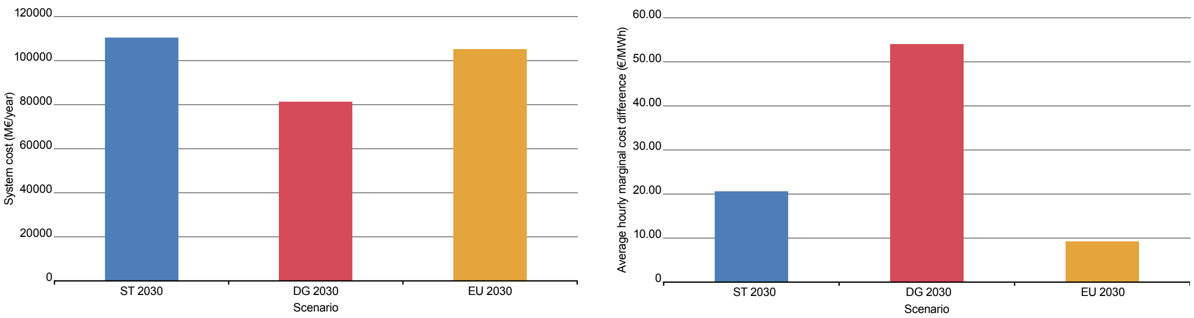
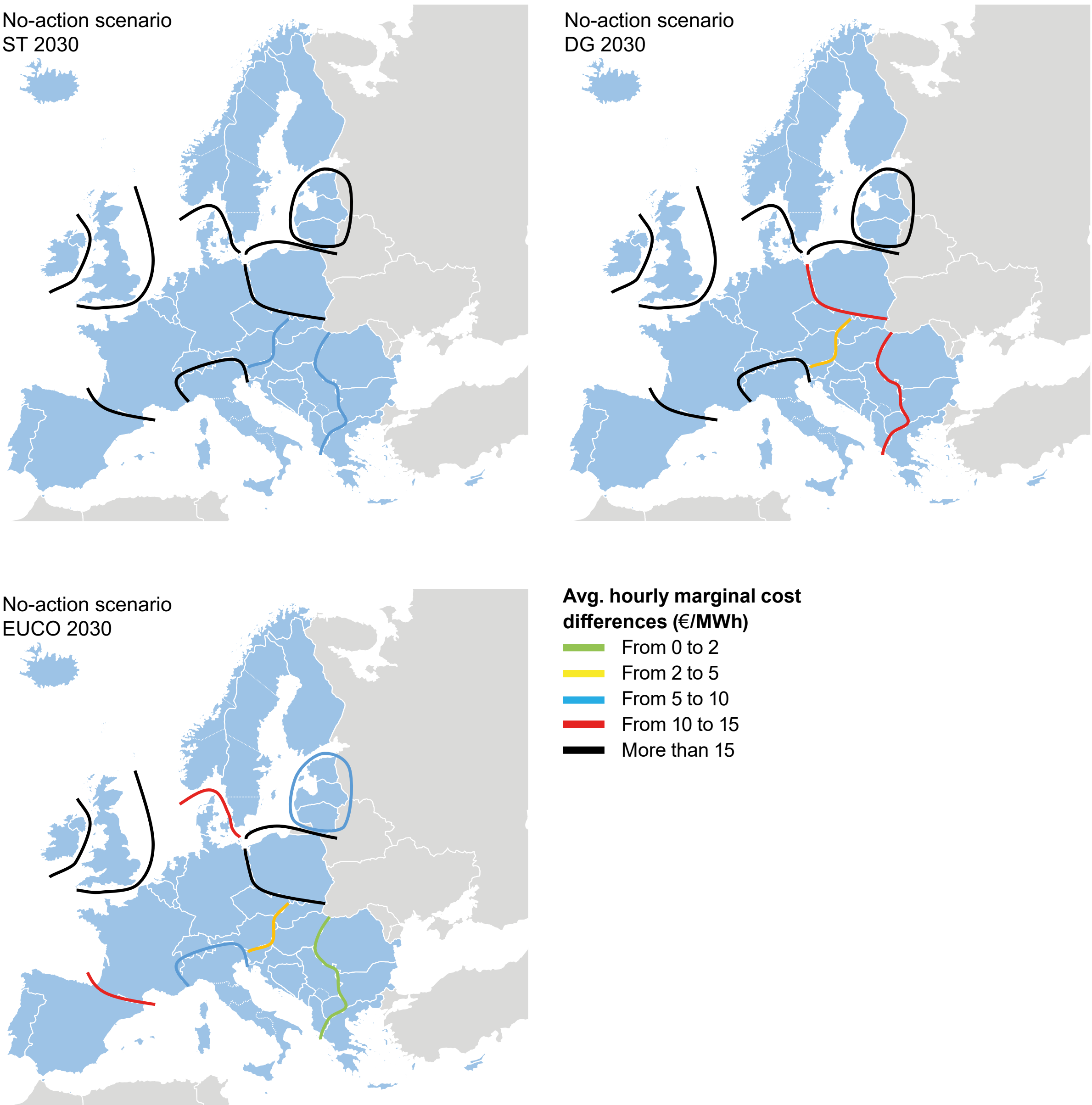


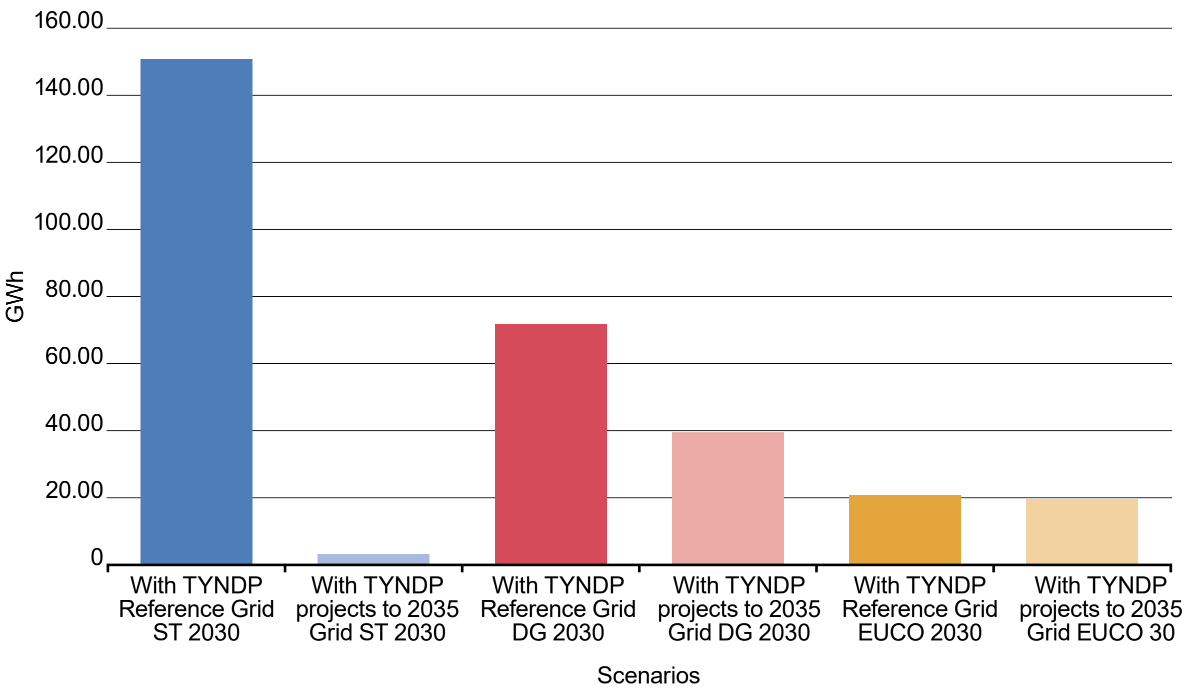
Figure 5.8: Average hourly price differences across main boundaries if no grid is developed by 2030



