TYNDP 2024

Opportunities for a more efficient European power system by 2050

Infrastructure Gaps Report

Version for public consultation | 31 January 2025

entsoe
ELECTRIFYING EUROPE

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The **40 member TSOs**, representing 36 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to using its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility**.

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its **legally mandated tasks**, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, Network Codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (**Ten-Year Network Development Plans, TYNDPs**);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

Opportunities for a more efficient European power system by 2050

Infrastructure Gaps Report

Version for public consultation | 31 January 2025

How to use this interactive document

To help you find the information you need quickly and easily we have made this an interactive document.

Home button

This will take you to the contents page.
You can click on the titles to navigate to a chapter.

Arrows

Click on the arrows to move backwards or forwards a page.

Interactive data visualisation tool

https://www.entsoe.eu/outlooks/tyndp/2024/#SystemNeeds

ENTSO-E Technopedia

www.entsoe.eu/Technopedia

Hyperlinks

Hyperlinks are highlighted in bold text and underlined throughout the report.
You can click on them to access further information.

Questions?

Contact us as at **tyndp@entsoe.eu**

Contents

Executive Summary

The Ten-Year Network Development Plan (TYNDP) 2024 is a biennial European electricity infrastructure development plan. It aims to provide a European-wide vision of the future power system, focusing on how cross-border power transmission and storage can facilitate the energy transition in a cost-effective, secure, and environmentally sound manner.

The legal framework behind the TYNDP is set by Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure ('TEN-E Regulation'). The TYNDP aligns with the European Green Deal and the EU's ambitious climate targets, including carbon neutrality by 2050 and a 55 % reduction in greenhouse gas emissions by 2030.

2030 Targets and System Needs

With the generation mix and electricity grid expected in 2030 the EU meets its energy transition targets for CO_2 and RES. However, with further investments in its electricity system Europe could reduce its system costs while accelerating its energy transition. By 2030, an additional 88 GW of cross-border capacity and 56 GW of storage capacity would minimise the cost of Europe's power system, reducing system costs by 8 billion euros with an investment of 5 billion euros. These investments create a net economic gain of 3 billion euros, reduce CO_2 emissions by 19 million tons/year, and decrease RES curtailment by 30 TWh/year.

2040 Opportunities

By 2040, each euro invested in the electricity grid translates into over 2 euros saved in system costs. The study highlights the need for 108 GW of additional cross-border capacity, including 20 GW of offshore hybrid corridors, to minimise total system costs. In the EU, addressing these needs will reduce RES curtailment by 114 TWh/year, CO_2 emissions by 18 Mton and generation of electricity by gas power plants by 48 TWh. Reaching the level of cross-border exchanges that result from the capacity increases identified in the study will create new needs for reinforcement of internal networks in the European national grids.

Investing in electricity infrastructure creates jobs and benefits Europe's economy. By 2040 the TYNDP 2024 project portfolio, worth 288 billion euros in the EU, is expected to generate 4.1 million jobs, mobilise 603 billion euros in production, and increase the EU GDP by 247 billion euros. Public administration revenues through taxes could reach 111 billion euros, benefiting European society.

2050 vision

The report introduces for the first time an analysis of system needs for 2050, emphasising the importance of investing in grid and storage infrastructure to achieve a CO_2-neutral energy system. An additional 224 GW of cross-border grid capacity and 540 GW of storage capacity are economically-efficient by 2050, representing an investment of 13 billion euros per year, which will save 23 billion euros annually in system costs. The total investment in electricity infrastructure in 2050, also considering offshore hybrid and radial connection infrastructure, amounts to 863 billion euros over 25 years.

Infrastructure Gaps, Challenges and Solutions

- **Existing transmission projects address only part of the cross-border needs in 2040.** There are significant opportunities for new solutions across Europe, particularly in regions with high needs for cross-border capacity increases. The TYNDP 2024 project portfolio includes 178 transmission and 33 storage projects, located all over Europe and with neighbouring countries. Transmissions projects expected after 2030 represent a total of 78 GW of additional cross-border capacity increase by 2040.
- Measures to improve **energy efficiency should be the first step**, with targets to reduce energy demand and measures to increase grid capacity by improving the performance of existing system assets. However, the increase in electrification levels that is necessary for the decarbonisation of the energy system cannot be achieved by simply optimising current infrastructure. Investments in new infrastructure will be necessary to support the transition to a carbon-neutral energy system.

- There is a need to take action to secure **resilient and efficient supply chains** to meet the rising demand for grid technologies. TSOs have significant investments in the pipeline by 2030. Current manufacturing capacities in Europe are insufficient, leading to delays and reliance on non-EU suppliers and significant increase on investment costs. There is also a critical shortage of skilled labor, particularly in advanced technical roles required for the construction, maintenance, and management of grid infrastructure.
- Another significant challenge is the **lengthy and complex permitting processes** for new infrastructure projects. These delays can slow down the implementation of critical projects necessary for the energy transition. Securing adequate financing for large-scale infrastructure projects is also a challenge.
- This TYNDP notably demonstrates that **the challenges cited above apply not only to interconnections but also to national electricity grids**. The energy mix development by 2040 by itself creates significant needs for building and renewing national infrastructure to a great extent. The system needs originating from the integration of the pan-European internal electricity market and those from the national RES integration target mutually impact each other. On the one hand, optimising the socio-economics welfare of the European energy system via the development of cross-border exchange capacity puts an additional strain for national networks, and on the other hand national transmission system reinforcements to accommodate RES integration impacts cross-border flows and capacities. Therefore, the results of this TYNDP should be read in conjunction with those of National Development Plans in order to ensure the sound development of electricity infrastructure.
- Finally, the transition to a decarbonised energy system will require managing the decrease in **system inertia** due to the replacement of synchronous generators with inverter-based resources. Investments in synchronous condensers, energy storage with grid-forming capability, and other technologies will be necessary to maintain system stability.

Next Steps

The TYNDP 2024 package is open for public consultation until 14 March 2025. The report will be submitted to ACER, the European Commission and EU Member States for opinion. After reception of all opinions ENTSO-E will finalise and publish the report. In March 2025 ENTSO-E will release Regional Investment Plans which will deep dive into the findings of the system needs study at regional and national level.

TODAY	2030 Starting point of the study	2040	2050

Europe's cross-border grid needs reinforcing to yield all benefits of the energy transition and minimise costs (in the ENTSO-E area)

TODAY	2030	2040	2050
126 GW available cross-border electricity transmission capacity	**161 GW** expected cross-border capacity		
	+88 GW of additional cross-border capacity would minimise system cost	**+108 GW** (additional to expected capacity in 2030) would minimise system costs	**+224 GW** (additional to expected capacity in 2030) would minimise system costs
24 GW of storage capacity	**56 GW** of storage capacity*	**227 GW** of storage capacity*	**540 GW** of storage capacity*
	Investment of **5 Billion euro/year**	Investment of **6 Billion euro/year**	Investment of **13 Billion euro/year**

* Values for storage capacity include battery storage capacity in the scenario

Infrastructure projects in the pipeline today do not cover all the needs

based on TYNDP 2024 projects portfolio

2030: **35 GW** of projects in construction or in advanced stage, expected to commission by 2030

2040–2050: **+80 GW** of cross-border transmission capacity increase, based on projects expected after 2030 in National Development Plans or under consideration stage.

- Gap/opportunity for infrastructure or other solutions to provide 28 GW out of the 108 GW of cross-border transmission capacity required to minimise system costs.

Why Europe should invest in its electricity infrastructure

comparing with a hypothetical future where Europe would stop investing in its cross-border electricity grid after 2030

2030	2040	2050
8 Bn euro/year reduction in system costs ▸ Net saving of **3 Bn euro/year**	**13 Bn euro/year** reduction in system costs ▸ Net saving of **7 Bn euro/year**	**23 Bn euro/year** reduction in system costs ▸ Net saving of **10 Bn euro/year**
30 TWh/year avoided curtailment of RES energy in the EU	**114 TWh/year** avoided curtailment of RES energy in the EU	**122 TWh/year** avoided curtailment of RES energy in the EU
19 Mton/year avoided CO_2 emissions in the EU	**18 Mton/year** avoided CO_2 emissions in the EU	**15 Mton/year** avoided CO_2 emissions in the EU

By 2040, the projects in the TYNDP portfolio would benefit the EU by:

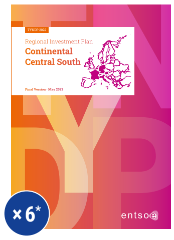
- Creating **4.1 Million** extra jobs
- Increasing its GDP by **247 Bn euro**
- Increasing tax revenues by **111 Bn euro**

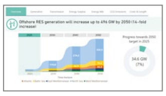
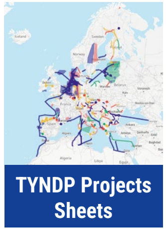
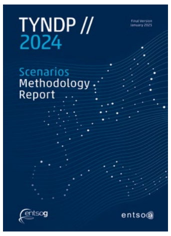
Content of the TYNDP 2024 package

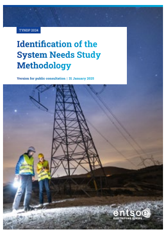
<table>
<tr><th></th><th>Scenarios</th><th>Assessment of future system needs</th><th>Assessment of individual projects (Cost-Benefit Analysis)</th></tr>
<tr><td>Studies results

* To be published in Q2 2025</td><td>

</td><td>




</td><td>
</td></tr>
<tr><td>FOR EXPERTS</td><td></td><td></td><td></td></tr>
<tr><td>Methodologies</td><td>
</td><td>


</td><td>
</td></tr>
<tr><td>Input data</td><td colspan="3">All datasets needed to replicate the study are publicly available
› Datasets of scenarios National Trends 2030, National Trends 2040 and Distributed Energy 2050 (Scenarios Download page)
› Starting grid 2030
› List of investment candidates and cost assumptions for the system needs study, including candidates from ONDP corridors
› Network dataset: will be made available in aggregated form upon request on this page.
› TYNDP 2024 project portfolio and Cost-benefit analysis results</td></tr>
</table>

1 Introduction: About the TYNDP

Structure of this report

After a first introductory chapter on the TYNDP and its methodologies, this report presents the results of the study in 2030 (Chapter 2), 2040 (Chapter 3) and 2050 (Chapter 4). Chapter 5 investigates gaps in infrastructure planning, by comparing the study's results on infrastructure needs with the infrastructure projects being developed by TSOs and other promoters. Chapter 6 provides a consistency check by comparing the results with those obtained in TYNDP 2022. Chapter 7 is dedicated to maintaining system inertia in the Continental Europe Synchronous Area in the future. Chapter 8 concludes by looking at the next steps, for TYNDP 2024 and for future TYNDP 2026..

About the terminology used in this report

This report refers to system needs and to projects, which must be distinguished.

- System needs/opportunities/optimised grid: refer to the findings of the system needs study. System needs are increases in cross-border transmission or storage capacity that would make the overall European power system more efficient from an economic perspective. Needs can be addressed by different solutions, including infrastructure and non-infrastructure based solutions.
- Projects/projects portfolio: Correspond to concrete infrastructure projects (transmission or storage) that are being developed or considered today by TSOs or other project promoters.

An essential step in Europe's long-term electricity infrastructure planning

ENTSO-E's 10-year network development plan (TYNDP) is the biennial European electricity infrastructure development plan. It complements, supports and links national grid development plans (NDP) prepared by every TSO. The TYNDP provides a European-wide vision of the future power system and investigates how power transmission lines, storage and new technologies can be used to make the energy transition happen in a cost-effective, secure and environmentally-sound way. The TYNDP has been released every two years since 2010. The legal framework behind the TYNDP is set by Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure ('TEN-E Regulation').

Why does Europe need a plan for electricity infrastructure?

Europe has embarked on an unprecedented societal transformation journey with its Green Deal objective to reach carbon neutrality by 2050. The European Climate law sets an ambitious path towards decarbonisation with an intermediate target of reducing net greenhouse gas emissions by at least 55 % by 2030, compared to 1990 levels. The Fit for 55 Package and REPowerEU Plan will fast-forward the energy transition to carbon neutrality at a much greater scale with the increase of renewable energy and energy efficiency targets for 2030. The rapid replacement of fossil-fuel generation by renewable energy sources (RES) including the replacement of the Russian gas supply after February 2022, the greater electrification of other sectors, increasing energy efficiency, the increasing development of new technologies (storages systems, electrical vehicles, …) and interlinking the various energy sectors (Hydrogen technology, P2X, …) will be key.

Europe will only reach its decarbonisation objective and the successful deployment and integration of increasing volumes of variable renewables if:

- the costs of transforming the system are kept lower than the benefits from doing so, by an appropriate set of investments enabling better market integration and leading to competitive power prices, and
- the continuous secure access to electricity is guaranteed to all Europeans.

Achieving this requires a coordinated, pan-European approach to electricity system planning, connecting borders, sectors and regions and including new technologies. The TYNDP is essential to the timely and effective development of transmission infrastructure to realise the long-term European policy goals and aspirations while keeping the electricity transmission system secure and efficient. This is also recognised in the EU Grid Action Plan[1] of November 2023, which aims to help Europe deliver the European Green Deal with measures focused on accelerating the roll-out of the electricity grid. Investments in electricity infrastructure is also a pillar for EU competitiveness and decarbonisation, according to the Draghi report of September 2024[2].

Projects included in the TYNDP may apply to obtain the status of European Projects of Common Interest or, if they involve a country which is not an EU member, of Projects of Mutual Interest.

1) Grids, the missing link – An EU Action Plan for Grids
2) The future of European competitiveness

TYNDP development process

The development of the TYNDP follows the following three steps, spread over approximately 3 years and partially overlapping:

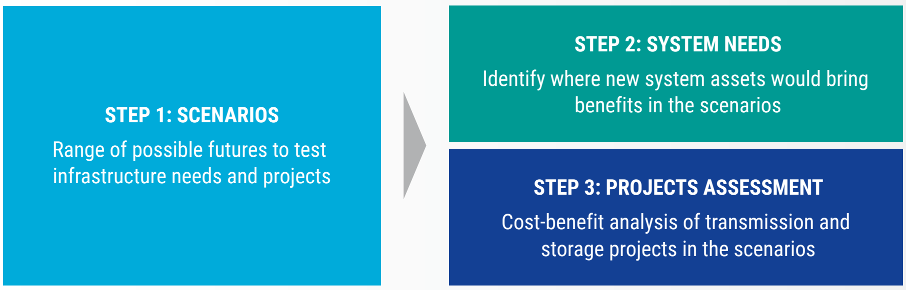


Figure 1.1 – The three main steps in the TYNDP process

STEP 1 – Developing scenarios: At the heart of the TYNDP lays the elaboration and definition of scenarios indicating how the European power system might look in the future. ENTSO-E and its gas counterpart ENTSO-G have developed scenarios looking as far as 2050 together with engagement of a wide range 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 where, from an economic viewpoint, the network infrastructure is working well, and where it needs to be reinforced and further developed. The main role of the TYNDP is therefore to identify where future investments in the electricity system can help to reach the EU climate and energy goals. This process is organised in the next two steps.

STEP 2 – Identifying system needs: Investigating where increasing cross-border electricity exchange or storage would bring economic benefits in the future energy scenarios and identifying infrastructure gaps. This step also includes the identification of offshore corridors to meet EU Member States targets of offshore RES development. The two main deliverables of this step are the Infrastructure Gaps Report and the Offshore Network Development Plans per sea basin[3].

STEP 3 – Performing an individual assessment of the performance of every project considered in the TYNDP 2024 under the different scenarios. TYNDP 2024 assessed 178 transmission projects and 33 storage projects. The outcome of this step is presented in an online platform which includes interactive data visualisation and Project Sheets summing up the key information and CBA results of each project assessed[4].

3) **TYNDP 2024 Offshore Network Development Plans**, published in January 2024
4) **TYNDP 2024 project sheets**

The identification of system needs and the cost-benefit analysis of projects complete each other to help policymakers identify the most relevant projects at a given time. The System Needs study considers the European electrical system in its entirety, from a global point of view, while the cost-benefit analysis of projects evaluates each project individually by assessing its specific impact on the overall system.

TYNDP 2024				
	Scenarios	**Assessment of system needs**		**Cost-benefit analysis of projects**
		Offshore Network Development Plans	**System needs study/ Infrastructure gaps**	
Driving question	What would the European Energy System look like in different possible futures, defined by different storylines, at horizons 2030, 2040 and 2050?	What does it take to integrate between 360 GW and 496 GW of offshore RES in 2040 and 2050?	Where could the onshore and offshore power system be more economically efficient?	How does this infrastructure project impact the European energy system?
Approach	The investment model can invest in generation, network infrastructure, demand-side response, flexibility measures etc. All-in-one optimisation.	The investment model is only allowed to invest in offshore infrastructure, starting from candidate links without a specified transmission capacity. All other parameters remained locked in this first edition 2024.	The investment model can invest in transmission (single-purpose interconnector or hybrid) and storage based on a list of candidates defined by fixed capacity and cost values. The outcome is a coordinated onshore – offshore needs assessment.	We assess a series of indicators including the gain in the overall system operational costs associated with every evaluated project, as well as its impact on RES integration, CO_2 and other emissions, electricity losses, security of electricity supply….

Identifying solutions to address system needs is up to project promoters, who may propose their projects for assessment in the next cycle of the TYNDP.

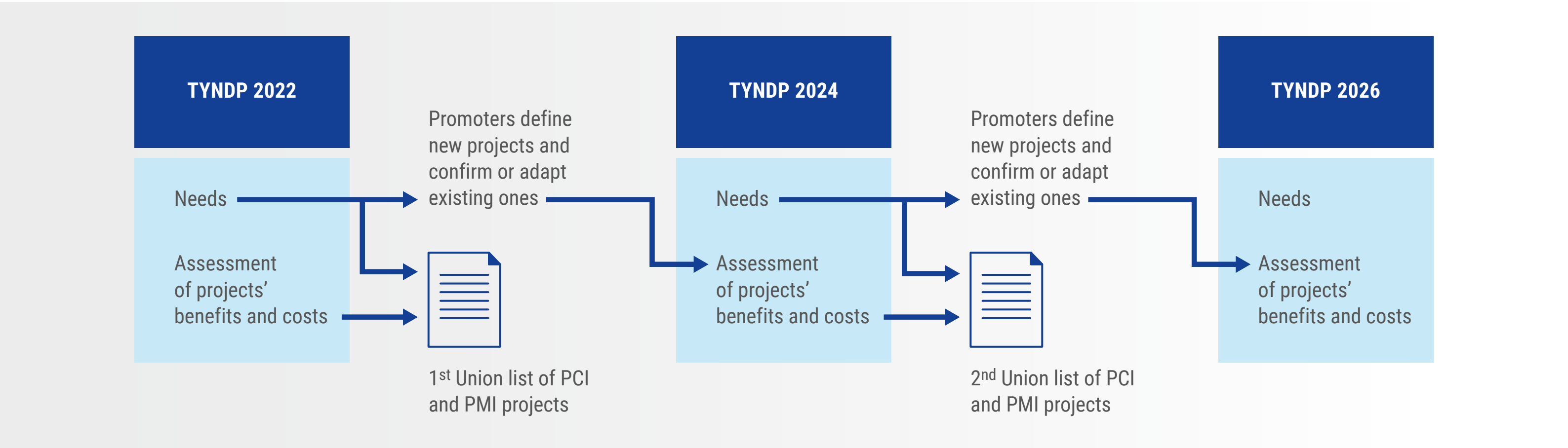


Figure 1.2 – Interrelation between system needs studies, project portfolios and project assessments in successive TYNDPs

Stakeholders play a key role in shaping the TYNDP

Stakeholders get involved in the TYNDP from the start of the process until its finalisation, via public consultations, stakeholder events and, for scenarios, via the scenarios Stakeholder Reference Group. The development of TYNDP 2024 included 6 public consultations and 12 workshops or webinars. Annex 1 provides a high-level overview of stakeholder engagement activities and how they contributed to shape the TYNDP.

Aside from the TYNDP 2024 process, stakeholders have been heavily involved throughout 2022 and 2023 in the development of the Cost-Benefit Analysis methodology (CBA 4.0) applied to perform the CBA of projects. The feedback received so far from stakeholders played an important role in ensuring the draft TYNDP 2024 released for consultation meets stakeholders expectations.

The entire TYNDP 2024 package is submitted to public consultation from 31 January to 14 March 2025. Stakeholder webinars and/or workshops will be organised to explain in more detail the various parts of the package and gather further stakeholder feedback. Stakeholders wishing to engage further with ENTSO-E are welcome to contact us at tyndp@entsoe.eu.

Overview of the TYNDP methodologies and assumptions

System needs study methodology

To analyse system needs by 2030, 2040 and 2050 we determined the combination of potential increases of network capacity between countries and of storage that minimises the total system costs, composed of total network investment (including costs of related necessary internal reinforcements) and generation costs, and maximises the overall socio-economic welfare. To do that, a set of possible capacity increases were proposed to an optimiser, which identified the most cost-efficient combination. To take into account the mutual influence of capacity increases, the optimisation was performed simultaneously for all price-areas and all countries in a single optimisation process at the pan-European scale.

KEY DOCUMENT

TYNDP 2024 Identification of system needs Implementation Guideline

The study was performed on a NTC model for the 2030 horizon, and on a zonal model for the 2040 horizon thus providing a finer description of the grid at the main time horizon of the study. For these two horizons, the study was performed on the National Trends scenario, which reflects National Energy and Climate Plans and other long-term national strategies, in 2030 and 2040. For the study of the 2050 horizon, a simplified zonal model and the Distributed Energy scenario were used (there is no National Trends 2050 scenario because EU Member States do not have detailed plans for that time horizon), to capture the very long-term system needs. The time horizons 2030 and 2040 are assessed independently from each other. The 2050 time horizon is assessed while considering already the results obtained for 2030.

The area covered by the study includes [all 36 European countries members of ENTSO-E](), as well as United Kingdom, Moldova, Georgia, Malta and Med-TSO countries bordering the Mediterranean Sea (Morocco, Algeria, Tunisia, Libya, Egypt, Palestine, Israel and Turkey). Results and benefits presented in this report are provided for the entire area covered by the study and/or for the EU. Results for all countries studied are available on the **online data platform**. The gain in socio-economic welfare and related investment costs are only available for the entire area covered by the study and cannot be split per country.

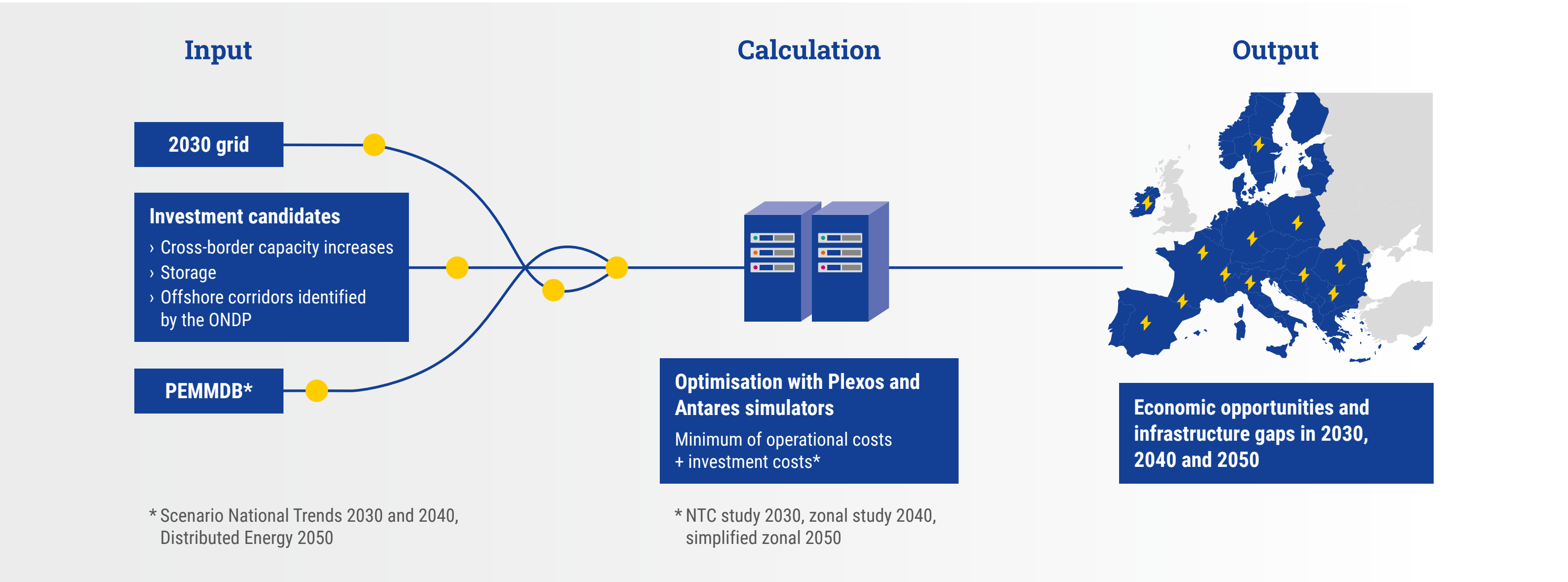


Figure 1.3 – Overview of the system needs identification methodology

New in TYNDP 2024: Integration of the findings of the ONDP 2024

KEY DOCUMENT
ONDP 2024 Methodology

The **Offshore Network Development Plans (ONDP)** released as part of TYNDP 2024 in January 2024 deliver information on the infrastructure needed to connect offshore renewable generation and the potential additional expansion of the hybrid transmission infrastructure between aggregated offshore generation nodes.

The results of the ONDP, in the form of offshore corridors, were considered in the system needs study as additional investment candidates proposed to the optimisation process. This allows the study to identify where hybrid offshore infrastructure, which serves a dual purpose of connecting RES generation and interconnecting two countries, is part of the overall most economically efficient solution for the whole of Europe.

The starting point of the study: the European power system in 2030

The starting point of the study performed is the 2030 National Trends scenario (2030 NT), which also includes storage flexibilities. Based on the 2030 NT starting point, all horizons are assessed to identify opportunities and gaps in terms of needs in increasing cross-border capacities, offshore corridors and storage flexibility.

The electricity cross-border transmission grid expected in 2030 sums up to a total of 161 GW[5] of cross-border transmission capacity. This grid, visible in Figure 1.4, includes the infrastructure available in 2025 plus all projects currently under construction or in advanced stages and that are expected to be commissioned until 2030. These projects are considered the most mature according to the identification criteria set in the 4th CBA Guidelines, because their timely commissioning by 2030 is reasonably certain and correspond to our best view of the evolution of the European transmission grid in the coming five years. In consequence they are not questioned in the study and along with the existing grid serve as the starting grid for the analysis. They represent 35 GW of cross-border transmission capacity additional to the 126 GW already available in 2025. These projects include both cross-border projects and internal projects with a cross-border impact.

For storage flexibilities the starting point is 2030 National Trends scenario capacities for battery storage (46 GW).

5) Including borders within the ENTSO-E area and between ENTSO-E TSOs and neighbouring TSOs not member of ENTSO-E

Cross-border grid in 2030

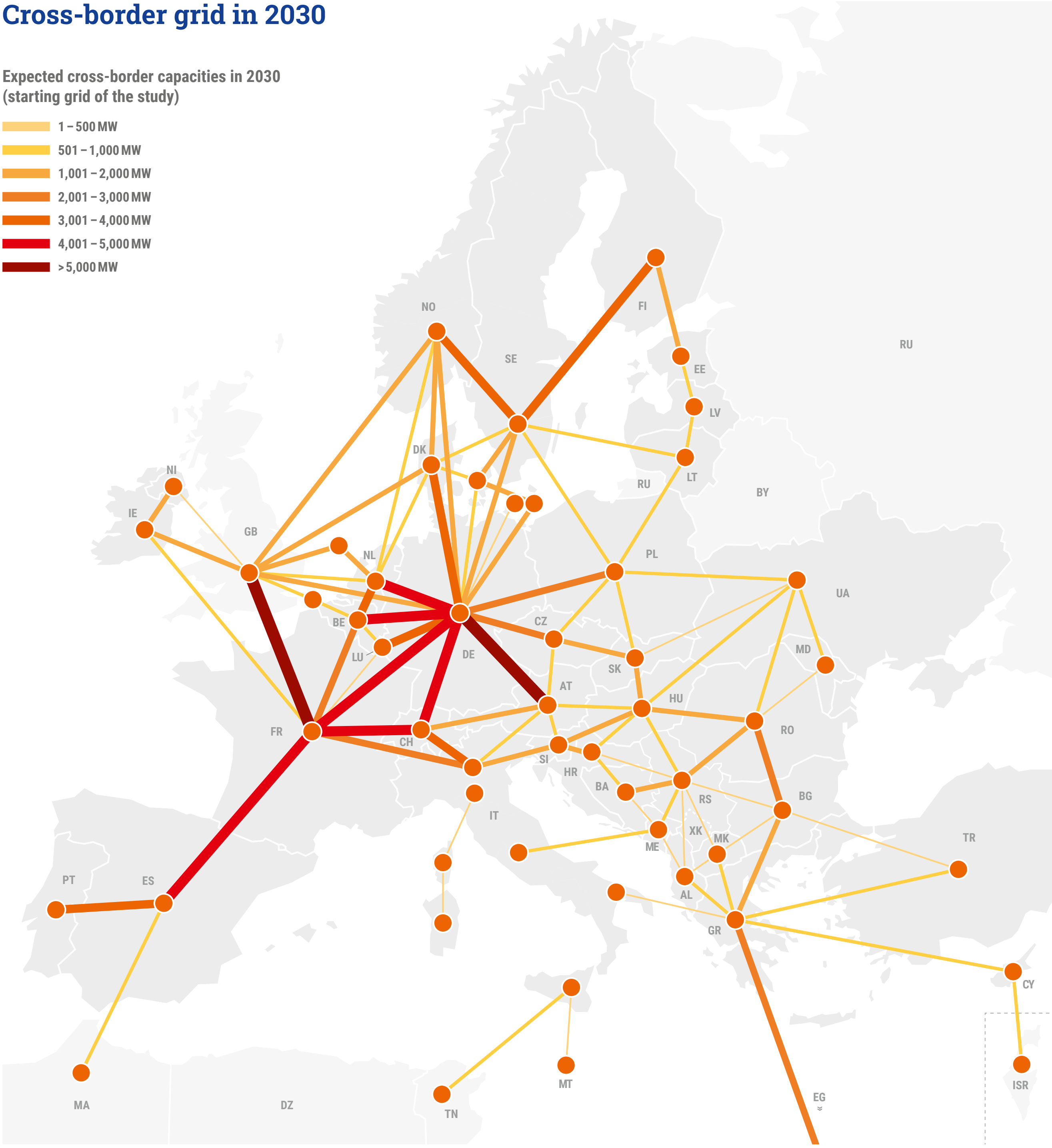


Figure 1.4 – The expected grid in 2030, starting point of the system needs study, representing ENTSO-E's estimate of available cross-border transmission capacities in 2030. Needs identified in 2030, 2040 and 2050 are additional to the 2030 capacities.

Overview of the Cost-Benefit Analysis methodology

KEY DOCUMENTS

[CBA methodology 4.0](#)

[TYNDP 2024 CBA Implementation Guidelines](#)

To ensure a full assessment of all benefits of the project candidates, ENTSO-E applies a multi-criteria approach to describe the indicators associated with each project. To the extent possible the indicators are monetised, where this is not possible for justified reasons, indicators are quantified in their typical physical units (i.e. tons or GWh). The set of common indicators forms a complete and solid basis for project assessment across Europe, both within the scope of the TYNDP as well as for project portfolio development in the PCI and PMI selection process.

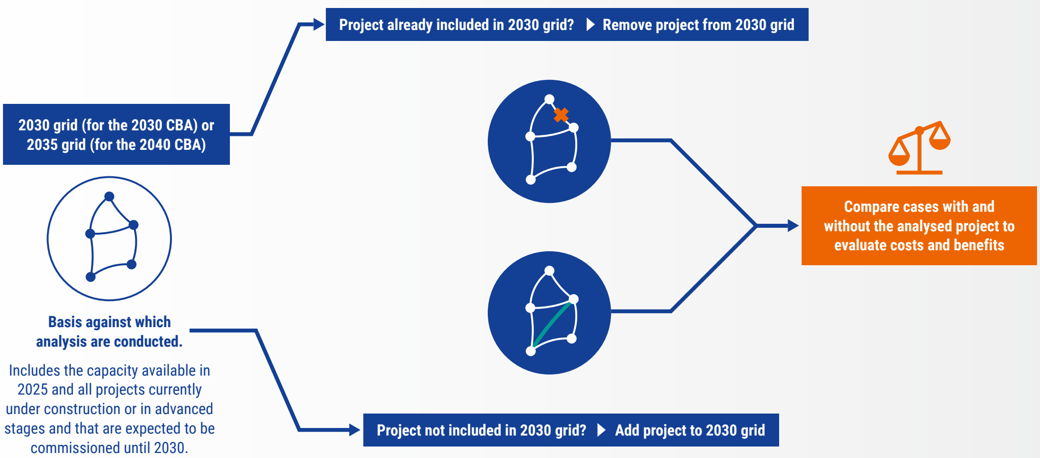


Figure 1.5 – General principle of the cost-benefit analysis

ENTSO-E is constantly working on improving the methodologies, data etc. for the assessment of projects within the TYNDP project assessment. In TYNDP 2024, for the calibration of the scenarios a new Security of Supply loop was introduced, to ensure realistic adequacy levels for all countries in the reference grid. The inclusion of hydrogen generation in the market database, also an improvement compared to TYNDP 2022, enables to capture and assess the cross-sectorial coupling impacts. Furthermore, the generalisation of the socio-economic welfare (SEW) by formulation of the global SEW to include the interlinkage between the electricity and the gas sectors enhances the robustness of the results.

All datasets needed to replicate the study are publicly available

- Datasets of scenarios National Trends 2030, National Trends 2040 and Distributed Energy 2050 (Scenarios Download page)
- Starting grid 2030
- List of investment candidates and cost assumptions for the system needs study, including candidates from ONDP corridors
- Network dataset: will be made available in aggregated form upon request on this page.
- TYNDP 2024 project portfolio and Cost-benefit analysis results

2 With further investment in its electricity grid and storage infrastructure, Europe could reduce its system costs while going beyond its 2030 targets

The electricity cross-border transmission grid expected in 2030 represents a total of 161 GW[6)] of cross-border transmission capacity. This grid, visible in Figure 1.4, includes the infrastructure available in 2025 plus all projects currently under construction or in advanced stages and that are expected to be commissioned until 2030. These projects represent 35 GW of cross-border transmission capacity additional to the 126 GW already available in 2025. The expected total amount of storage in 2030 is 66 GW.

The system needs study for 2030 considers a scenario where EU Member States implement the objectives set in their National Energy and Climate Plans. Because the compilation of all national plans falls short of meeting EU targets for 2030, our scenario bridges the gap to make sure that targets are reached.

With this scenario and this electricity grid in 2030, the EU meets its CO_2 emissions reduction target and the share of RES in the primary energy supply mix reaches 40 % by 2030. System costs in the whole area studied are expected to reach about 95 billion euros by year 2030, accounting for the significant evolution of the production mix, of the overall European demand and of the forecasted grid. However, with further investments in its electricity system, Europe could reduce its system costs while accelerating its energy transition. By increasing the level of interconnection within Europe to facilitate the connection of more consumers with more producers, a more efficient energy system is created from a socio-economic perspective. European countries can exchange more electricity to be able to replace expensive generation (gas and coal) with cheaper one (mainly renewable). The overall efficiency of the energy system and Europe's competitiveness are enhanced.

Indeed, optimised investments in an additional 88 GW of complementary cross-border capacity and 56 GW of storage capacity (including 47 GW of battery storage capacity in scenario NT2030 and 9 GW of storage capacity increase), would be cost-efficient to reinforce Europe's power system in 2030. These capacity increases would reduce the overall system costs from 95 billion euros to 87 billion euros, therefore saving 8 billion euros per year, with investments costs of 5 billion euros per year.

6) In the ENTSO-E area and with neighbouring TSOs not member of ENTSO-E

Increasing exchange and storage capacity in Europe helps the integration of renewable energy by enabling an increased deployment of RES generation. Without network reinforcements, in some countries a part of the RES generation would have to be curtailed due to grid constraints. In 2030, the amount of curtailed RES could reach up to 30 TWh/year in the EU, equivalent to Ireland's net electricity production in 2023[7]. By taking advantage of the different energy mix over Europe, of the various European electricity consumption profiles and the different RES peaking period between countries, a reinforced energy system infrastructure reduces significantly the curtailed RES energy. The optimised increase of the cross-border capacities across Europe would lead to reduction by nearly half the RES energy curtailment, with an avoided curtailment in 2030 of 30 TWh/year in the EU.

By allowing a better integration of CO_2-free generation, an optimised energy system would similarly lead to a reduction of CO_2 emissions of 19 Mtons. This highlights the important role of the network in the path towards carbon neutrality by 2050.