The results of the no-action scenarios confirm that without the ability to rely on cross-border exchanges, many European countries will simply lack generation capacity.

In the no-action scenarios, unserved energy across Europe and all its regions is rising. These results demonstrate that interconnectors contribute to ensuring adequacy through the sharing of resources in Europe and that they are at the basis of a secure and reliable power system in the mid/long-term scenarios.

Figure 5.9: The system security costs of no action by 2030 and 2040

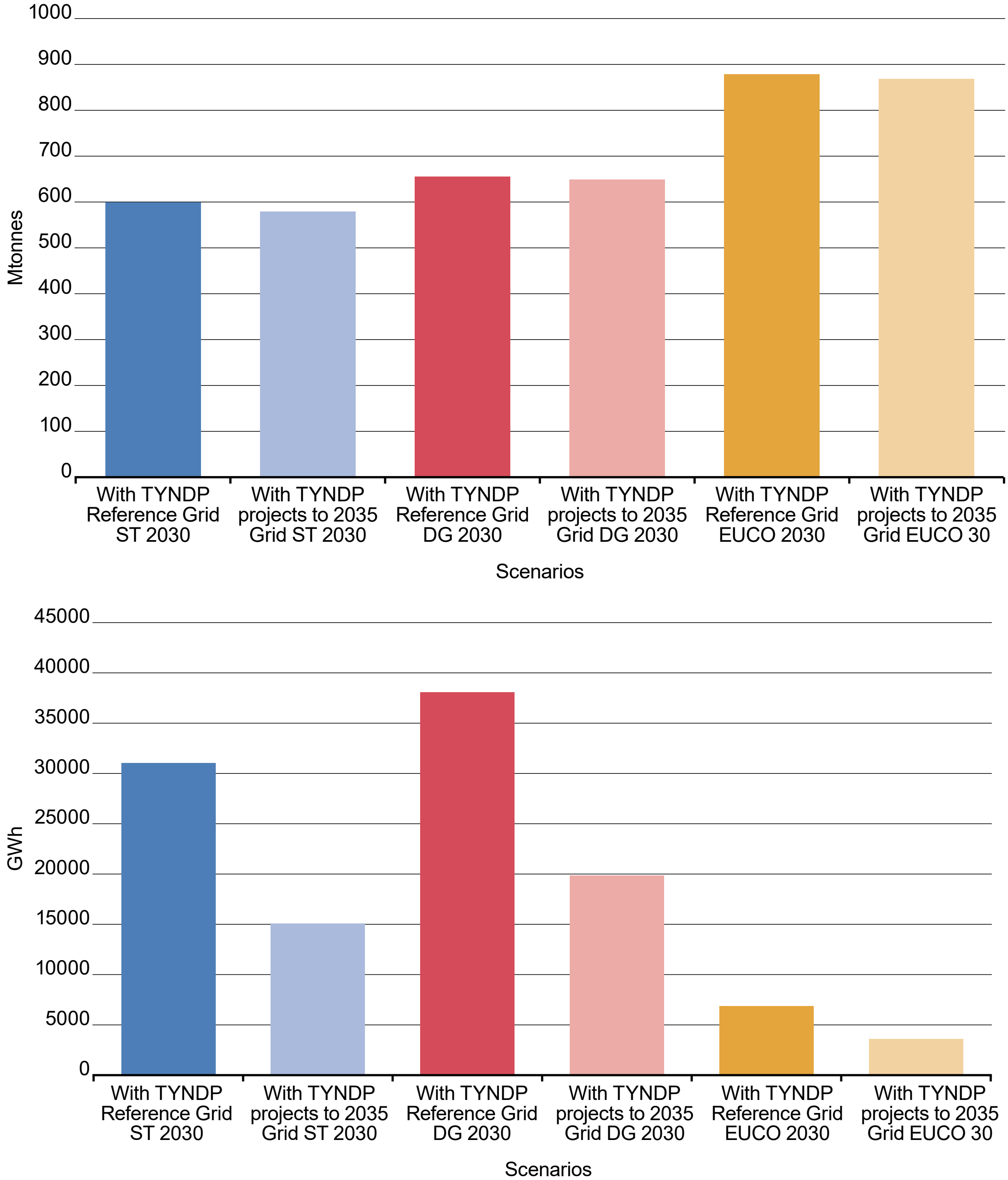


Figures 5.9, 5.10 and 5.11 show a vision of the Pan-European energy landscape, with and without the TYNDP 2018 project portfolio. In the no-action scenarios, significant amounts of renewable energy would go to waste as they could not be exported because of the lack of cross-border capacity. Additionally, the limitations in cross-border exchanges would be compensated by local production from peaking units, representing more CO_2 emissions. By 2030, no action would mean that around 50% of the total electricity sector CO_2 emissions will be concentrated in Germany, Great Britain, Italy and Poland (see details in the Regional Insight Reports). Germany and Spain experience 60% of the total renewable energy spillage in Europe in ST and DG scenarios. Even with the delivery of the infrastructure needed by 2040, the amount of curtailed energy remains very significant despite an increase in interconnection capacities: this confirms that further reduction of curtailed energy will necessitate further optimisation of the geographical spreading of RES and/or complementary solutions (storage, etc.) to network development.

It can be argued that in the no-grid case, because RES promoters will know that they will not be able to sell their production in foreign markets and therefore will be unable to benefit from this revenue, they will not build the RES units in the first place. This would reduce the amount of lost or 'dumped' energy from RES, but whilst overall pushing up the level of CO_2 emissions.

It is important to bear in mind that all scenarios were developed under the assumption that CO_2 emissions would be reduced, as defined in the European climate goals. That means that, at the European level, installed coal capacity and production has been reduced in the 2030 scenarios and even more in 2040 compared to 2020 and 2025. Any old coal unit that is retired after 2030 will not be rebuilt, i.e. they are not included in the 2040 scenarios if they reach the end of their lifetime.