Our study finds that cross-border capacity reinforcements are beneficial on half of European borders, especially on German borders and on Swedish borders[8]. There are also high needs to integrate the Iberic peninsula and on borders between Continental Europe and the UK (Figure 2.1). To enable these cross-border capacity increases, strong reinforcement of national internal grids will be necessary, and the costs of these internal reinforcements are considered in the assumptions of our study. Regarding storage, it could be reinforced in Italy, the Netherlands and Spain (Figure 2.2).

7) Source: Eurostat

8) It is important to note that several evolutions have taken place since the building of TYNDP 2024 scenarios and other input data, for example the decision of the Swedish government to cancel numerous offshore RES development in the Baltic sea. In addition, modelling choices, in particular the modelisation of electrolysers as electric load only introduced in this TYNDP cycle, have had important impacts on the needs identified in Nordic countries including on the borders between Finland, Sweden, Norway and Denmark. Modelling will be further improved in next editions of the TYNDP.

2030 System Needs

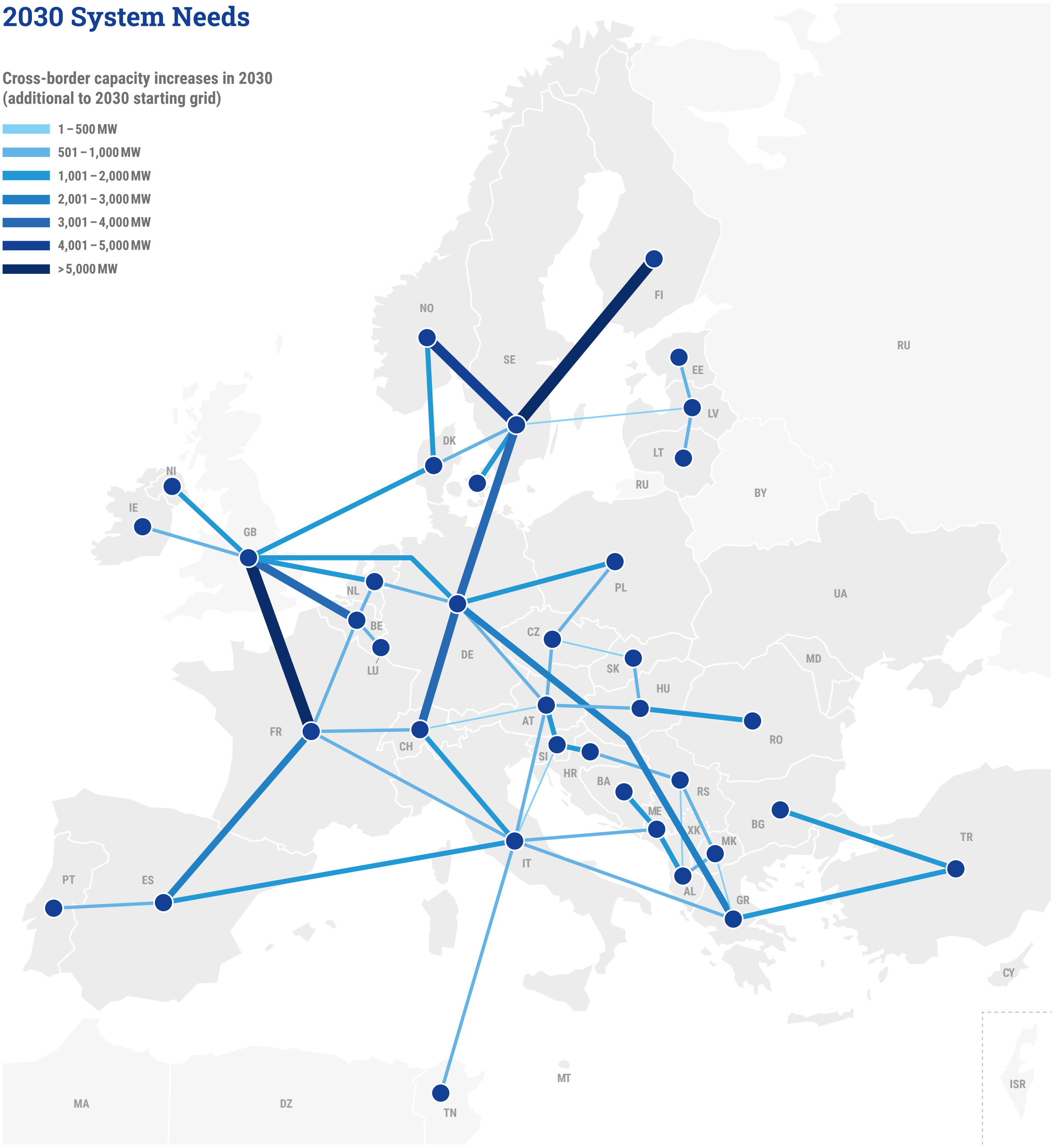


Figure 2.1 – Identified cross-border capacity increases needs of 88 GW in 2030, additional to the expected cross-border grid in 2030

2030 System Needs

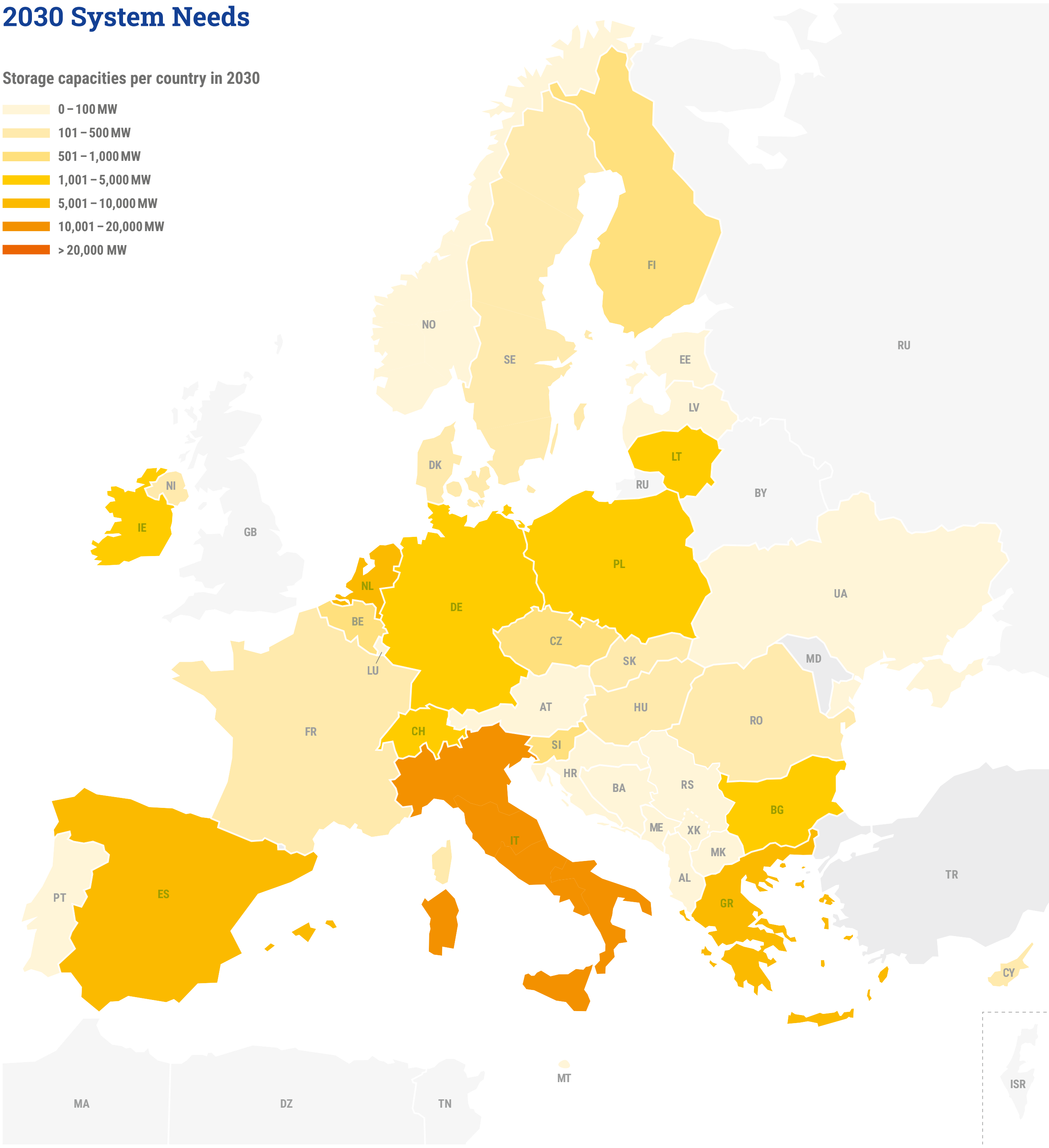


Figure 2.2 – Identified storage needs in 2030 (NT2030 capacities + identified needs)

The System Needs study results show capacities that are very high on some borders, especially France-Great Britain, and the borders of Sweden with Finland and Norway. These values are higher than realistic expectations of what is implementable considering the capacities of internal networks. In addition, the 2030 horizon is too close to today for completely new infrastructure projects to materialise by then, although non infrastructure-based solutions could also address part of the needs (more on that in Chapter 5).

Cross-border interconnector capacity increases expected by 2035

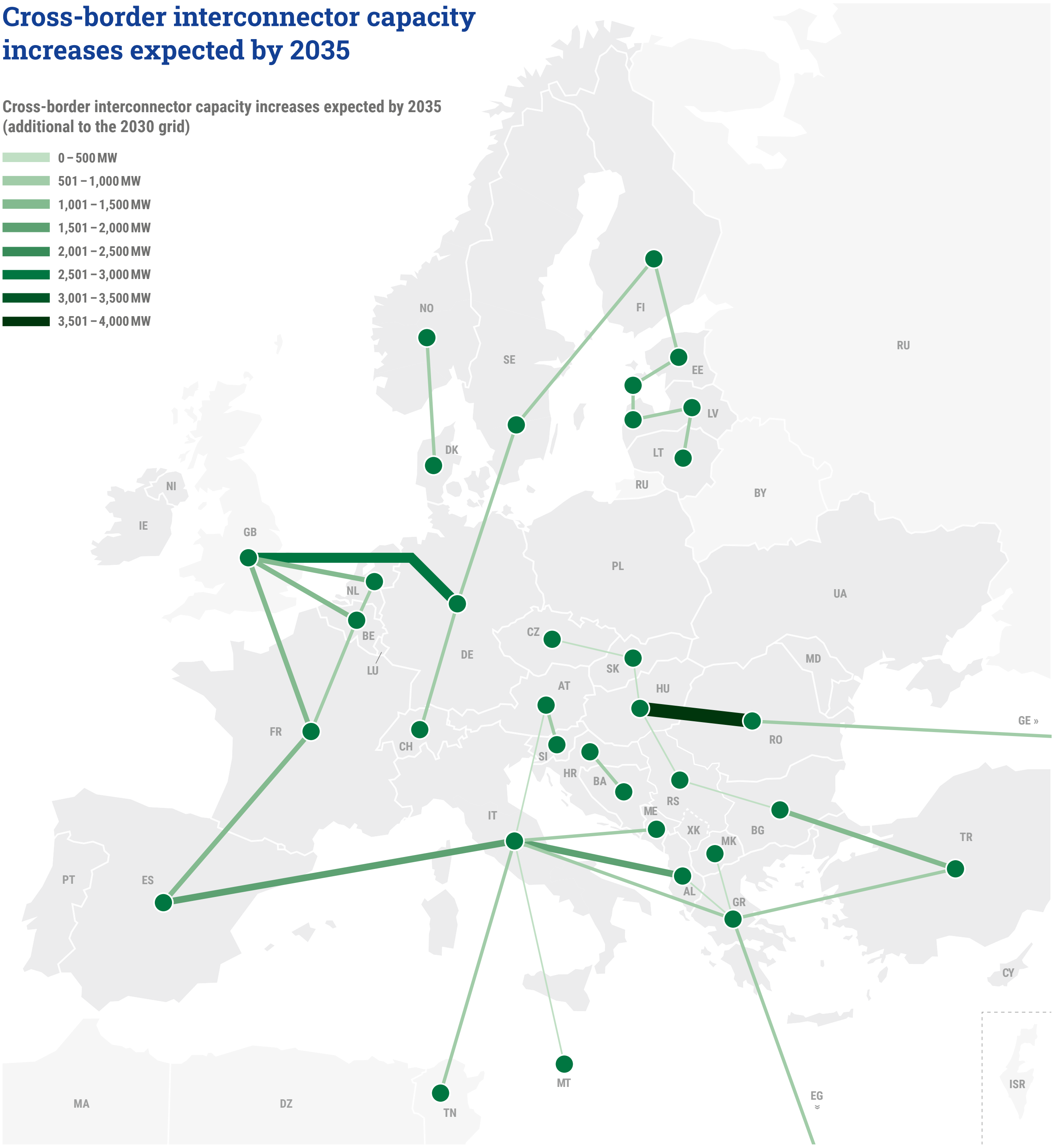


Figure 2.3 – Cross-border capacity increases foreseen by projects in the TYNDP portfolio between 2030 and 2035

To provide an order of comparison between the optimal grid and realistic expectations, transmission projects already in the TYNDP portfolio and that are expected to commission between 2030 and 2035 represent 47 GW of additional cross-border capacity (see Figure 2.3). The optimal system in 2030 is not fully implementable considering the short timespan. However, our study shows that it is urgent to take action. Looking at the 2040 horizon, there is a real opportunity for Europe to optimise its energy system by investing now in reinforcing its energy infrastructure.

Interconnection targets confirm high needs for interconnection development in 2030

In 2017, the European Commission Expert Group on Interconnection Targets (ITEG)[9] proposed that the European Commission complement the existing 15 % interconnection target for every country and electrified island with a new methodology, developed collaboratively between the European Commission, ENTSO-E, ENTSOG, representatives of the industry, universities and other experts. The methodology is based on the TYNDP cost-benefit analysis methodology and is based on three concepts that aim at providing an indication of the urgency of increasing interconnections.

- an efficient internal energy market should translate into competitive electricity prices throughout the EU. Member States should aim at achieving a 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.
- 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 RES integration 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 RES installed, Member States should investigate options for additional interconnectors.

Figure 2.5 shows the results of the ITEG methodology applied for the National Trends scenarios for the 2030 horizon, taking into account the 2030 grid (starting point of the system needs study, visible in Figure 1.4). The computation of these indicators is based on a number of assumptions, including:

- the nominal cross-border capacity used to compute the indicators 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 TYNDP. Therefore, they are not necessarily fully exhaustive.

Large price differentials (> 2 € / MWh) appear for many European borders, which highlights the need for additional interconnection development. The security of supply and RES integration criteria show additional needs for interconnection development in most of Western and Northern Europe as well as in Italy and Poland, with the most urgent need in Ireland, Norway, Finland, Germany, Italy and Spain.

9) https://energy.ec.europa.eu/topics/infrastructure/electricity-interconnection-targets_en

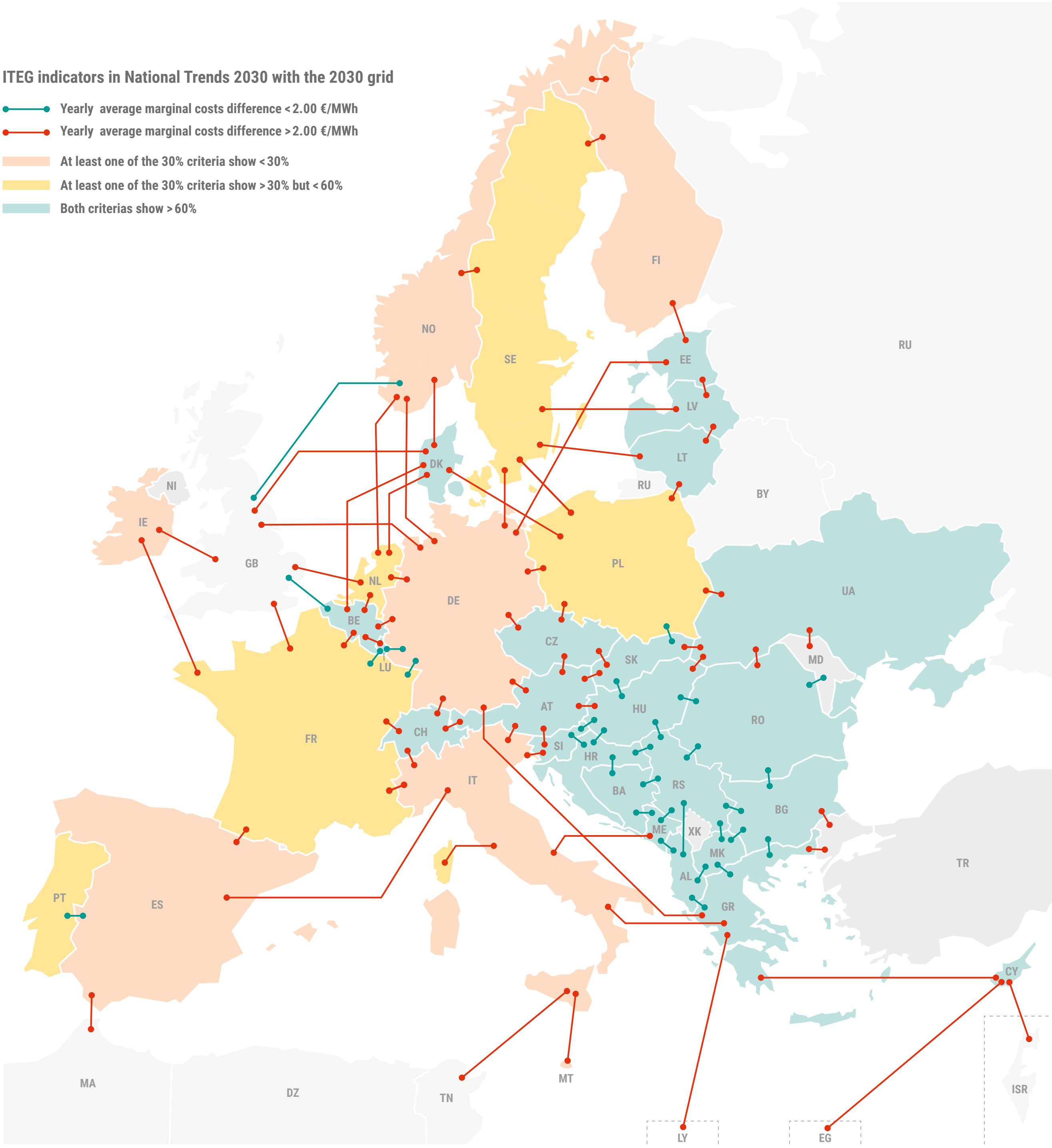


Figure 2.4 – ITEG indicators in National Trends 2030, considering the 2030 grid (starting point of the system needs study)

3 By 2040, each euro invested in the electricity grid translates into over 2 euros saved in system costs

By 2040, 108 GW of cross-border capacity increases additional to the 2030 grid (Figure 1.4), including 20 GW of offshore hybrid corridors, would minimise the total costs of Europe's electricity system. Like in 2030, further investments in grid infrastructure and in electricity storage allow connecting more consumers with more producers, and therefore making better use of the cheapest generation. Addressing the identified needs represent an investment of 6 billion euro/year between 2025 and 2040, for a yearly increase in socio-economic welfare of 13 billion euro/year until 2040.