Figure 5.10: The environmental costs of no action by 2030 and 2040



5.5
2040: completing the map

In the TYNDP, a set of scenarios with a long-term perspective is examined and necessary network developments most able to meet the outcome of all of its scenarios[3] into the future are derived. For the first time, the TYNDP 2018 includes a pan-European future system needs assessment report as part of its package, with a focus on the 2040 time horizon.

The year 2040 has been carefully chosen to be right in the middle of the transition process of the European electricity infrastructure to a carbon-free system.

Therefore, it provides not only the short-term development needs based on the current portfolio of network participants that either currently exist or are under development, but also a progressive analysis of the system needs.

Methodology: identifying capacity increases

In order to go beyond the learning of the TYNDP published in 2016 (focusing on 2030 scenarios), ENTSO-E analysed which new capacity increases would be necessary by 2040.

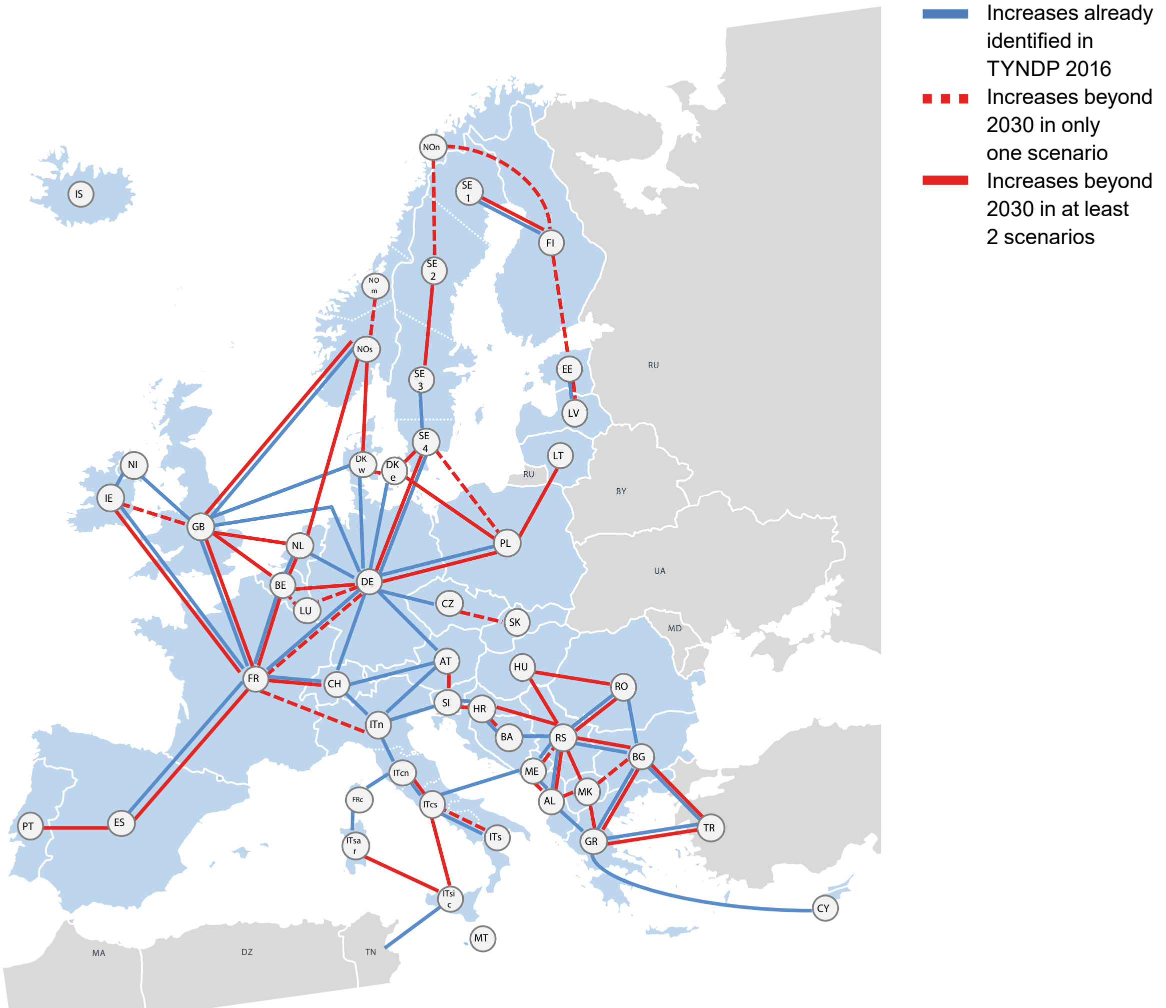
To do so, ENTSO-E determined, for three distinct 2040 scenarios, which European borders presented the highest economic gains when equipped with an additional interconnector (using standard development costs for each border). This operation was repeated until no new profitable route could be identified. Following the economic analysis, ENTSO-E tested two additional criteria in order to identify borders where additional capacity was needed beyond the economic reasons (integration of RES and security of supply).

All European regions are affected by the transformation of the energy landscape. The analysis therefore showed a need for new projects in each European region. Many of the identified capacity increases are required in more than one scenario, and justified by more than one driver Socio-Economic Welfare (SEW), Renewable Energy Sources (RES) and Security of Supply (SoS).

Each of the identified capacity needs requires further investigation. It is also certain that the proposed set of capacity increases does not represent the only solution, as other combinations of capacity increases could also address the same needs. Furthermore, the value for society of a capacity increase can only be assessed by considering their interaction with each other. A change in the sequence of capacity increases could have led to another valid end result. Additionally, the phenomenon studied in this report could, and will also have to, be addressed through new market designs and the development of storage and smarat grids (although these elements are already ambitiously represented within the scenarios, and would therefore necessitate an exceptional and unforeseen development to address efficiently the needs described in this report).

[3] It should be noted that the scenarios do not present the most extreme outcome of any of the range of possible futures but instead what is considered to be a reasonable outcome where the drivers behind a scenario emerge.

Figure 5.11: Increase in capacities from 2020 to 2040 (ST 2040)



5.6

New challenges in real-time system operations may reshape the electricity system

The replacement of traditional thermal units, which traditionally provided system operation ancillary services, by renewables creates new challenges. These services will become increasingly important, as the system complexity grows, and more difficult to provide as thermal units are decommissioned. In response, the design, construction and use of both the network and users will also need to change over time, being adapted through a series of changes to migrate to a carbon-free environment by 2050.

Previous TYNDPs have identified the main capacity-related benefits and developed a comprehensive assessment methodology for the cost and benefits of network developments.

Although only sufficient capacity for the transmission of power from its source to its drain is required, it will not be adequate to provide a reliable network to supply electricity to users in a carbon-free network. Essential services and capabilities to support stability, voltage, frequency, protection and the introduction of new technology and users into the network are becoming increasingly important to support the network. Although 2050 is over three decades away, the lead-time required for large-scale network development means that this migration has already begun and will continue in the coming years.

This increases both the interdependency of TSO processes to operate the system in a secure and efficient manner and the need to take into account the challenges associated with the operation of the future system when designing the transmission network.