In 2040, like in 2030, needs appear on most European borders. The highest needs for cross-border capacity increases remain on Swedish borders[10)] with Finland and Norway, on UK borders with the continent and to integrate the Iberian Peninsula (see Figure 3.1).

The TYNDP 2024 system needs study presented in this report complements the findings of ENTSO-E's Offshore Network Development Plan (ONDP) of January 2024. By optimising the whole electricity grid, including the onshore cross-border network, offshore interconnections and the offshore hybrid corridors identified by the ONDP, the system needs study identifies where hybrid offshore infrastructure, which serves a dual purpose of connecting RES generation and interconnecting two countries, is part of the overall most economically efficient solution for Europe. Results largely confirm the findings of the ONDP, which found 25 GW of cross-border capacity increase between 2025 and 2040 via offshore hybrid projects. The system needs study results identify offshore hybrid needs in the North Sea, between Norway, Denmark-West, Germany, the Netherlands, the UK and Belgium. Another hybrid offshore corridor is identified between Ireland, the UK and France, and in the Baltic Sea between Germany and Sweden.

The System Needs study did not identify additional needs for storage in 2040, however identified needs are additional to the development of flexibility assets in the scenario considered. New challenges brought by the evolution of generation portfolios are already partially covered within the National Trends scenarios (based on National Energy and Climate Plans) by an increase of assets that provide flexibility to the system. Indeed, from 2025 to 2040 battery capacity in the ENTSO-E area increases to reach 227 GW according to NECPs.

10) It is important to note that several evolutions have taken place since the building of TYNDP 2024 scenarios and other input data, for example the decision of the Swedish government to cancel numerous offshore RES development in the Baltic sea. In addition, modeling choices, in particular the modelisation of electrolysers as electric load only introduced in this TYNDP cycle, have had important impacts on the needs identified in Nordic countries including on the borders between Finland, Sweden, Norway and Denmark. Modeling will be further improved in next editions of the TYNDP.

2040 System Needs

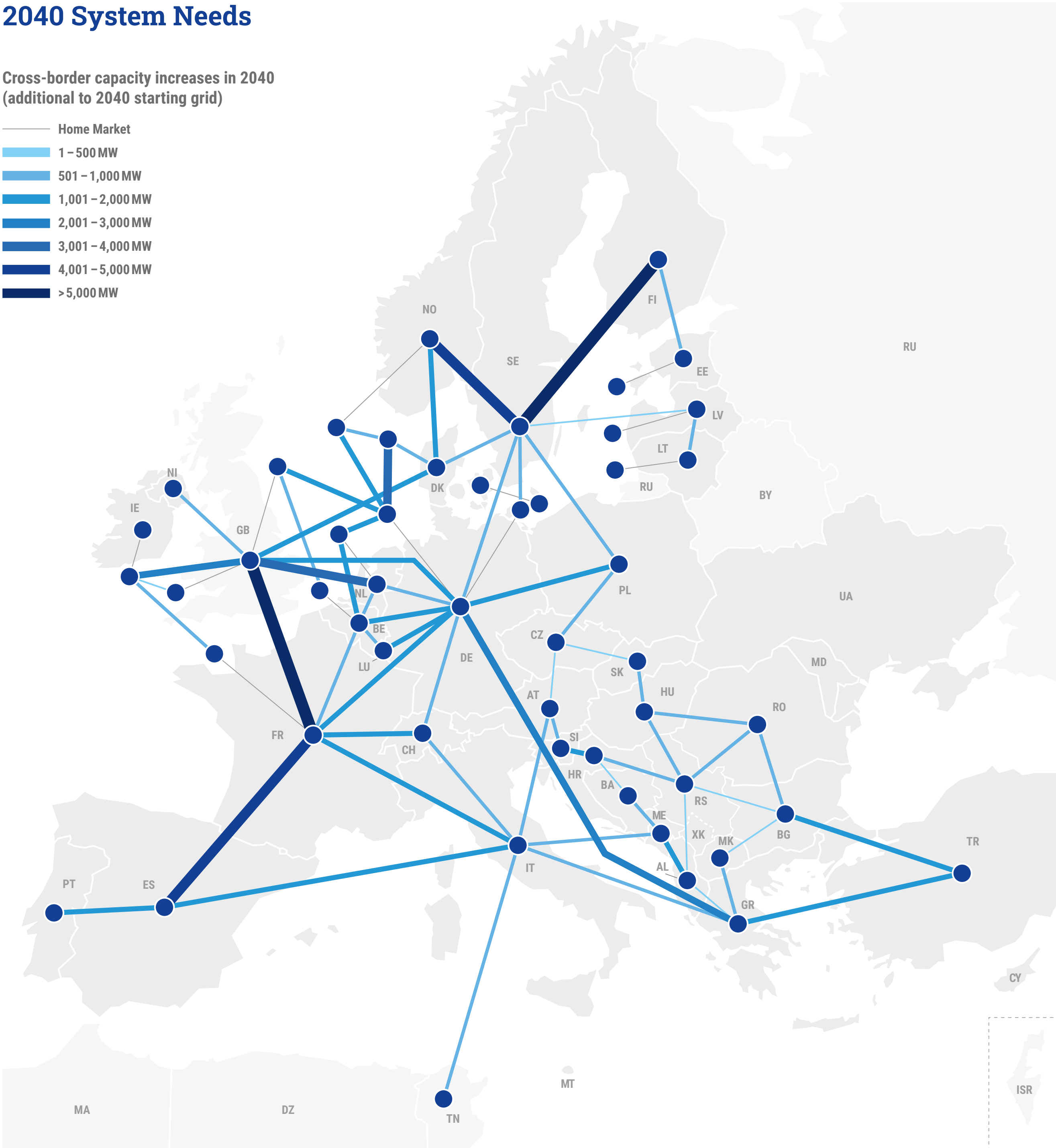


Figure 3.1 – Opportunities for increases in cross-border capacity and hybrid offshore corridors in 2040, additional to the 2030 grid for cross-border transmission.

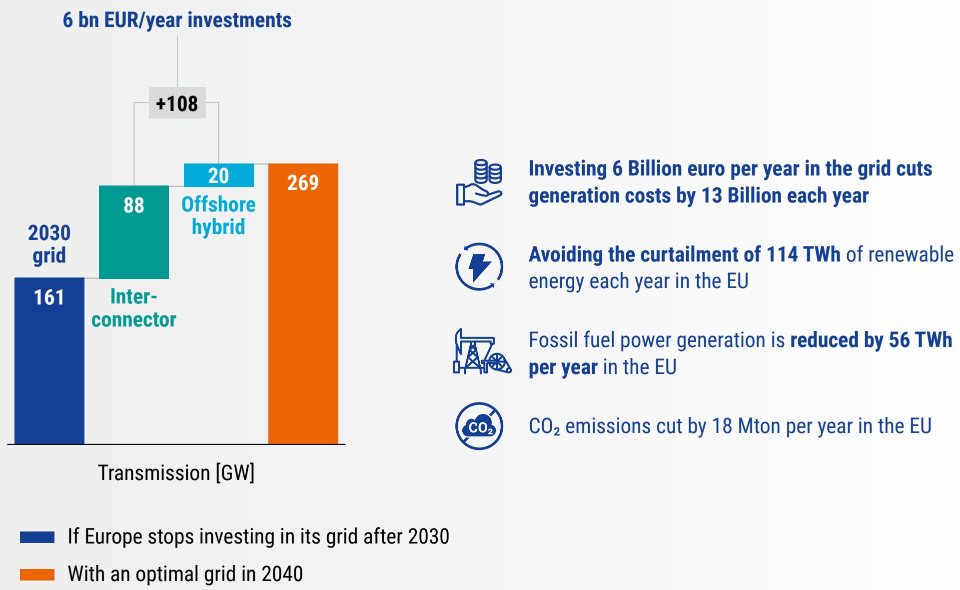


Figure 3.2 – Needs in 2040 and expected benefits.

2040 System Needs

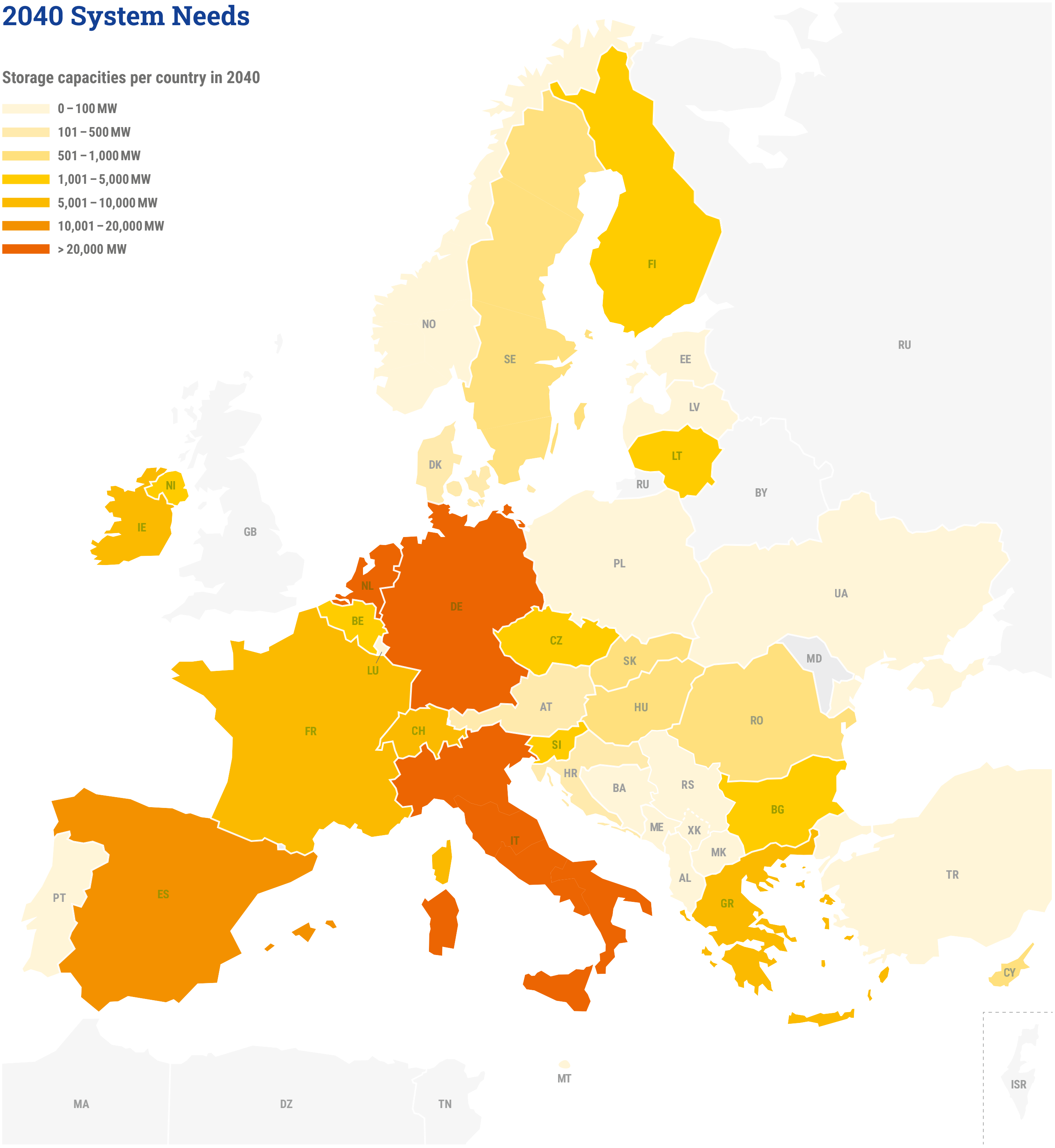


Figure 3.3 – Storage capacities in the scenario National Trends 2040. The study did not identify storage needs additional to these capacities.

Addressing 2040 opportunities cuts RES energy surplus and CO_2 emissions, increases electricity exchanges and price convergence between countries

As mentioned previously, the increase of interconnection capacities between European countries is essential to optimise further the European electricity system from a socio-economic perspective. A huge increase of installed RES capacity is required by 2040 to meet the European CO_2 emission targets. Without an adequate and appropriate transmission system to transport the RES generation across Europe, a significant part of it would have to be curtailed. By taking advantage of the different energy mix over Europe, of the European electricity consumption profiles and the different RES peaking periods between countries, the optimal grid identified in the study decreases drastically the curtailed energy, by 114 TWh in 2040 in the EU. As visible in Figure 3.4, most of the RES curtailment reduction is located in Germany and in Spain, where the RES generation surpluses are very high by the year 2040. Besides, the influence of grid development on RES integration is even more important because, without grid reinforcements, RES promoters would not build their units in the first place knowing they will not be able to sell their generation to foreign markets. This demonstrates the economic interest of adapting the grid development to support the European energy transition.

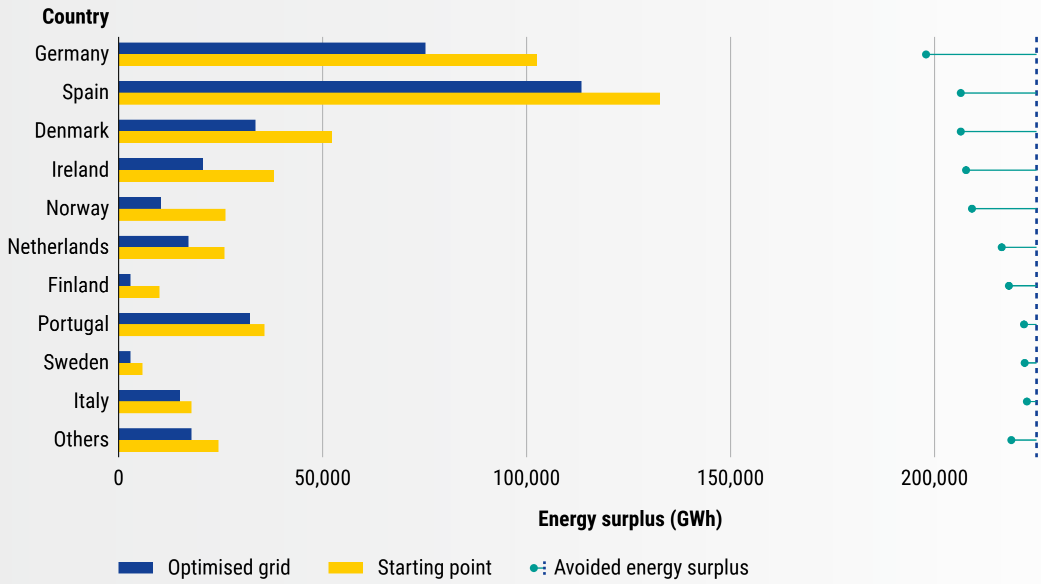


Figure 3.4 – RES energy surplus in 2040 in two grid configurations: with the optimised grid 2040 (Optimised grid), and in a hypothetical future where Europe would stop all investments in its cross-border grid after 2030 (Starting point). On the right-hand side, avoided energy surplus in 2040 when addressing system needs (difference between the two grid configurations). Figure includes only ENTSO-E area.

Additionally, by allowing the effective use of this large amount of renewable electricity, the optimal interconnection portfolio identified in the present study contributes to the displacement of more expensive and fossil electricity sources. The additional 108 GW cross-border capacities by 2040 allow to substitute 48 TWh of electricity produced by gas by RES generation in the EU. On top of that, the increased RES integration will allow European countries to produce more green hydrogen through power-to-gas, approximately 57 TWh each year in the EU (Figure 3.5 and 3.6).

As visible in Figure 3.7, by allowing a better integration of non-CO_2 emitting generation, an optimised system leads to a significant reduction of European CO_2 emissions. Finally, the better use of the European generation mix translates into an important decrease in generation costs (Figure 3.8). On the opposite, limiting exchange capacity alters market integration and would result in splits between regional market prices. Fragmented markets lead to higher marginal costs in some countries, with direct impact on consumers' electricity bills.

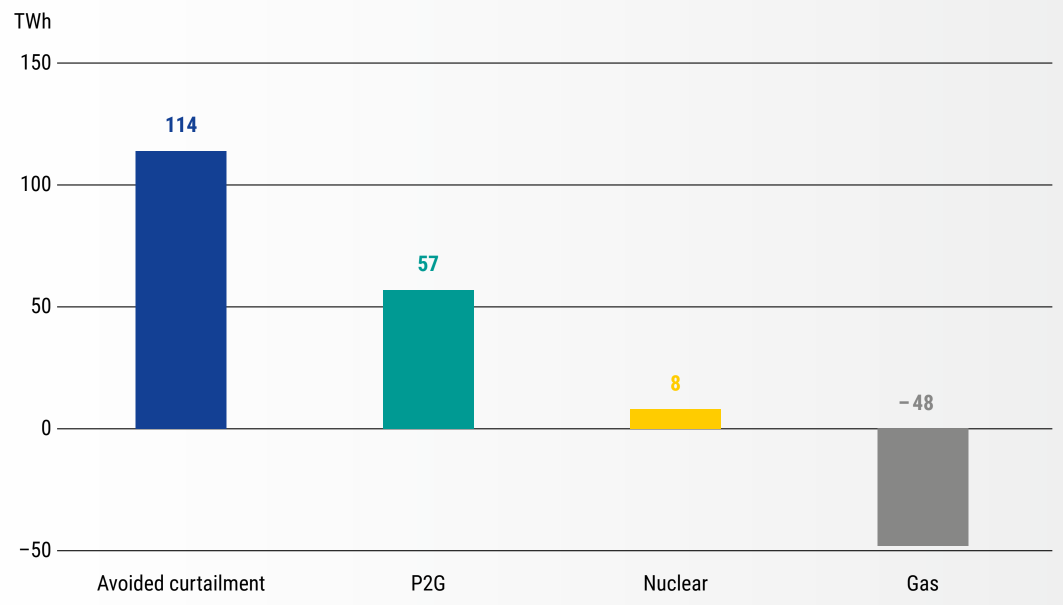


Figure 3.5 – Impact on the generation mix of addressing system needs, in the EU (TWh) (Difference between the case when needs are addressed and a hypothetical future where no investment would be made in the cross-border grid after 2030). P2G value refers to the load.