Future studies will be necessary to clearly understand the scale and nature of measures to be taken by system operators in order to adapt to the situation presented in this report. Some of the needs may be addressed through the specification of capabilities and services that users (generation or demand) are expected to provide as part of their connection. However, additional national and regional network reinforcement projects can also be expected to address the specific dynamic stability needs.

More on system needs identification in the TYNDP package

Power System 2040: Completing the map report
The Scenario Report provides a developed overview of the scenarios. This includes the storylines and key assumptions of these scenarios (section 2) that lead into the scenario results (section 3) in terms of demand, supply and EU climate targets. The stakeholder engagement process (section 4) has been fundamental in selecting which scenarios to consider and to give them their framework. The significant changes in the scenario-building process that have taken place compared to the latest TYNDP editions are summarised in the scenario-development methodology (section 5). This intensive scenario-development process is the starting point to the TYNDP's next steps towards electricity and gas (section 6).

Regional Investment Plans
The Regional Investments Plans have been developed as part of the Power System 2040 package and focus on similar topics from the ENTSO-E regional standing.

Regional Insight Reports
The Regional Insight Reports refocus on the four European PCI regions and provide similar insights to those in the Regional Investment Plans.

Methodologies
Many studies have been performed during the TYNDP process as we have tried to establish the system's needs. We always endeavour to share the results with stakeholders in order to get their opinions and improve our processes. It is therefore important that we share our methodologies and approaches to the work undertaken during the development of the TYNDP.

Section 6

A resilient portfolio of tailor-made investment solutions

To accommodate the energy transition and help Europe to face the needs and challenges described in the previous section, a large number of projects must be commissioned by 2030. In the TYNDP, a European call for transmission and storage projects has been performed and all the projects which meet the minimum maturity criteria have been selected. The impact of all of these projects is analysed in 2025 and 2030 scenarios against a number of indicators described in the European Cost Benefit Analysis Methodology of Projects (to be published by the European Commission).

There are 166 Transmission and 20 Storage Projects.

6.1

Technologies, maturity, status: a snapshot of existing projects

The vast majority of projects are expected to be in service by 2027 (Figure 6.1 shows the overall progression status of the project portfolio).

Figure 6.1: Project portfolio status for each European corridor

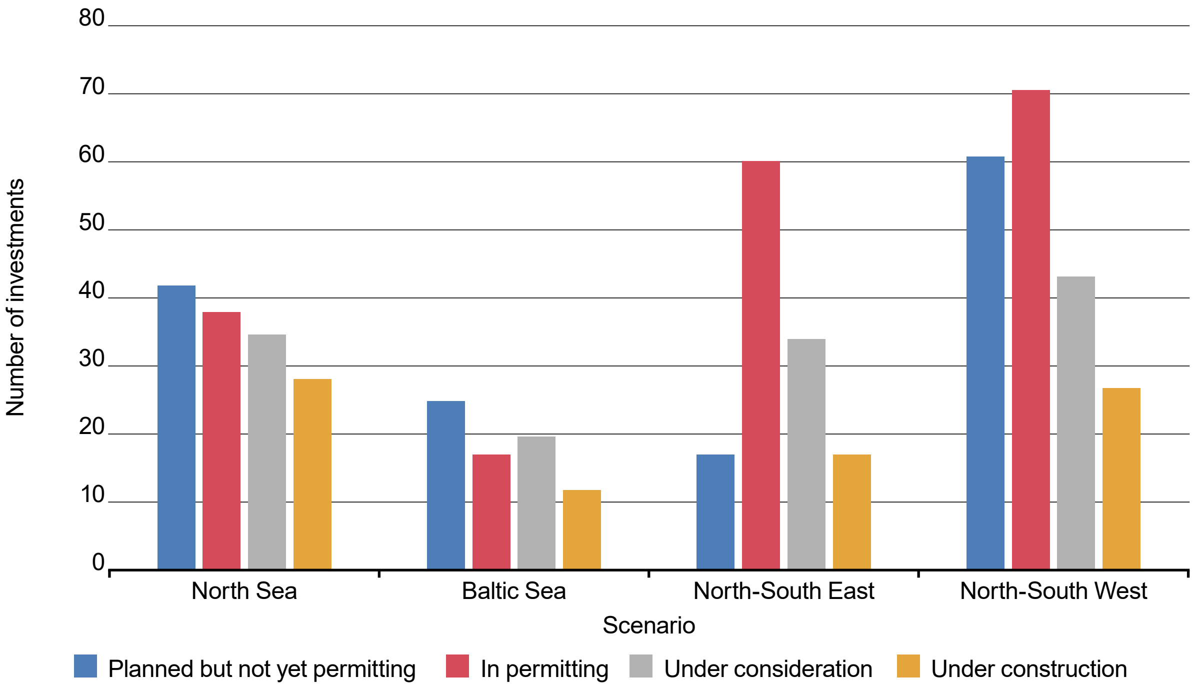
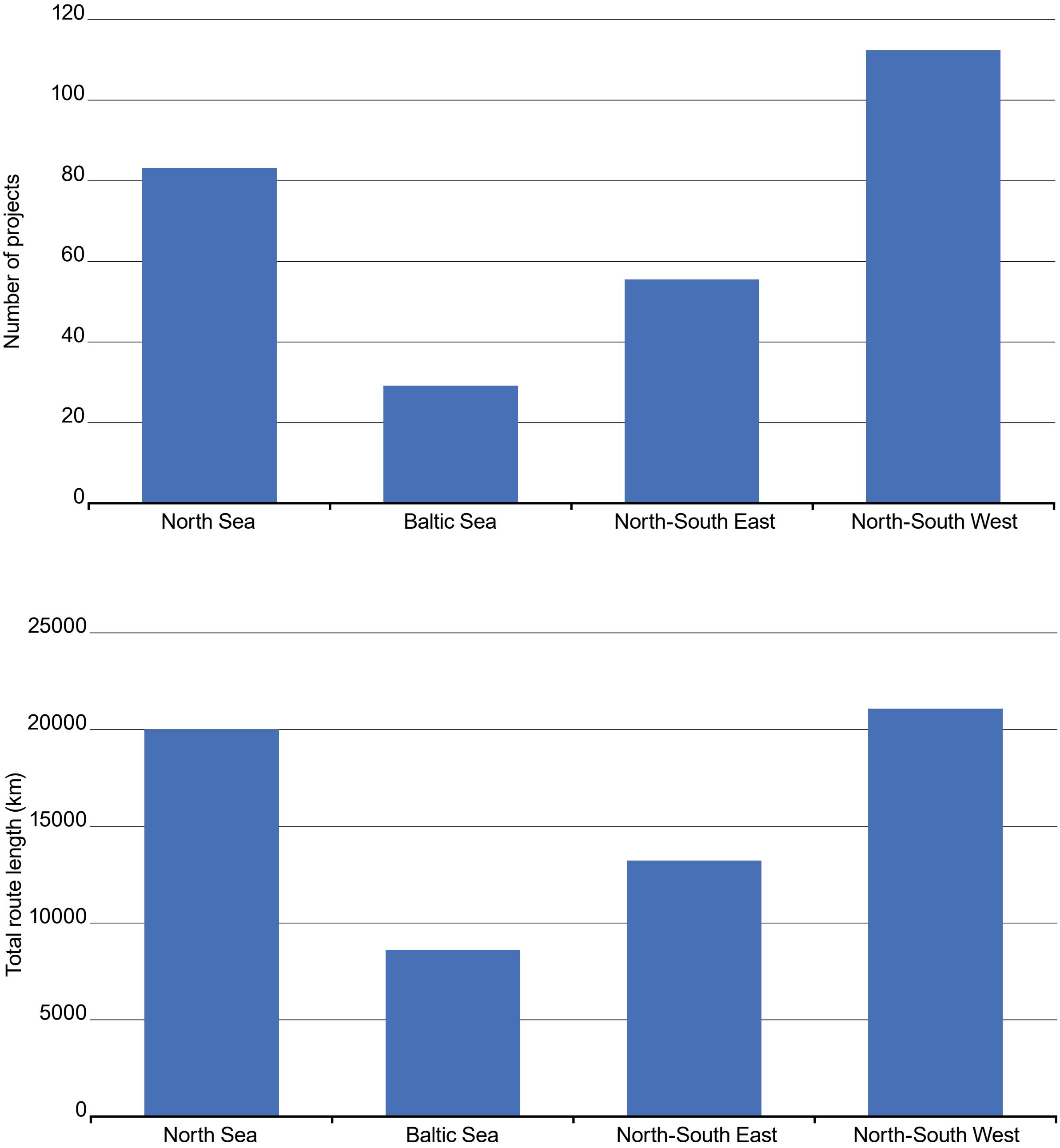