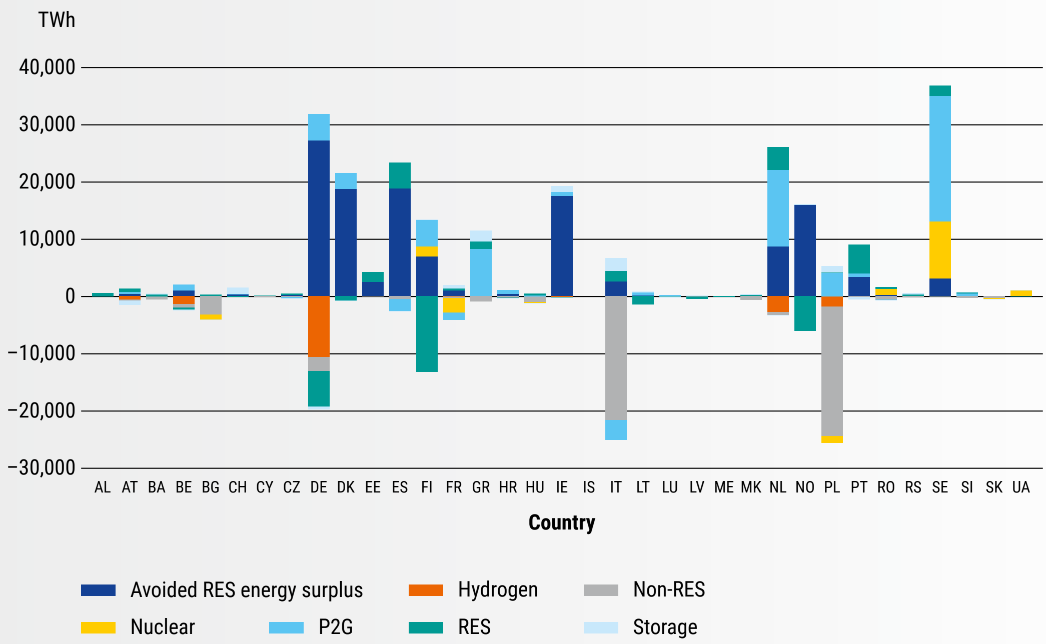


Figure 3.6 – Impact on the generation mix of addressing system needs, at country level (TWh) (Difference between the case when needs are addressed and a hypothetical future where no investment would be made in the cross-border grid after 2030). Figure includes only ENTSO-E area. P2G value refers to the load.

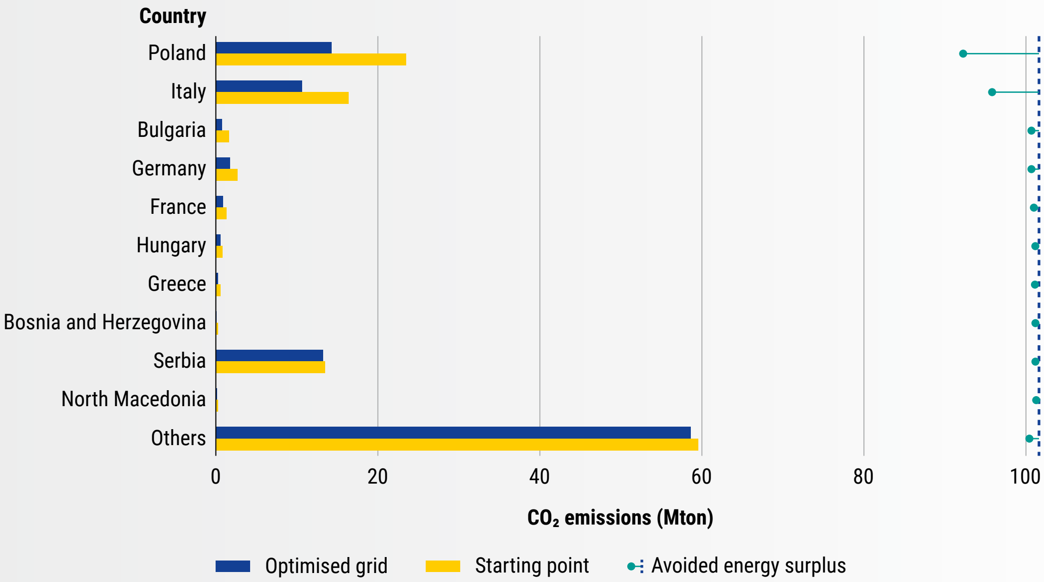


Figure 3.7 – CO_2 emissions in 2040 in two grid configuration: with the optimised grid 2040 (Optimised grid), and in a hypothetical future where Europe would stop all investments in its cross-border grid after 2030 (Starting point). On the right-hand side, avoided CO_2 emissions in 2040 when addressing system needs (difference between the two grid configuration). Figure includes only ENTSO-E area.

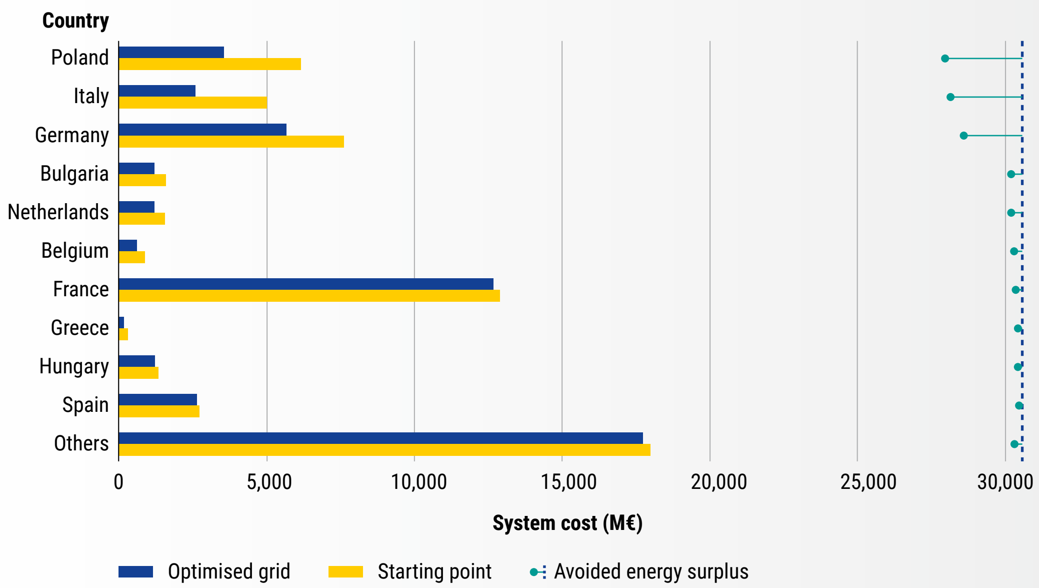


Figure 3.8 – Reduction in generation costs when addressing system needs in 2040, compared with a hypothetical future where Europe would stop all development of its cross-border grid after 2030 (Million euro). Figure includes only ENTSO-E area.

Comparison with the Distributed Energy and Global Ambition scenarios confirms that system needs exist in different potential futures

The Distributed Energy (DE) and Global Ambition (GA) scenarios represent very different futures for Europe's energy system than the future represented in the National Trends scenario studied in the TYNDP 2024 system needs study.

Both scenarios illustrate a pathway achieving EU27 carbon neutrality by 2050 and at least 55 % emission reduction in 2030. Distributed Energy is driven by a willingness of the society to achieve energy autonomy based on widely available indigenous renewable energy sources. It translates into both a way-of-life evolution and a strong decentralised drive towards decarbonisation through local initiatives by citizens, communities and businesses, supported by authorities. This leads to a maximisation of renewable energy production in Europe and a strong decrease of energy imports. By contrast, Global Ambition pictures a pathway to carbon neutrality driven by a fast and global move towards the Paris Agreement targets. It translates into development of a very wide range of technologies (many being centralised) and the use of global energy trade as a tool to accelerate decarbonisation.

Key numbers, in TWh (EU area)	National Trends 2040	Distributed Energy 2040	Global Ambition 2040
Generation from wind	2,461	2,906	2,845
Generation from solar	1,345	1,583	1,444
Generation from methane	268	61	21
Generation from nuclear	522	402	553
Battery generation	180	159	155
Generation from hydrogen	103	1.6	0.6
Final methane demand	2,328	1,792	2,032
Final hydrogen demand	1,688	1,750	2,189
Final electricity demand	3,534	3,766	3,368
Electricity demand for electrolysis	812	1,124	1,354

Table 3.1 – Key parameters of scenarios National Trends, Distributed Energy and Global Ambition in 2040 (**TYNDP 2024 Scenarios Report Data Figures**)

The process of building the DE and GA scenarios implied the computation of optimised cross-border capacities at European level. Although this is not an identical exercise to the system needs study performed on National Trends, comparing these capacities with those obtained in the system needs study still offers valuable insights.

The analysis of capacities in DE and GA 2040 confirms that there are system needs on most European borders. In the 2040 horizon, the DE optimisation leads to an overall cross-border capacity in the EU of 374 GW, with 213 GW of battery storage. GA leads to 330 GW of cross-border capacity, with 213 GW of storage. By comparison, the system needs study performed on National Trends amount to 269 GW of final cross-border capacity and to 250 GW of final storage capacity in 2040 in the EU.

Even higher needs in DE and GA confirms the immediate need for significant network reinforcements under any plausible scenario that achieves carbon neutrality in 2050 while minimising costs.

Addressing 2040 cross-border needs will require significant reinforcements of national electricity grids

Eventually, an integrated, efficient and carbon neutral energy market affects the ability of networks to handle the physical flows of electricity. Even in the absence of increases in cross-border transmission capacity, the internal networks would need reinforcements to accommodate the flows resulting from the new generation mixes described in the scenarios. With increases of cross-border capacity, even more reinforcement of internal networks is needed.

New generation mixes require significant reinforcement of internal networks by 2040

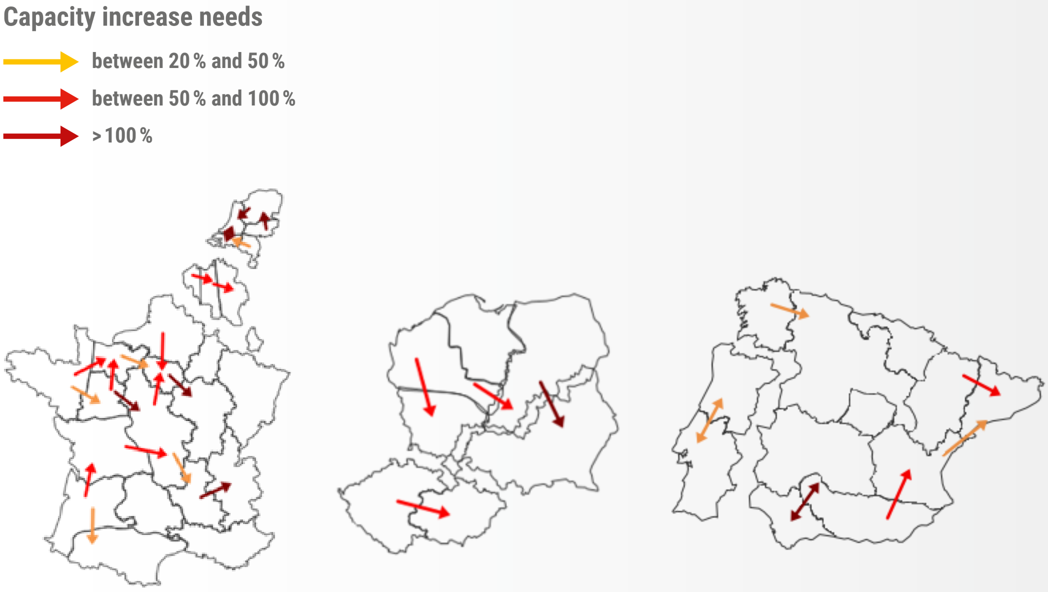


Figure 3.9 – Regional snapshots of internal constraints in 2040 without internal investments after 2030, in 1/France, Belgium and the Netherlands; 2/Poland and Czech Republic; and 3/Spain and Portugal. In %, how much internal network capacity needs to be increased to return to an unconstrained level. The arrows indicate the capacity increases needed to avoid congestion on interzone networks.[11)]

Figure 3.9 shows snapshots of internal constraints in 2040 in the hypothetical situation where European countries would stop investing in their national network after 2030. By 2040, the increase in renewable energy production and electricity consumption will lead to new flows in all European countries. As a result, many regions will find themselves under pressure if no additional reinforcement of internal networks is planned after 2030. This underlines the fact that Europe's energy transition objectives cannot be achieved without joint development of electricity grids.

11) In the case of Spain the SRAP system was considered, an automatic power reduction system that is implemented as an IA operational tool in the control center already today. With observability and controllability devices it allows to accommodate congestion and integrate higher volumes of RES without need for physical reinforcements.

The need to reinforce internal networks is amplified by addressing 2040 cross-border needs

Reaching the level of cross-border exchanges that result from the needs identified in the System needs study will create new needs for reinforcement of internal networks in the European national grids. Capacity increases may require some additional reinforcement of internal networks and cost approximations for these reinforcements are taken into consideration in the costs assumed for the study.

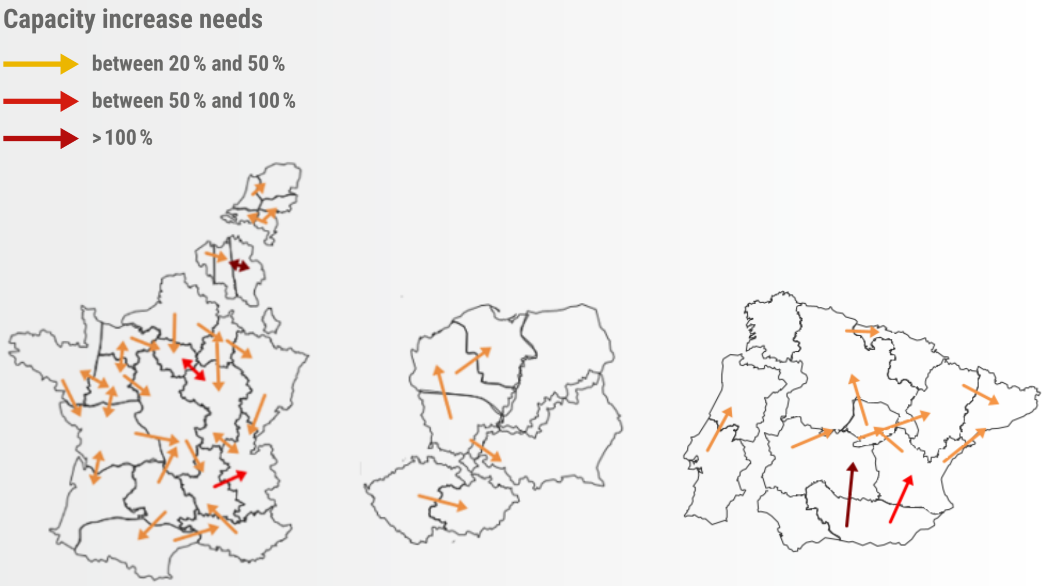


Figure 3.10 – Additional internal constraints in 2040 if the needs identified in the 2040 horizon are addressed, in 1/France, Belgium and the Netherlands; 2/Poland and Czech Republic; and 3/Spain and Portugal. In %, how much internal network capacity needs to be increased to return to pre-investment level. The arrows indicate the capacity increases needed to avoid the additional congestion caused by the new flows with the grid addressing system needs.

Figure 3.10 shows regional snapshots of the need to reinforce additional internal networks after addressing 2040 cross-border needs. The needs for cross-border capacity increases, if they are addressed, will create additional flows throughout Europe. This increase in flows will further stress an already constrained network. Some identified needs may no longer provide as much benefit as expected in terms of exchange capacity if the internal network is not reinforced.

Whether in terms of generation mixes or cross-border needs, these objectives cannot be achieved without significant parallel development of internal networks.

National Development Plans address these internal constraints. They analyse the situation of internal grids in the national framework as well as in the European framework, to ensure that internal grids accommodate future flows and are fit-for-purpose in the energy transition.

4 What electricity infrastructure do we need for a cost-efficient and CO_2-neutral energy system in 2050?

The European Union has committed to achieving carbon neutrality by 2050, with the electricity sector taking a pivotal role in this transformation. A CO_2-neutral energy system, with increased electricity demand and powered largely by variable RES such as wind and solar, will require substantial expansions in grid and storage infrastructure. Investments in the power grids will be crucial to achieve energy transition and carbon neutrality in a timely, secure and reliable way.

Investing in electricity grid and storage infrastructure is a no-regret option

TYNDP 2024 introduces for the first time an analysis of system needs in the 2050 time-horizon. Our study is based on the Distributed Energy 2050 Scenario, which is aligned with the "Energy Efficiency First" objective and with EU ambitions for carbon neutrality by 2050. The System Needs analysis explores a distant and uncertain future in only one scenario. It provides therefore just a glimpse at one possible far-off potential future. The realisation of this future will largely depend on economic growth, electricity demand, technological progress and political ambitions.

Nevertheless, as highlighted in key publications such as the **World Energy Outlook**, **Electricity Grids and Secure Energy Transitions**, and **The future of European competitiveness (Draghi Report),** electricity grids will be pivotal in all scenarios for advancing toward carbon neutrality. Their role extends beyond electricity market and environmental benefits, offering substantial economic returns by directly driving job creation and technological innovation, while indirectly enhancing the competitiveness of European industry through more efficient markets and reducing dependency on non-European countries.

The System Needs study investigates a potential future where the EU's offshore ambitions are fully realised. This means concretely that EU Member States' non-binding agreements provided in January 2023[12] are implemented. Of course, EU Member States' offshore strategies will evolve, and ENTSO-E will re-assess their impact on infrastructure needs in the next editions of the Infrastructure Gaps report and of the Offshore Network Development Plans per sea basin (TYNDP 2026).

12) See **Member States agree new ambition for expanding offshore renewable energy**

13 billion/year € of investment in electricity infrastructure to save 23 billion/year in system costs

The System Needs study finds that by 2050 investing in an additional 224 GW of cross-border grid capacity, including 44 GW of hybrid offshore capacity, and 540 GW of storage capacity (including 312 GW of battery storage capacity in scenario DE 2050 and 228 GW of storage capacity increase) would maximise the cost-efficiency of Europe's carbon-neutral electricity system.

In addition to these opportunities, the study assumes the existence of 61 GW of transmission infrastructure that would become available between 2030 and 2050 as radial offshore infrastructure and, in case of interconnections between two (or more) offshore nodes, would eventually become part of hybrid offshore infrastructure. The 44 GW of hybrid offshore infrastructure correspond to the links connecting these 61 GW of pre-existing radial connections and effectively transforming them into components of a larger hybrid or partly meshed network.

Infrastructure investments in 2050 would represent 13 billion euro/year until 2050, and would reduce system costs by 23 billion euro/year.

Total investment in infrastructure onshore and offshore in 2050

The total investment in 2050 include 13 billion euro/year for the capacity increases selected by the optimiser, but also 3 billion euro/year of investment in ONDP offshore corridors and 5 billion euros/year for the capacity increases identified in 2030 (88GW presented in Chapter 2) for a total of close to 20 billion euro/year. Over 25 years between today and 2050, these amount to a total of just over 500 billion euros.

ONDP 2024 found 400 billion euros of investment in offshore transmission connecting RES between 2023 and 2050. The methodology used to compute investment costs was not exactly the same in the two studies. In addition, 400 billion includes the costs of offshore radial connections which are not included in the 500 billion euros identified by the system needs study because offshore radial generation is part of the base case. For a valid comparison of the findings of both studies, these costs amounting to 363 Billion[13)] euros, should be considered, giving a grand total of **863 billion euros invested in the grid by 2050**.

Figure 4.1 shows that, as in other time-horizons, opportunities exist all across Europe. Interconnections between France and Great Britain and Sweden[14)] and Finland show the largest reinforcement needs. On storage, biggest needs are located in Germany (81 GW), Italy (65 GW) and the Netherlands (35 GW).

The offshore results confirm the findings of ENTSO-E's Offshore Network Development Plans (ONDP) 2024 in 2050, which found offshore hybrid corridors representing 44 GW of transmission capacity in the North Sea, Celtic Sea and Baltic Sea.

13) With the caveat that the value of 363 billion euros for offshore radial connections was computed as part of ONDP 2024 and is therefore based on a different scenario and assumptions than the investment costs computed in the system needs study.

14) It is important to note that several evolutions have taken place since the building of TYNDP 2024 scenarios and other input data, for example the decision of the Swedish government to cancel numerous offshore RES development in the Baltic sea. In addition, modeling choices, in particular the modelisation of electrolysers as electric load only introduced in this TYNDP cycle, have had important impacts on the needs identified in Nordic countries including on the borders between Finland, Sweden, Norway and Denmark. Modeling will be further improved in next editions of the TYNDP.

2050 System Needs

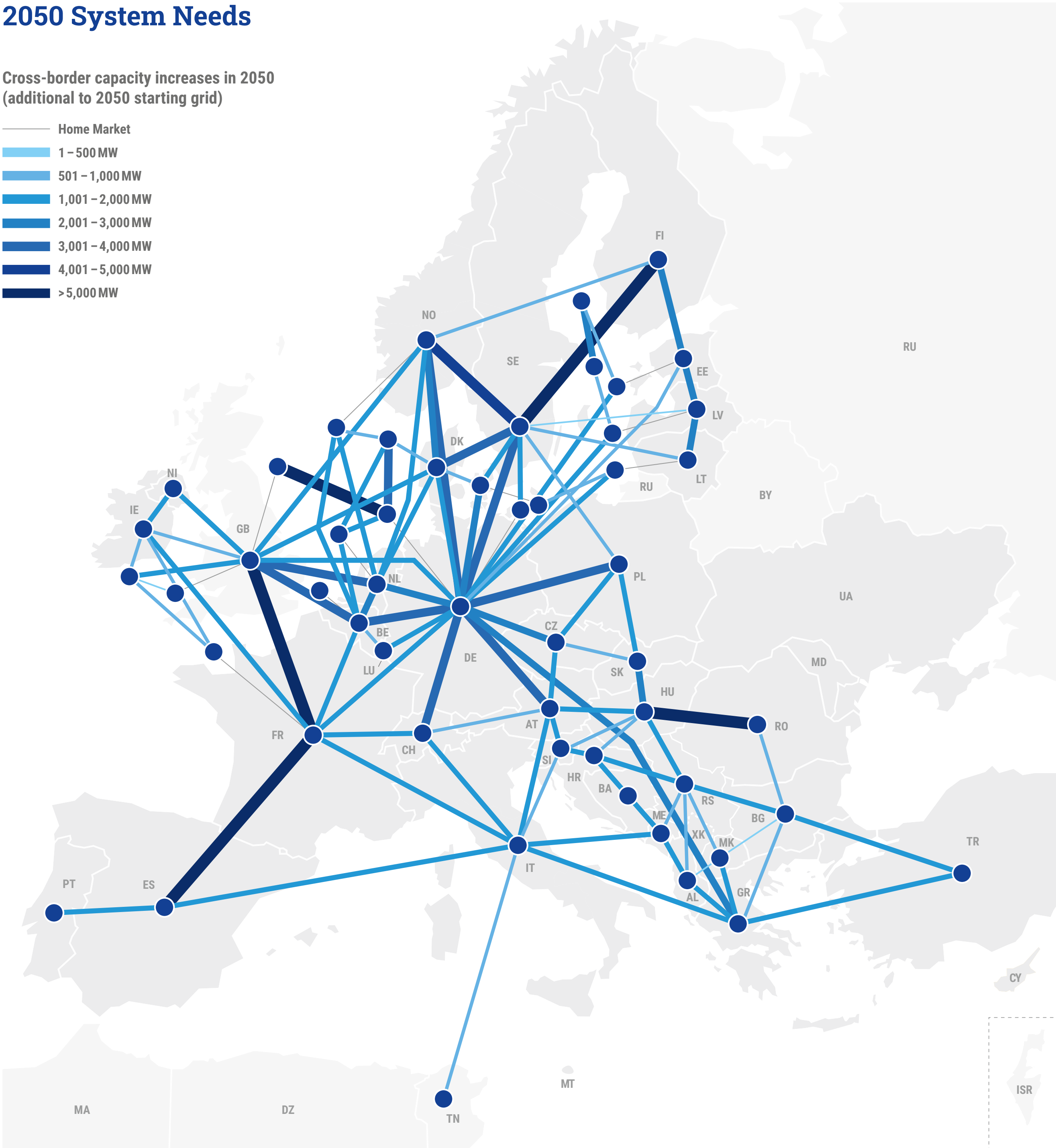


Figure 4.1 – Cross-border capacity increases to achieve a cost-efficient energy system in 2050, additional to the 2030 grid visible in Figure 1.4.

2050 System Needs

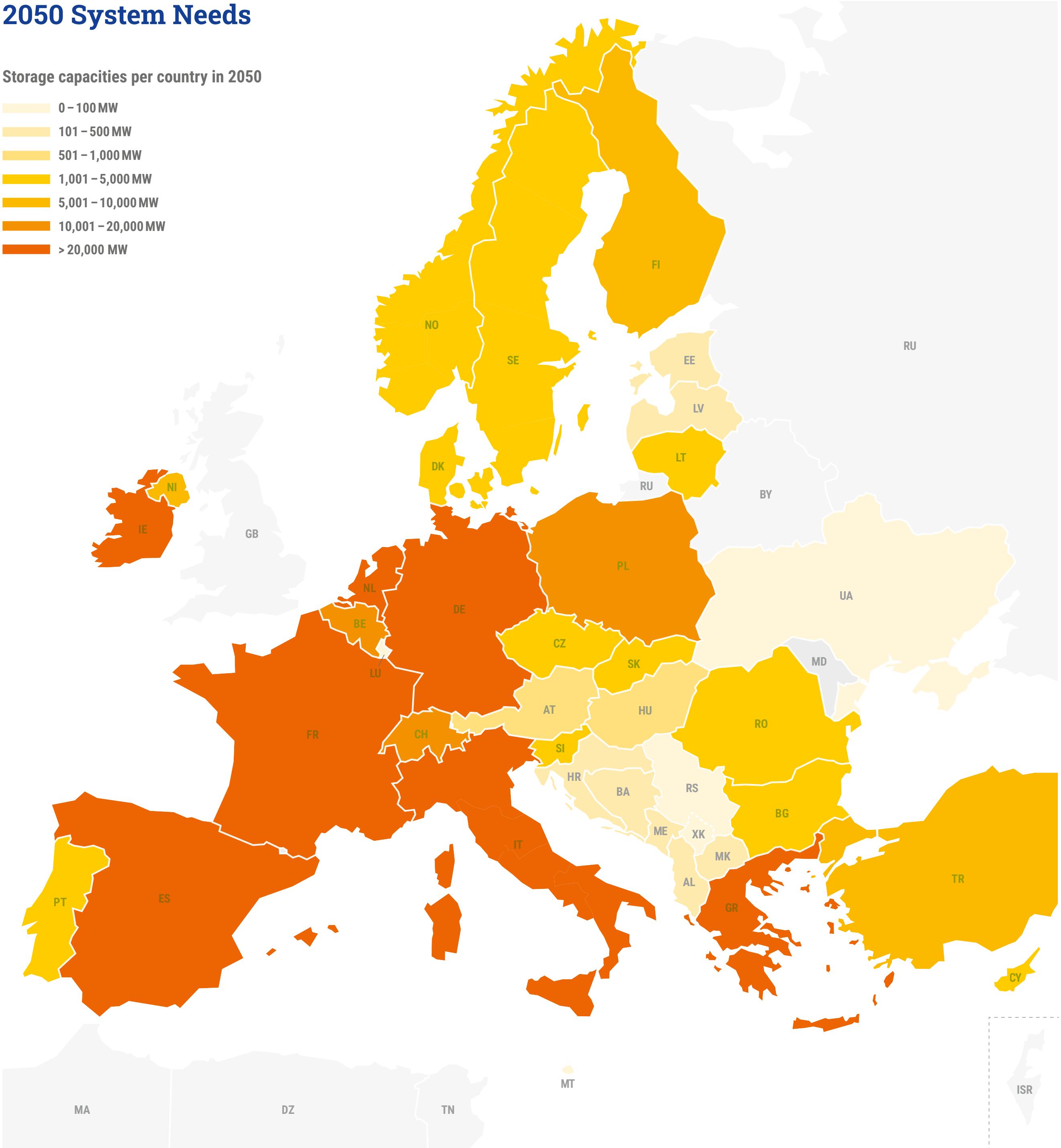


Figure 4.2 – Opportunities for increase in electricity storage capacity in 2050. The values include the battery storage capacities in scenarios Distributed Energy 2050 added to the optimised capacities identified by the study, for a total of 336 GW.

A cost-efficient Roadmap to carbon neutrality

As shown in the previous chapters, there are large economic gains from optimising grid and storage investments to achieve a climate-neutral energy system in 2050. Our future electricity landscape, largely driven by variable RES and a growing electricity demand, will need a strong electricity network to efficiently integrate such technologies. Starting from the 161 GW of available cross-border capacity in 2030, 88 GW of additional transmission infrastructure would already be beneficial in 2030, and increase to reach 224 GW in 2050. Moreover, our system would also greatly benefit from higher storage capacity capacity levels (336 GW).

The system needs study provides crucial insights for transmission system operators, regulators, industry, and policymakers on the requirements needed to achieve these ambitious EU climate goals. Addressing supply chain bottlenecks and delays in the commissioning of infrastructure projects will be essential to achieving climate objectives (see next Chapter). Transmission system operators, equipment manufacturers, generators, policymakers and many other stakeholders face the enormous challenge of ensuring that energy infrastructure is developed at the right place and the right time to enable the energy transition while keeping costs at an acceptable level for European citizens.

5 Europe needs to accelerate infrastructure development

How do infrastructure projects currently being developed compare to the needs presented in the previous chapters? To answer this question, we have looked at the 2040 time horizon and have compared identified needs with existing electricity transmission projects in the TYNDP 2024 projects portfolio.

TYNDP 2024 project portfolio represents 328 billion euros of electricity infrastructure by 2040

The TYNDP 2024 project portfolio includes 178 transmission and 33 storage projects, located all over Europe and with neighboring countries and that are at various stages of development. Projects were submitted on a voluntary basis by promoters and were accepted in the TYNDP after verification by ENTSO-E that they comply with a number of administrative (European relevance) and technical criteria as outlined in the **TYNDP guidance for applicants**. Figure 5.1 and 5.2 show transmission and storage projects in the TYNDP 2024 portfolio.

Focusing on transmission projects, projects expected after 2030 represent a total of 80 GW of additional cross-border capacity increase, additional to the 35 GW that will become available between 2025 and 2030. While most projects are expected to commission between 2030 and 2035 (47 GW of extra cross-border capacity), another 31 GW is planned to commission between 2035 and 2040, and for now only 2 GW after 2040. (Figure 5.3).

Reinforcement of internal networks will of course be needed to make it possible to increase cross-border flows. Internal reinforcement projects in the TYNDP 2024 portfolio represent 85 GW of extra transmission capacity within countries between 2030 and 2040, and are located mainly in Italy (22 % of additional transmission capacity) Germany (21 %), and Belgium (16 %). In addition, additional projects of national or regional relevance, not included in the TYNDP portfolio, also seek to reinforce national networks.

In total, TSOs and other transmission project promoters are planning investments worth 303 billion euros between today and 2040, based on projects in the TYNDP portfolio and without considering the necessary development of internal grids explained at the end of Chapter 3. ENTSO-E has analysed the benefits that each project could deliver from a socio-economic perspective. Our cost-benefit analysis results reveal that implementing the whole portfolio of transmission projects would create up to 33 billion euros increase in socio-economic welfare for EU citizens in 2040 (i. e., socio-economic welfare generated exclusively in that single year), depending on the scenario considered (Figure 5.4).

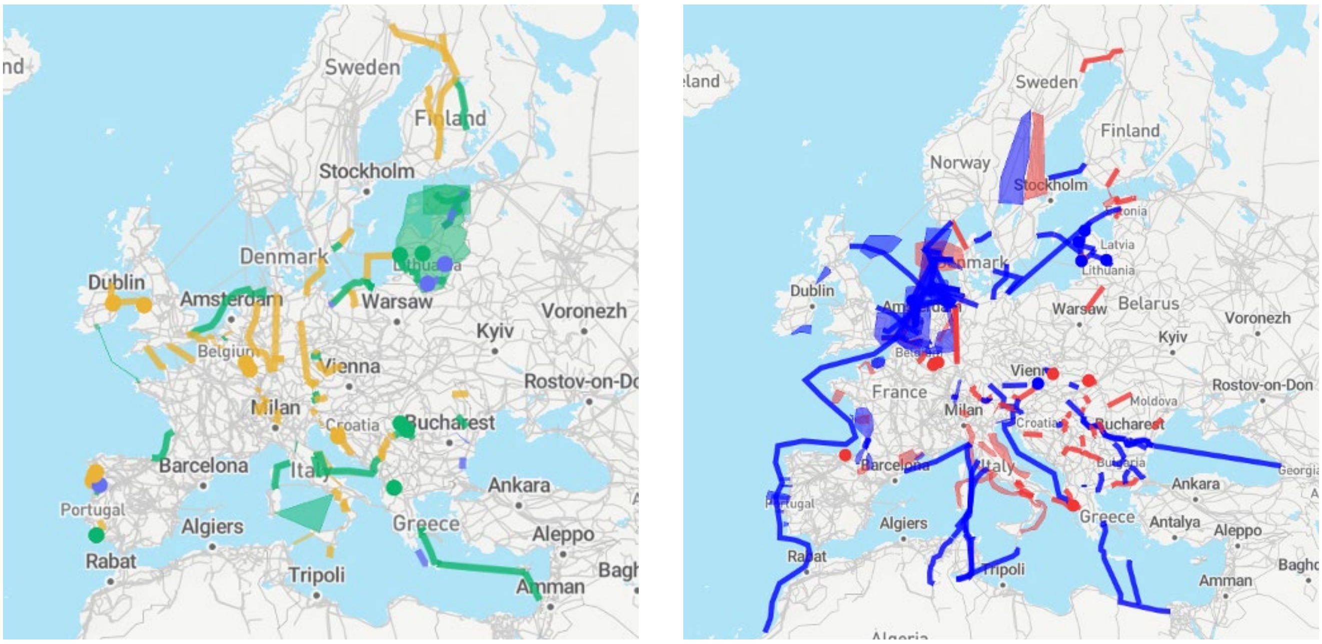


Figure 5.1 – Transmission projects in the TYNDP 2024 projects portfolio. On the left, more advanced projects under construction (green) and in permitting (yellow). On the right, less mature projects planned (red) or under consideration (blue).

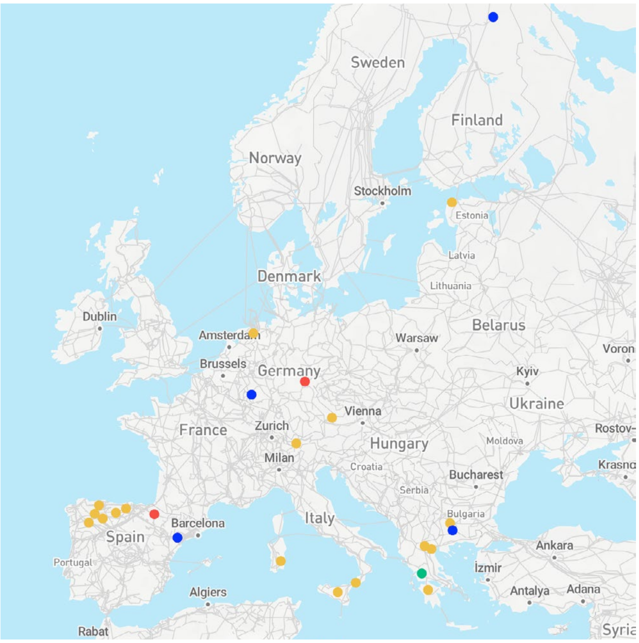


Figure 5.2 – Storage projects in the TYNDP 2024 project portfolio. Yellow: projects in permitting, red: projects planned, blue: projects under consideration

Visit our TYNDP 2024 platform to visualise all projects on a map of Europe.

You can filter by technology, country or current status and download the data in spreadsheet format.