Figure 6.2: Number of investments and total km for each European corridor



AC overhead lines are still the dominant technology in all the regions with a share of 78% of the project portfolio. Cable and High Voltage Direct Current (HVDC) technology will play a more prominent role in the future grid development than they have in the past.

Just 60% of the promoted projects are overhead line developments, with cables – underground and subsea – making up 25% of the portfolio and other substation components comprising the rest of the portfolio.

This evolution is mostly due to recent technological developments and the geography of projects with a growing development of overseas interconnectors.

For instance, there are several projects to integrate the island systems of Great Britain, Ireland and the Iberian Peninsula with Continental Europe. These interconnections will require a significant amount of subsea HVDC cable.

In addition to technical requirements, the political pressure, mainly with the aim of increasing public acceptance, is driving the transition from overhead lines to cable technology. In Germany, wide area transmission corridors should preferably be implemented in HVDC-cable technology. This entails significantly higher project costs.

Figure 6.3: Alternating Current and Direct Current projects

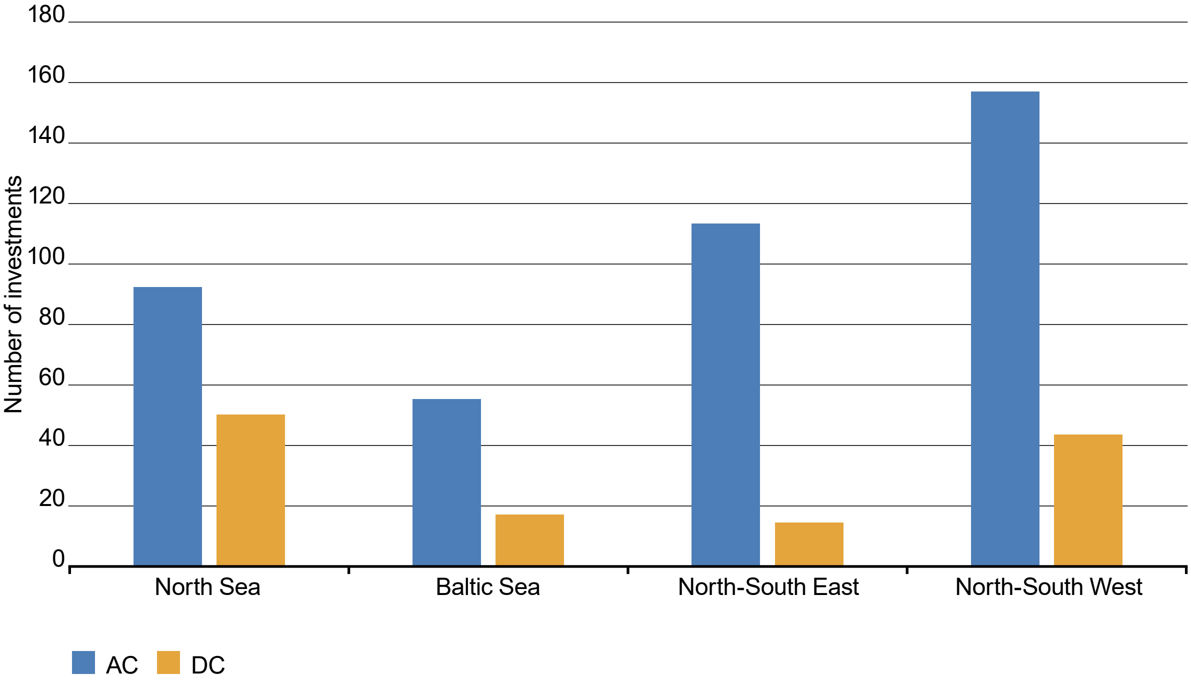
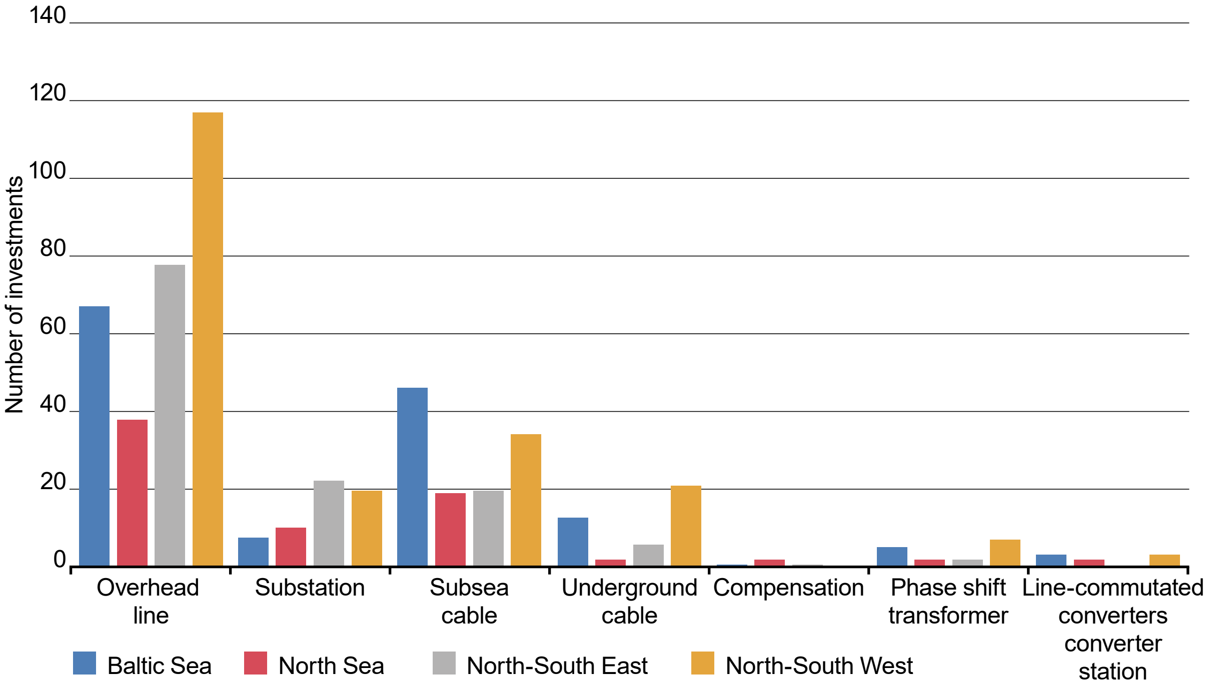


Figure 6.4: Investments by technology type



6.2

Complex implementation for complex projects

The TYNDP 2018 confirms the trend identified in the previous TYNDPs, for moderate progress: about 17% of TYNDP investments suffered delays in the past two years (compared with 25% in 2018).

All or most PCIs now in the authorisation process appear to meet the 3.5-year time frame set for obtaining all authorisations. However, the alignment of national procedures for cross-border projects may require further harmonisation, as some authorisations may fall outside of the 3.5 year time frame. Experience will show where inconsistency issues may require improvements in the future. It is also important to note that PCI best practices could be applied to national transmission projects which are crucial to achieving Europe's targets for climate change, renewable energy and market integration.

The Connecting Europe Facility, the European Investment Bank and specific funds are ready to support project promoters. Financing is becoming less of a structural issue, although it can remain critical for some projects.

One key element often generating delays and expensive redesigning of projects is their local acceptability. ENTSO-E believes that this question should become a central part of project design, in order to ensure that projects limit and compensate their environmental or other local impacts in coordination with local authorities and associations. Consumers would win on both sides, as local groups see the direct benefits of the new infrastructure for their communities, while development costs are kept down by avoiding costly delays eventually paid by the consumer.

Figure 6.5: Investments by evolution status

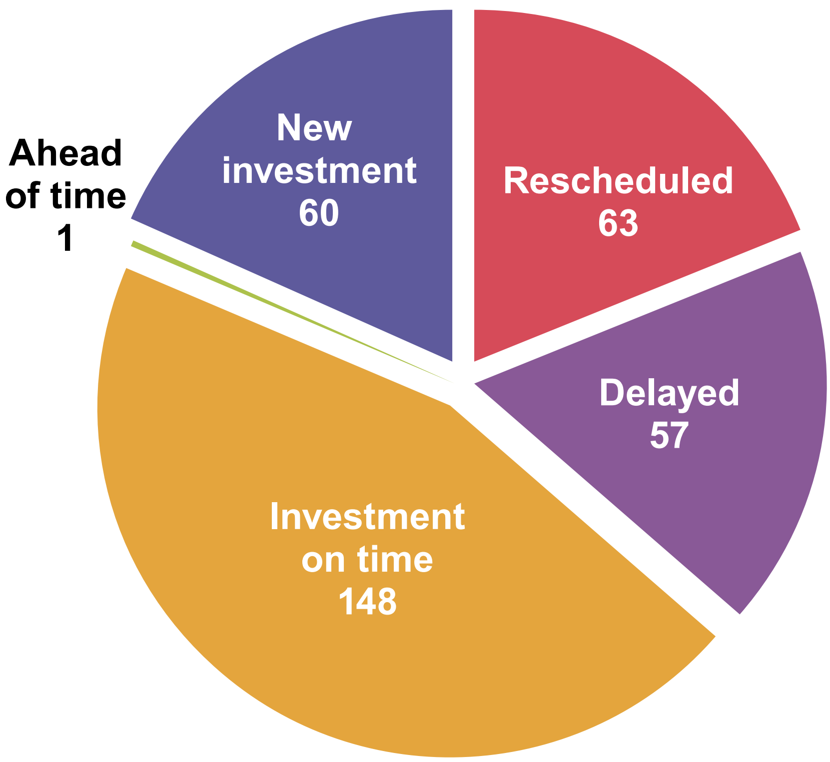
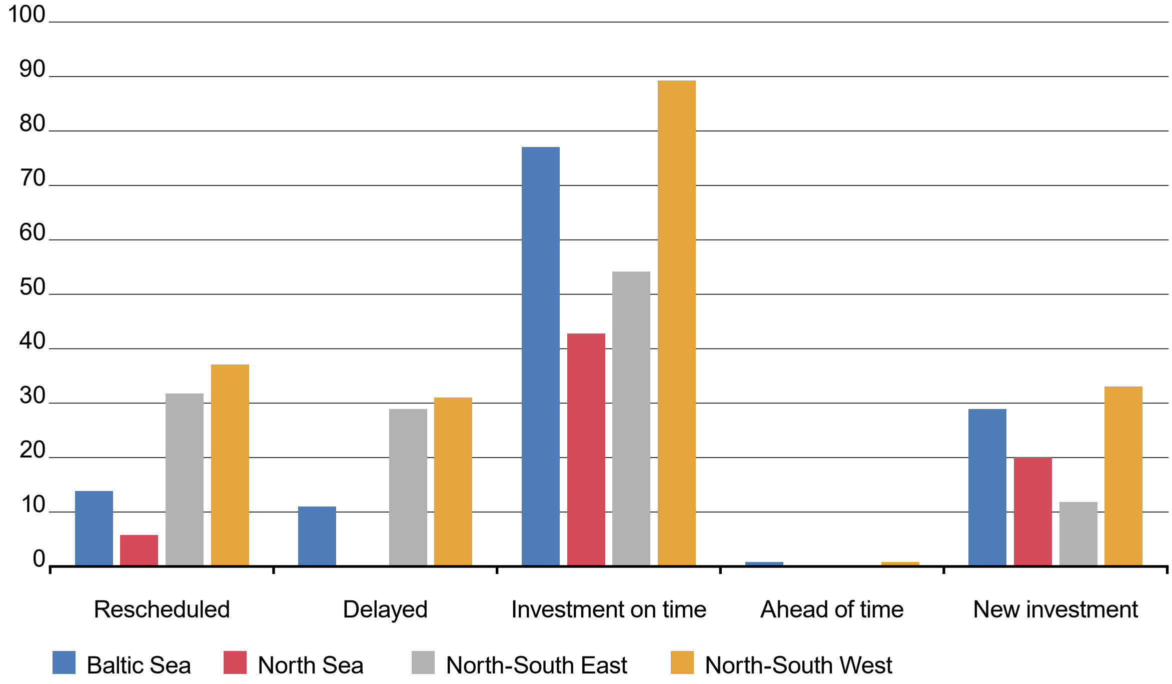