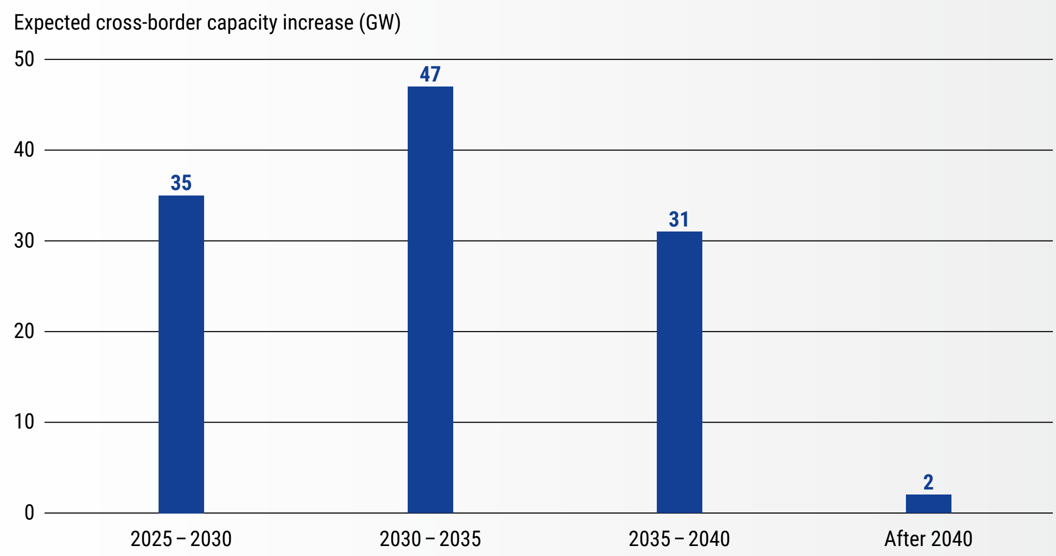


Figure 5.3 – Expected cross-border capacity increase from cross-border transmission projects in the TYNDP 2024 portfolio, per their commissioning year.

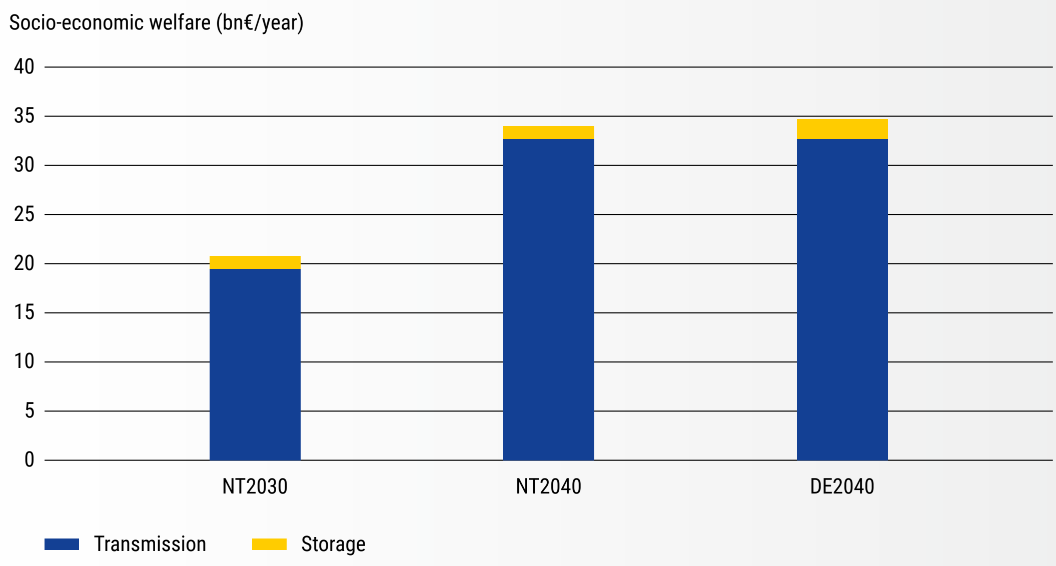


Figure 5.4 – Impact of the TYNDP 2024 projects portfolio on socio-economic welfare in NT2030, NT2040, DE2040 (Bn€/year). Computed by ENTSO-E.

Investing in electricity infrastructure creates jobs and benefits Europe's economy

As far as the progress of projects in the TYNDP project portfolio allows companies to invest, this progress stimulates the economy. ENTSO-E has computed the impact of the TYNDP 2024 project portfolio in the European Union economy during the whole cycle of each project. The analysis considers therefore not only the awardee and direct tenderers of the investments (e. g. companies involved in the construction phase of a project, …), but also the intermediate consumption e. g. goods and services purchased by awardees and direct tenderers, and the final consumption derived from all salary incomes generated at all the steps. Results refer only to EU Member States and the goods and services generated in European Union countries, while imports from outside the EU in or out the European continent are not considered.

The results show that during the construction and commissioning of the projects in the TYNDP 2024 project portfolio:

- 4.1 million jobs could be ensured,
- 603 billion € could be mobilised in production, understood as the accounting value of payments of the project promoters and their suppliers,
- the European Union GDP could increase by close to 247 billion €, and
- public administration revenues through taxes collection could reach about 111 billion €, a value that could reverberate in the European society.

These results are significantly higher than in the similar study performed in 2022, because of the notable increase of the number of transmission and storage projects in the TYNDP portfolio. TYNDP 2022 included 161 projects representing a CAPEX of 144 billion €, while TYNDP 2024 has 211 projects for a total CAPEX of 328 billion € (of which 288 billion € inside the EU).

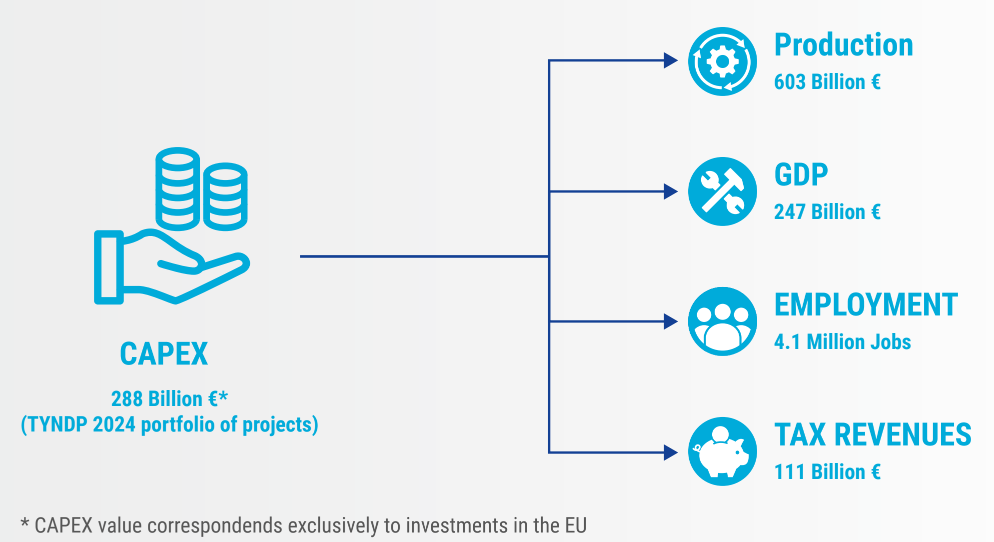


Figure 5.5 – Projects being developed by 2040 compared with identified needs by that time horizon.

Existing transmission projects address only part of the cross-border needs in 2040. Opportunities for new solutions exist all over Europe.

Comparing the TYNDP project portfolio with the optimised grid identified in 2040 shows that existing projects address only part of the needs. In 2040, our study finds 108 GW of opportunities for cross-border capacity increase after 2030. By comparison, transmission projects with cross-border impact after 2030 and under development today amount to 80 GW of cross-border capacity increase (Figure 5.3). Therefore, there is a gap of 28 GW of cross-border transmission capacity.

Of course, needs may be addressed by a variety of solutions beyond transmission lines, including cross-sector solutions, but this comparison already gives an idea of the localisation and size of opportunities for investments in additional infrastructure. To try and provide an indication of where policymakers and promoters should focus and investigate potential additional solutions in 2040, we have compared needs for cross-border capacity increases and existing transmission projects in Figure 5.5. The comparison shows without surprise that there are opportunities for additional solutions all over Europe, with peaks in the North on Norwegian and Swedish borders, in the West on Spanish, French, Belgian and UK borders, and in the East in a corridor going from Turkey to central Europe through the Balkans.

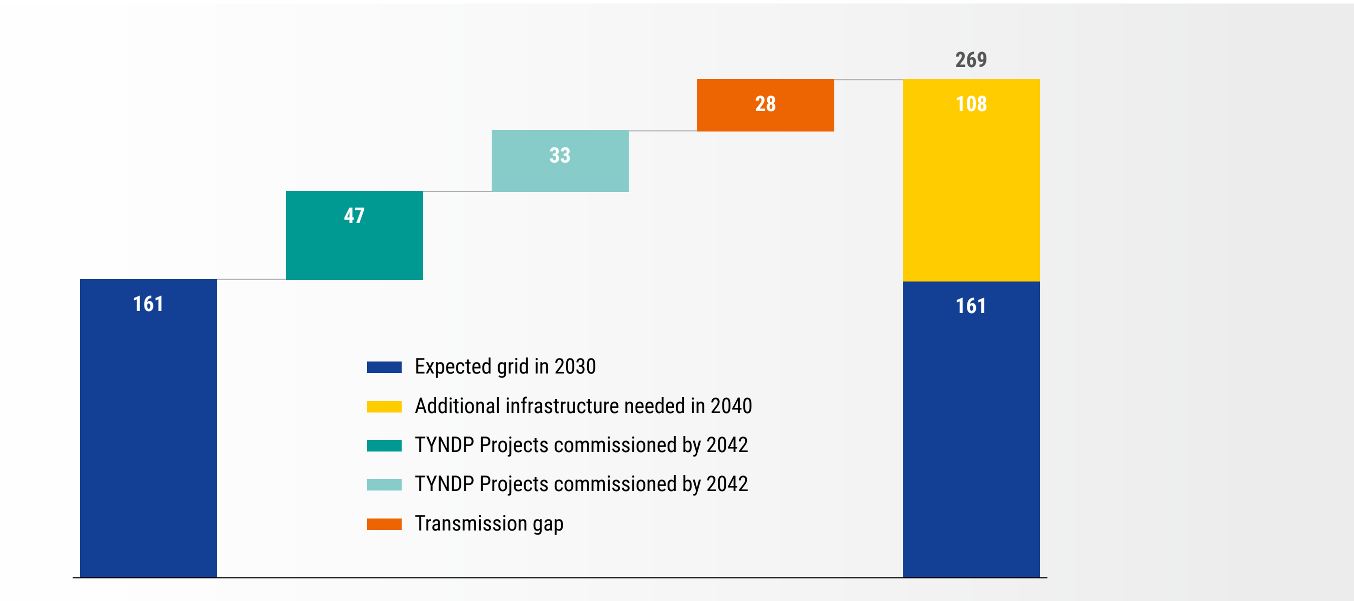


Figure 5.6 – Projects being developed by 2040 compared with identified needs by that time horizon.

Infrastructure gaps

Difference between the identified needs in 2040 and existing transmission projects by that time horizon (MW). The bigger the circle, the bigger the opportunity for new solutions to increase cross-border capacity.

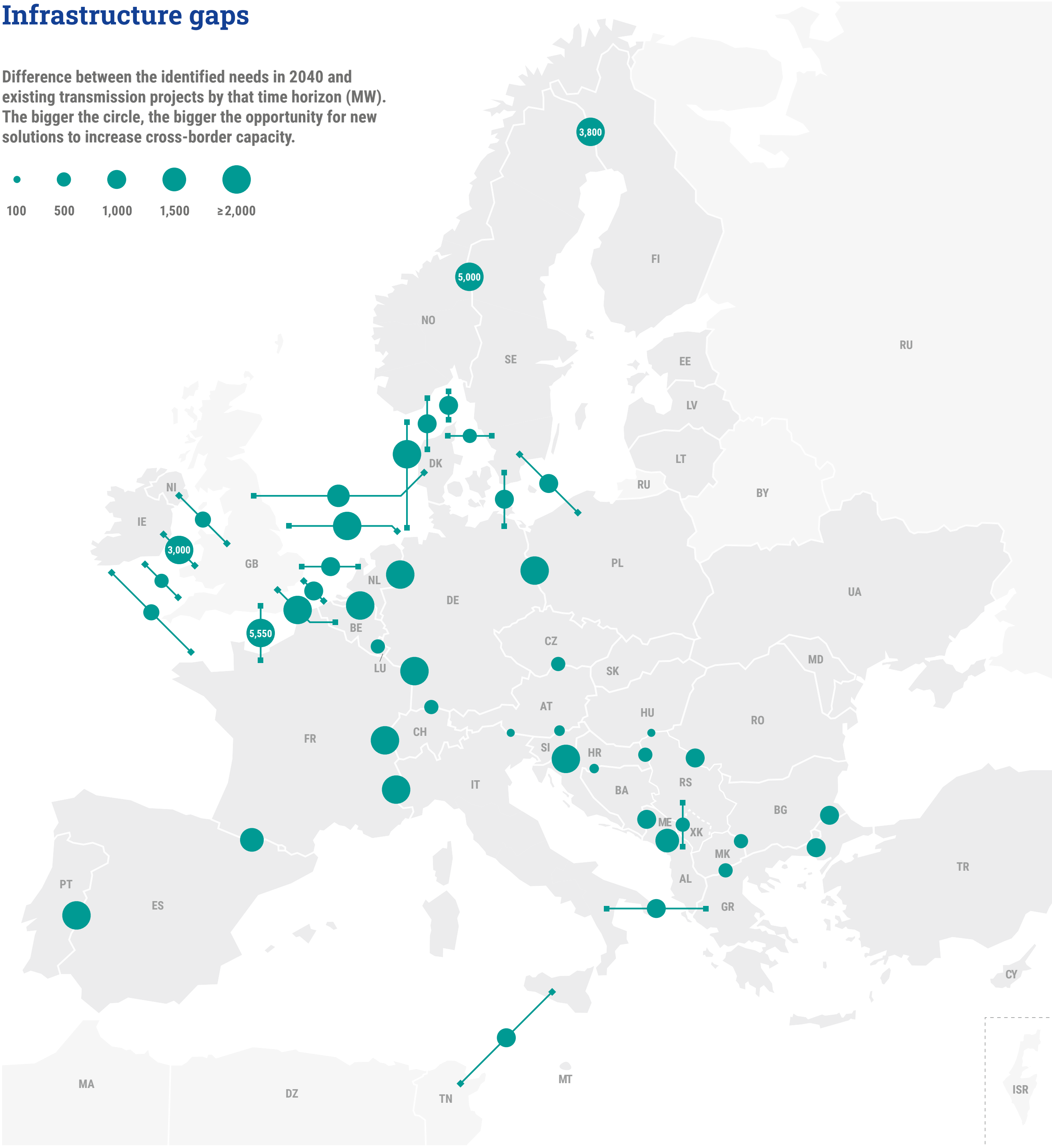


Figure 5.7 – Difference between the cross-border needs identified in 2040, and the cross-border capacity increases expected from transmission projects due to commission by 2040. The bigger the circle, the bigger the opportunity for developing new solutions to increase capacity.

By 2040 the array of projects and solutions that can still be developed and implemented in time to address identified needs is entirely open. There is time for policymakers and project promoters to propose solutions, including infrastructure solutions such as new storage or transmission assets that can take more than a decade to become available to the market. The EU does not yet have energy efficiency targets for the 2040 horizon. Infrastructure projects under development that are being designed for commissioning in or around 2040 are still limited. TYNDP 2024 includes 20 transmission projects and no storage project expected by their promoters to commission between 2036 and 2040, and only one transmission project after 2040.

Efficiency measures can decrease system needs, but investments will be necessary to support the transition

Measures to increase energy efficiency should of course be the first step, with the objective to decrease system needs by reducing energy demand. The study is based on the National Trends scenario, which is rooted in EU Member States' National Energy and Climate Plans (NECPs). When developing these plans, EU Member States were required to meet the EU's objectives for 2030, including the energy efficiency target of reducing energy consumption by at least 32,5 % (compared to projections of the expected energy use in 2030). Our National Trends 2040 scenario builds on the 2030 objectives. Although there are not yet EU target for energy efficiency in 2040, the needs for capacity increase identified in the study exist in a world where significant energy efficiency gains have already been achieved.

Besides energy efficiency targets to reduce demand for electricity, an additional way to partly satisfy system needs, without building new infrastructure, is to increase grid capacity by improving the performance of existing system assets. Electricity Transmission System Operators already today apply various solutions to optimise and expand the present capacity of the grid, including both new infrastructure solutions (for example hybrid offshore infrastructure combining generation and interconnection) but also non-infrastructure solutions such as software, new design ideas upgrading the current assets, operational measures to enhance the utilisation of transmission capacities and new technologies to help address grid constraints. Non-infrastructure based solutions are already included in several projects in the TYNDP portfolio and their main advantage is that they are relatively fast to implement.

However, not all infrastructure solutions are equally lengthy in terms of development time. Some assets, such as phase shifting transformers (PSTs), can be deployed faster and help optimize the performance of the lines being served. PSTs do not increase the capacity of the lines themselves, but if some lines are overloaded while capacity is still available on other lines parallel to them, optimising the power flows with PSTs can increase the overall grid capacity.

Having said how important it is to use the present assets at their maximum capacity (in compliance with the rules for the secure operation of the transmission), the increase in electrification level that is necessary for the decarbonisation of the energy system cannot be achieved by simply optimising current infrastructure. In a European power system transitioning towards high RES and aiming at carbon neutrality in 2050, reducing needs for additional transmission infrastructure is not enough. It is necessary to support the transition by preparing Europe's grid for a future with higher flows of RES electricity across borders and across regions.

The gaps identified in TYNDP 2022 are partially addressed by new projects in TYNDP 2024

The System Needs 2022 study found many gaps between needs and existing projects, especially in 2040 in a corridor going from borders with Turkey all the way to Czech Republic and to connect Scandinavia to mainland Europe through the Baltic Sea, and in Western Europe for storage capacity. 25 of the projects that are new in TYNDP 2024 aim at addressing a gap identified in TYNDP 2022, 10 by targeting cross-border reinforcement and 15 by reinforcing internal networks or replacing ageing infrastructure. In particular, a set of cross-border capacity reinforcement is proposed on 9 borders of South-Eastern and Eastern Europe.

Regarding storage, in 2022 we found opportunities for increased storage capacities in Western Europe, mainly in Spain, Germany, Italy, France, the Netherlands, Ireland and also in Hungary. The TYNDP 2024 project portfolio sees 13 new storage projects which were not in previous TYNDPs, in particular in Spain (2 projects) and Italy (4 projects).

The supply chain challenge: Action is needed to enable timely implementation of electricity infrastructure projects

The ambitious energy transition goals of the European Union, including integrating vast amounts of green electricity and electrifying consumption sectors, will require significant expansion and modernisation of infrastructure. However, implementing this infrastructure comes with a series of challenges. Permitting delays often slow project timelines, financing complexities hinder investment flows, and gaining public acceptance for new infrastructure can be difficult.

A critical focus in overcoming these barriers lies in addressing the resilience and efficiency of supply chains. As the demand for grid technologies rises sharply, the availability of critical components, skilled labor, and effective procurement processes will be central to meeting Europe's energy and climate objectives. Ensuring robust supply chains is essential to delivering the infrastructure required for a sustainable and secure energy future.