Figure 6.6: Evolution status per priority corridor



Key principles for decisions based on CBA results

The following principles guiding the identification of projects are a conclusion of the elements presented in this and the previous sections:

– The TYNDP describes several indicators, monetised and qualitative from a technical perspective at the European level for non-discriminatory comparison. The actual costs and benefits of projects are heavily dependent on local aspects, e.g. local acceptability, specific needs, acceptable alternatives, etc.
– The more mature a project becomes the better the CBA method supports the project promoter for assesment of the individual project.
– The analysis presents several indicators which provide tell decision-makers what projects to prioritise.
– The CBA offers a standardised method for assesment if a project's benefits calculated in the TYNDP outweigh the costs from a European perspective. Benefits which are not monetised (e.g. some aspects of security of supply) or even not captured by the CBA (e.g. system services) will come in addition to the economic benefits measured in the CBA, meaning that the project can bring down the system costs even more than shown.
– The TYNDP offers a spread of scenarios and analysis for assessing project viability; in order to manage the project risks, further sensitivity analysis are recommended.

The TYNDP CBA is conducted every two years and acts as a reliable basis to define a set of benefits of potential candidate projects for the PCI status (the process and selection is under the responsibility of the European Commission and uses the TYNDP as a reference). ENTSO-E is striving to improve the CBA methodologies for each consequent TYNDP process to align the assessment approaches with the realities and challenges of power system development at the ENTSO-E perimeter and worldwide.

Despite the best efforts of ENTSO-E, stakeholders and the European Commission's, the current CBA methodology does not capture all the benefits of the proposed projects.

For instance, further data and analysis would be necessary to evaluate the worth of the system services needs, which are developed in the previous section. Furthermore, the tools currently available to ENTSO-E (which are among the most advanced on the market) also create some structural limitations. For example, the infrastructure is tested in an energy-only, day-ahead, fully transcient market design (meaning that the system knows how much renewable energy will be produced any given day before it is produced). This does not correspond to the reality of the market design by 2030 and 2040 which, by definition, is unknown. The benefits of storage projects would also be better assessed with a higher time granularity of the models (15 minutes instead of 1 hour).

Value or benefits of projects?

TYNDP CBA results tend to decrease with each new edition of the TYNDP. In this edition, new scenarios with a higher share of new gas generation (which is modelled as having the same costs in all countries), and the penetration of zero marginal price generation (in particular wind) lead to smaller benefits on day-ahead market prices for interconnection or storage projects.

In an ideal system, where the entire load would be flexible, storage and interconnection contributing to maintaining the balance on an almost entirely renewable generation mix, the overall value exchanged on the system would be zero. The value for Europeans of each of the system components cannot be properly assessed in the current market design.

The more energy systems are optimised (in terms of market or network), the less benefit the energy market will bring to new interconnection capacity or other solutions.

Furthermore, not all CBA indicators can be monetised, and the CBA results can significantly evolve from one edition of the TYNDP to the next, and between scenarios.

However, this is due to a very large extent to the specificities of grid planning in very long time horizons rather than on the methodology followed. The future is uncertain. It is impossible to know for sure which countries will import or export, and how much electricity will cost to produce.

The future also evolves as the present unfolds. New uses, regulations or technologies lead to scenario changes with each edition of the TYNDP.

An eventual investment timeline for electricity infrastructure projects implies most of the investment will be made at the late stage of the project implementation process (up to 90% overall). Therefore, a coordinated planning process strives to avoid unnecessary investments at the early stage and points to the correct and sustainable development path.

Therefore, efficient energy-system development requires constant revision of the benefits of the electricity infrastructure. This allows for a streamlined approach on the way to an integrated and sustainable ENTSO-E power system.

What's new in the 2018 analysis approach?

New CBA methodology: An updated CBA guideline has been created and used for this TYNDP (2nd CBA). This has a direct impact on the CBA assessment of TYDNP 2018. Some indicators have changed, others have been redefined and the numbering of the indicators has also been changed.

Demand side: As for the scenario building, new approaches to better reflect the evolution of demand (electric vehicles, smart grids, demand response, heat pumps, temperature sensitivity) have an impact on CBA results. In particular, as one of the scenarios tested (Distributed Generation) focuses on the new active role of consumers.

Climate conditions: The TYNDP 2018 is the first to consider several climate conditions. Each project has been tested in our models for a full sample year (8760 hours!) using three different climate situations: a wet year, a dry year and a normal year.

Reference grid: The reference grid is used as a starting point in the TYNDP CBA. Market and network models simulation with projects either added to the reference grid, or removed from it, are compared to the reference grid situation. The selection of projects which compose the reference grid has a strong impact on overall CBA results (although for each specific project, being in or out of the reference grid leads to similar CBA results). When defining the reference grid, ENTSO-E seeks objective criteria which may point to the projects that have a strong chance of being implemented by the date of the scenarios considered (2025 or 2030). In TYNDP 2018, the projects in the reference grid were determined based on their maturity and restricted to only those either under construction or in the permitting phase of development.

Benefits not captured by the CBA: Although each edition of the TYNDP sees new approaches and more mature methodologies, the CBA methodology cannot capture all the benefits that interconnection or storage projects might deliver to the electricity system. Furthermore, several indicators are challenging to monetise (for instance, security of supply indicators). This is because the TYNDP CBA can only accept robust, proven, non-discriminatory methodologies. ENTSO-E teams have been conducting several experiments on new indicators or monetisation in parallel with the TYNDP delivery for possible implementation in future editions once the results are considered strong enough. Recognising this, ENTSO-E has permitted project promoters who would have suitably justified quantification of these benefits for their respective projects to be able to augment the project sheets with this information. ENTSO-E, in close collaboration with project promoters, the storage industry association EASE, the European Commission and ACER, has prepared a list of benefits not captured by the CBA and guidance on how project promoters may calculate them. N.B: the information on benefits not captured by CBA will be provided by project promoters during the consultation period and is therefore not currently available in this package.

6.3
How and why have CBA results evolved since the last TYNDP?

In the current TYNDP, the results are considerably changed compared to those published in the previous edition. These changes for the three main indicators (RES integration, socio-economic welfare, variation of CO_2 emissions) showed a decline in project benefits. For some regions, such changes may account for up to 80-90% compared to the results shown previously.

The main drivers for such substantial changes may be summarised as follows:
- Change in the generation portfolio with the switch to gas technologies which are characterised by low differences in generation costs;
- Use of multiple climate conditions in the assessment, ensuring more robust but lower assessment results;
- Decreased variable wind generation due to more optimised RES allocation, causing fewer price differences between the neighbouring markets;
- Increasing transmission capabilities in the reference grid between certain market areas as a consequence of the maturing of transmission projects at these borders, resulting in decreasing SEW indicators for projects crossing related boundaries;
- Change in CO_2 prices driving dispatch at the ENTSO-E perimeter;
- To ensure adequacy standards are met, new flexible thermal generation has been assumed in the TYNDP 2018 scenarios. This generation is not necessarily economically viable in an energy-only market. The implications of this are, on the one hand, that benefits of additional grid capacity may be underestimated in the TYNDP 2018 analysis, and, on the other hand, it raises concerns about the present market´s ability to incentivise sufficient generation capacity to ensure adequacy. This issue will be further investigated in coming TYNDPs.

It is important to acknowledge that the current ENTSO-E CBA process focuses on the simulation of an ideal energy market without taking into account the costs of balancing ancillary services and capacity markets and network constraints in depth. Hence, a considerable number of possible benefits are not monetised to date although they may become very impactful in the distant future.

In general, the TYNDP 2018 CBA results showed fewer benefits within the TYNDP perimeter. In terms of socio-economic welfare and RES integration criteria indicators, the overall trend is indicated at the level of 30-40% below zero compared to TYNDP 2016 results.

Information on projects and their assesments in the TYNDP package

Appendices:

TYNDP project sheets
The TYNDP 2018 project sheets provide data and/or analysis on projects which have been included in the TYNDP 2018 package. There project sheets can be viewed on an online platform with the option to print.

Cost Benefit Analysis Methodology 2.0
The TYNDP used a new version of the methodology developed with the input of stakeholders, and reviewed following the opinion of ACER and the European Commission. The version followed by ENTSO-E is published on the TYNDP website. ENTSO-E understands the European Commission may soon adopt the methodology.

Data-sets
Complete data-sets about the projects will be made available for download. Sample modelling results will also be made available, and further data are available on request.

Detailed methodologies
The complete CBA methodology (implementation guidance document) is available on the TYNDP website. This helps to make the TYNDP calculations replicable, although any advanced user will understand the sensitivity of precise results to the data used and approaches in building the models.

Section 7

The TYNDP 2020 is already on the way

The development of the TYNDP is a living and constantly developing process with the ongoing aim of better preparing Europe for an uncertain and complex electricity future.

In 2015, an international benchmark showed that the European TYNDP is globally unique in terms of the number of TSOs collaborating, the total number of customers served, the methodologies applied to tackle long-term challenges, and both the transparency of data and the processes used.

For example, scenario storylines will have to answer the questions which remain open about future power system operation and profitability issues. To date, only some of these open questions have been answered, and most in an overly simplified manner. Therefore, market modelling will need to continue to evolve to respond to rising concerns about the SoS and/ or increasing DSR.

The scope of TYNDP 2020 has already been discussed and partly outlined. It will be discussed in the Network Development Stakeholders Group and is also being discussed through public workshops on the scenarios, recognising that:

- the two ENTSOs joined forces in 2016 for a combined process (scenario building, milestones) to deliver their respective TYNDP 2018 from a harmonised gas/electricity perspective. As a part of this, an interlinked gas and electricity model is being developed;
- the TYNDP focus on identifying longer-run pan-European relevance system needs (beyond 10-15 years);
- the TYNDP 2020 will feed the PCI selection process by supplying CBA of projects on the PCI list,
- for the TYNDP 2020, the interlinked scenario-building process has already started. In order to maximise output and resource utilisation, the ENTSOs recommend exploring new 2040 scenarios and corresponding investment needs. The plan is to compile and submit for consultation the 'Scenario development report' in the first half of 2019;
- the 2040 analyses (identification of system needs) will basically rely on pan-European market studies (to derive target capacities, but also indicators of system inertia, ramps, adequacy issues, etc.). These will be supplemented by regional analysis (for each need, its evolution from only a 10-year to further horizons, and possible reinforcement concepts). The plan was to compile and consult the "identification of system needs" package in the pan-European report and Regional Investment Plans reports by the end of 2019;
- the CBA process was updated in 2018 to support the TYNDP process. Following consultation, it was submitted to ACER and EC later for validation and implementation for the TYNDP 2018. Similarly, a process has commenced to review this 2018 version for the TYNDP 2020 process;
- subject to the dedicated EC guidelines, ENTSO-E proposes to organise two windows for project promoters to ask for TYNDP assessment, one in Q3 2019 (based on which the reference grid will be set up), and one in late 2019.

8
Glossary

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CO_2	Carbon Dioxide
CWE	Continental West Europe
DC	Direct Current
DG	Distributed Generation
DSR	Demand-side Response
EC	European Commission
ENTSO-E	European Network of Transmission System Owners for Electricity
ENTSOG	European Network of Transmission System Owners for Gas
EU	European Union
EUCO	European Commission Scenario
HVDC	High Voltage Direct Current
ITEG	Interconnection Target Expert Group
LCC	Line Commutated Convertor
MWh	Mega-Watt Hour
NGO	Non-Governmental Organisation
OPEX	Operational Expenditure
PCI	Project of Common Interest
RES	Renewable Energy Sources
SEW	Socio-economic Welfare
SoS	Security of Supply
ST	Sustainable Transition
TSO	Transmission System Operator
TWh	Terawatt hour
TYNDP	Ten Year Network Development Plan

Consultation assesment

This document is part of the second public version of the TYNDP 2018 package. It was prepared based on recommendations received by stakeholders during the public consultation held from August to September 2018. This version was submitted to the opinion of the EU Agency for the Cooperation of Energy Regulators (ACER). Only after the ACER opinion has been received will ENTSO-E publish a final version of the TYNDP 2018 package.

We would like to thank the various organisations which took time to give us feedback. Producing the TYNDP is complex and challenging, and it is often only possible to find ways to improve it, stay relevant and in touch with sector evolutions by looking at it through external eyes.

Twenty-seven organisations sent us comments in this consultation. Each of the comments received has been answered individually in a separate document by ENTSO-E. From these answers, the majority suggested changes in future editions rather than in this one. This was also the case during previous TYNDPs. We have created a dedicated team tasked with keeping these recommendations and raising them at the right moment in the development process.

Several of the comments received could be addressed directly in this edition of the TYNDP.

In particular, ENTSO-E is releasing for the first time a new extensive document entitled “CBA implementation methodology”. This document provides detailed explanations on how the CBA was followed by ENTSOE experts. We are also making changes to our website, and have corrected several parts of the reports following your suggestions.

In parallel to the consultation, we have also continued to work on improving the TYNDP project portfolio. We completed the information which was not available in August for all projects. We also made some corrections where we identified mistakes.

Finally, we have made five new additions to the list of projects. It was reported to us that several storage projects which have been granted PCI status in 2017 were not candidates for TYNDP 2018. While we are still investigating why these projects did not receive the information or react to it, and correcting future project selection guidelines accordingly, we felt it was important, in close collaboration with ACER and the European Commission, to give these projects an opportunity to retain their status in the next PCI list planned for 2019. As a result, five storage projects have been added to this version of the TYNDP 2018.

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