TSOs investment pipeline by 2030

TSOs across Europe are investing every year more and more at national level in new transmission infrastructure and equipment. The projects in the investment pipeline to either enhance existing infrastructure or to expand it, to accommodate the expected high volume of RES capacities located in remote areas and transfer the produced energy to the load centers, to ensure security of supply of isolated areas, to ensure voltage levels within the limits and to replace ageing equipment are equally of outmost importance to support Europe's energy transition.

Up to 2030, bulk investments are planned. Over 150,000 km of transmission lines are expected to be completed onshore and offshore to enhance Europe's grid (Figure 5.9). The vast majority of transmission lines are overheard synchronous connections to the grid, because enhancing Continental's Europe existing infrastructure to achieve the targets remains a high priority for all TSOs. A fair share of underground and subsea cable lines is planned to connect to the transmission grid either remote areas such as islands, either offshore RES capacities, or to enhance the grid in urban areas. Moreover, for the utilisation of these infrastructure investments effectively, large scale investments in substation equipment are also included in the pipeline until 2030. Installation of more than 14,000 circuit breakers, 4,800 GIS switchgears and 1,900 power transformers are expected, while also 800 shunt reactors and 71 phase shifting transformers are to be completed (Figure 5.8).

The number of power transformers, PSTs, circuit breakers, and switchgear required highlights the demand for large-scale manufacturing output. These components form the backbone of the grid, enabling greater interconnection and integration of renewable energy sources. However, the projected numbers significantly surpass historical production rates, highlighting the pressure on the supply chain.

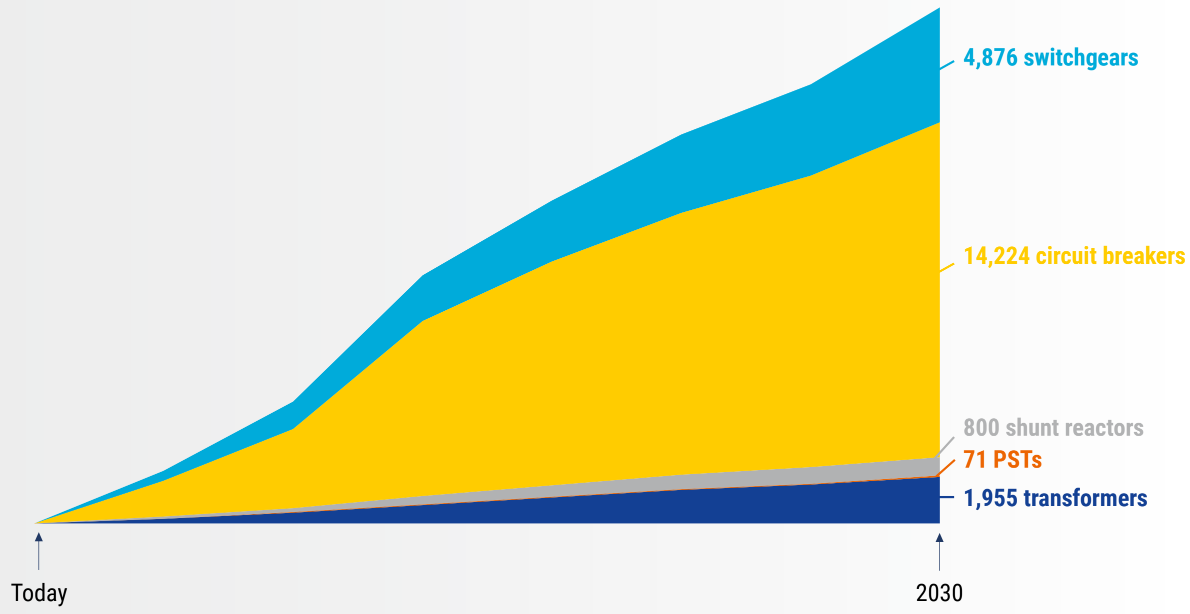


Figure 5.8 – TSOs investment pipeline until 2030 (number of power transformers, PSTs, circuit breakers, GIS switchgears)

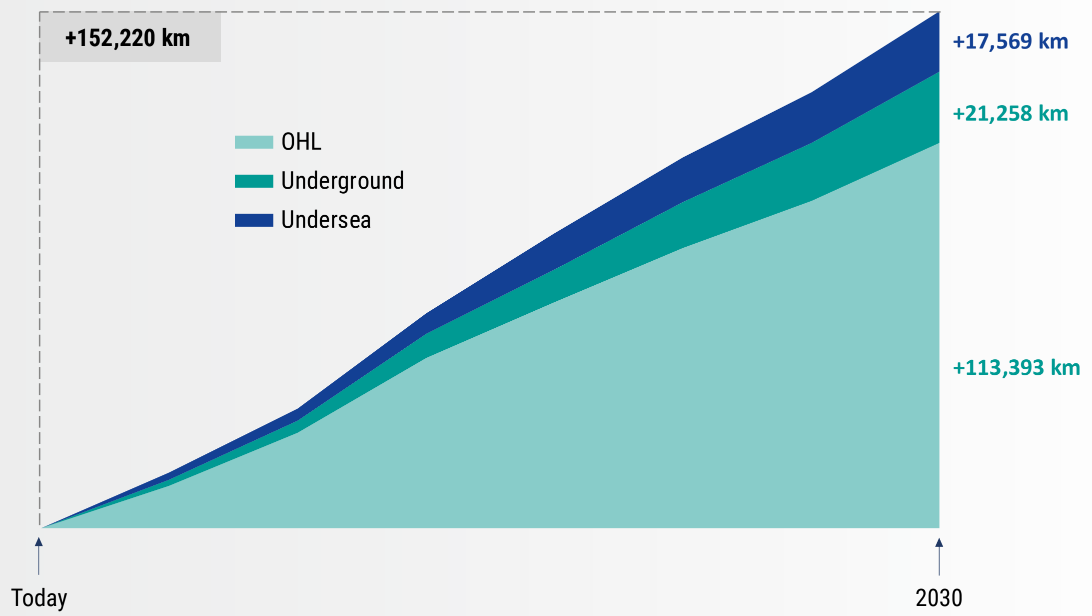


Figure 5.9 – TSOs investment timeline until 2030 (OHL, underground and undersea cables) (km)[15)]

15) Figures include national projects not explicitly part of the TYNDP portfolio, which may inflate the total requirements. Nonetheless, these numbers still provide a realistic view of the pressure on supply chains and the resources needed.

Even when implementing the efficiency measures mentioned in Chapter 5, addressing system needs in 2040 and 2050 will mean need for even more equipment than what is already planned. Looking only at offshore, the optimal connection of the generation capacities defined by EU Member States' non-binding agreements on offshore RES of January 2023 will require a notable amount of assets: cables to cover more than 50 thousand km of routes, 158 offshore converter stations, 123 offshore AC substations, 176 onshore converter stations and 34 sets of DC circuit breakers. All of this for a cost of at least 400 billion euros[16)].

Tackling the supply chains challenge

Current manufacturing capacities in Europe are insufficient to meet demand in the time required to deliver individual projects, resulting in significant lead times, delays and over-reliance on non-EU suppliers and significant increase in investment costs. Lead times for key assets such as HVDC converters, cables and power transformers often exceed four years, exacerbating project timelines.

The grid technology market in the EU includes few manufacturers. While leveraging non-EU suppliers may offer short-term relief, it also introduces risks related to quality, reliability, regulatory compliance, and geopolitical tensions. A balanced strategy of diversified sourcing and investment in domestic manufacturing capacity is essential to secure both short-term and long-term supply chain resilience.

The current EU procurement framework, originally designed for a buyer-driven market, is misaligned with today's supplier-dominated landscape. Lengthy approval processes, rigid frameworks, and inconsistent standards across Member States hinder TSOs' and other promoters' ability to secure critical components efficiently. Extending the duration of framework agreements and allowing greater flexibility during procurement negotiations would help align procurement processes with the realities of long-term grid projects.

The dependency on critical raw materials from outside the EU adds another layer of complexity. Rising costs of essential materials, such as copper and steel, have caused a 200 % increase in power transformer prices since 2022. The Critical Raw Materials Act and the Net-Zero Industry Act (NZIA) aim to reduce these vulnerabilities by promoting recycling and local resource development. However, while these initiatives address long-term resilience, they do not fully mitigate immediate difficulties.

The labour market for grid infrastructure faces critical shortages across the whole sector, particularly in advanced technical roles. Figures 5.8 and 5.9 highlight the scale of physical infrastructure expansion, requiring skilled workers for overhead line construction, substation maintenance, project management and digital systems management. The significant increase in smart devices and digitisation, as well as increased cyber security measures, are forcing TSOs to step outside their usual comfort zones and compete with other industries that face similar challenges to find relevant skilled workers. Smaller TSOs are disproportionately affected, as they struggle to compete for talent. Efforts to establish Net Zero Academies and align educational curricula with industry needs are promising but require substantial lead time.

16) Offshore Network Development Plan 2024 Pan European Summary

The IEA projects that annual grid investments must more than double to reach $ 600 billion worldwide by 2030[17]. Smaller TSOs, which lack the economies of scale of larger operators, face unique challenges in securing financing, purchasing assets and delivering projects on time, as they face additional difficulties due to their size and the amount of required assets, making them less attractive to potential suppliers. Public-private partnerships and EU funding mechanisms, while beneficial, often come with strict conditions that may slow project execution. Increasing threshold values for procurement contracts would be one way to attract larger investments.

ENTSO-E together with the EU DSO Entity, T&D Europe, and Europacable have launched a collaborative effort to address European manufacturing resilience through a joint roadmap.[18] This work forms part of the actions foreseen in the Grid Action Plan of the European Commission of November 2023, which outlines actions to accelerate the roll-out of electricity grids[19].

17) International Energy Agency. (2023). Electricity Grids and Secure Energy Transitions" (p.9)
18) Press Release, ENTSO-E
19) Press Release, European Commission

6 Results show overall consistency with system needs identified in TYNDP 2022

Comparing the results of the 2022 and 2024 system needs studies confirm that achieving increasingly ambitious policies depends also on an increase in the amount of transmission infrastructure to be deployed. The needs identified in TYNDP 2024 are slightly higher than those identified in 2022, therefore confirming the economic headroom for optimising the European electrical system through additional cross-border capacities, storage installations, or any other innovative solution tackling the identified needs.

Looking at the numbers, the total capacity that would be economically efficient in 2040 increased from 208 GW in TYNDP 2022 to 269 GW in TYNDP 2024. While the 2024 study no longer considers CO2-free peaking units among potential candidates , the study has assessed the offshore hybrid corridors coming from ONDP 2024 together with other transmission candidates[20], confirming the potential for developing these solutions in the framework of the EU offshore strategy and the realisation of the Member States' non-binding agreements.

	In 2030, for the entire area studied		In 2040, for the entire area studied	
	TYNDP 2022	TYNDP 2024	TYNDP 2022	TYNDP 2024
Identified needs (additional to 2025 in TYNDP 2022, additional to 2030 in TYNDP 2024)	64 GW	88 GW	88 GW of cross-border capacity increases 41 GW of storage	108 GW 0 GW of storage
Total transmission capacity (identified needs + starting grid)	184 GW	249 GW	208 GW	269 GW
Increase in socio-economic welfare	5 bn €/year	8 bn €/year	9 bn €/year	13 bn €/year
Avoided curtailment	32 TWh/year	52 TWh/year	110 TWh/year	175 TWh/year
Avoided CO_2 emissions	38 Mton CO_2/year	31 Mton CO_2/year	44 Mton CO_2/year	30 Mton CO_2/year

Table 6.1 – Comparison of the main results in TYNDP 2022 and TYNDP 2024

20) Close to 0 peaking capacity was identified in TYNDP 2022, so it was decided to focus efforts on other methodological improvements.

The National Trends 2040 scenario, that is the basis for the analysis of system needs in 2040, encompasses the realisation of the Member States' non-binding agreements on offshore generation capacities, together with the compliance with national and EU targets. This meant a significant increase in the amount of offshore RES considered in the 2024 edition of the system needs study. In the 2022 edition, 217 GW of capacities have been considered in the TYNDP for the 2040 time horizon (National trends), while in the 2024 edition, this value increased to 381 GW (in the EU, Norway and UK).

2040 results confirm that hybrid corridors in the northern basins, together with the onshore additional capacity, have the potential to efficiently connect the generation deployed and optimize a system compliant with the set of targets offered by the different policies. Although results show some differences, they are overall very consistent, especially considering the differences in methodology and assumptions between 2022 and 2024. These include in particular the modelling methodology: while in 2022 a zonal model was used in 2030 and an NTC model in 2040, in 2024 an NTC model has been used in 2030 and a zonal model in 2040 and 2050. Other differences include the use of climate years, with the 2022 edition using 3 climate years in 2030, 10 in 2040, while the 2024 study relied on only three climate years for all time horizons. Another significant change in TYNDP 2024 is the modelisation of electrolysers as electric load only.

7 Maintaining system inertia in the future system

The transition to a decarbonised energy system is a process based on the fast integration of large amounts of renewable energy sources, of which the vast majority is connected to the transmission and distribution networks through power electronics (inverter-based resources) and the corresponding replacement of fossil-fuelled synchronous generators. The TYNDP 2024 shows that this transition will be further accelerated at an unprecedented volume to achieve the energy policy targets and unlock further societal welfare to the European citizens.

The electricity transmission system will have to adapt during this transformation, not only to facilitate the changing patterns of demand and generation, but also to manage the different operational characteristics related to system dynamics and stability when inherent features of rotating masses are being replaced by control strategies of the inverter-based resources supporting power system stability. The decrease of the inertia of the system is one of the natural consequences of the replacement of rotating synchronous generators resulting in an increased frequency-sensitivity and reduced frequency stability of the electricity system. As a consequence, in the Continental Europe Synchronous area (CE SA), the electricity system will be exposed to larger frequency excursions in case of power imbalances resulting from system splits (normal operation would not represent an immediate challenge). Therefore, for this synchronous area, ENTSO-E identified an increased challenge to keep frequency stability in all those situations and ensure the effectiveness of emergency measures in extreme cases, e.g. out-of-range events such as system splits of the CE SA.

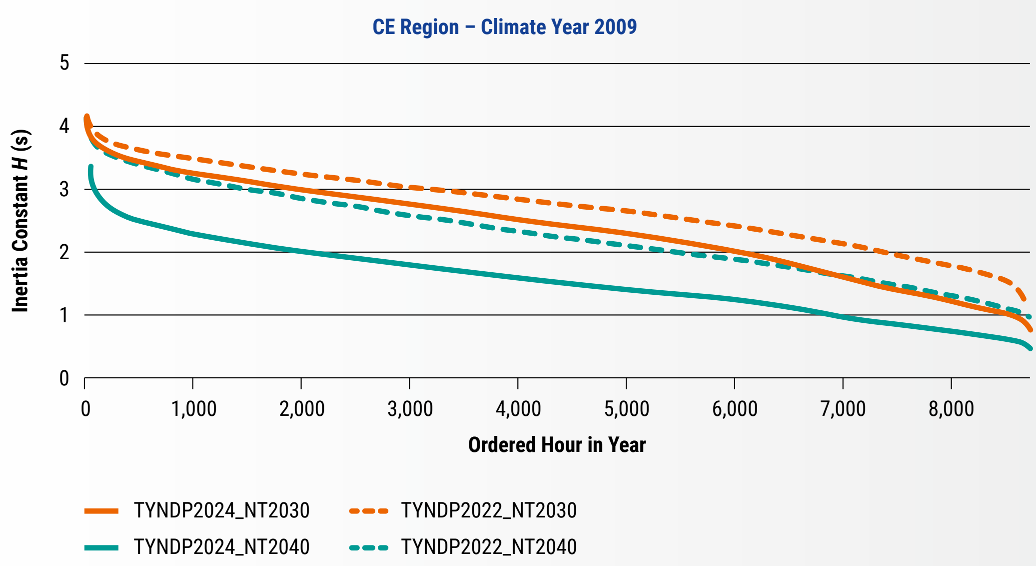


Figure 7.1 – Inertia duration curve of the Continental Europe Synchronous Area

Figure 7.1 shows the inertia duration curve of the CE SA for the National Trends scenarios of TYNDP 2022 and TYNDP 2024 for different target years. The accelerated decrease of inertia can be observed from the duration curves showing that in the TYNDP 2024 cases the values of inertia are lower in comparison to the same analysis performed in the TYNDP 2022. This difference become particularly evident in 2040 time horizon.

To recover the resilience up to a certain level, and to mitigate the occurrence of Global Severe Splits (GSS)[21)], all countries of the CE SA should ensure defined minimum levels of equivalent kinetic energy. The methodology identifying the inertia needs will provide guidance to the single countries on the minimum levels of kinetic energy ensuring the compliance with the assumed future rates of admissible rate of change of frequency (and considering that a larger number of out of range incidents could be managed with their countries own recovery services system).

In the past, system inertia was intrinsically provided by the rotating masses of connected synchronous generators and lack of resilience due to inertia was not an issue. Today and in future, robustness against GSSs requires investments that must be applied in a balanced and efficient manner either by network assets or by relevant capabilities of system users' installations.

ENTSO-E, through studies such as Project Inertia (based on the TYNDP data) proposes a step-by-step approach, aiming for no-regret and achievable steps to ensure system resilience against GSS, while continuously reassessing the needs and suitable solutions. Project Inertia, through its study of the CE SA, highlighted the trend in decrease of inertia for the said area and proposes a gradual and sustainable recovery of the system resilience. The challenge imposed by the decreasing level of inertia needs to be solved from both an operational point of view and an infrastructural point of view. Beyond the optimisation of enhanced remedial and preventive measures of the system defence plan, the following solutions will be necessary in terms of network assets or by relevant capabilities and availabilities of system users' installations:

- Synchronous Condensers,
- Energy storage with Grid Forming Capability,
- STATCOMs with Grid Forming Capability and storage,
- Power Park Modules with Grid Forming Capability and storage.

Long-term kinetic energy targets cannot be met without the contribution from all foundational measures[22)]. European countries need to agree on coordinated targets and to decide on the best mix of solutions to meet these targets.

21) A GSS is defined as an out-of-range event consisting in a separation of the interconnected CE SA into two subsystems after a disturbance, which cannot be managed by the system defence plan emergency measures and leads to a blackout of both subsystems.

22) For the definition of 'foundational measures' please read chapter 5 of the report "**Updated frequency stability analysis in long term scenarios, relevant solutions and mitigation measures**"

It is important to highlight that not all synchronous areas will have the same needs in terms of inertia at least in the near future, and the phenomena of its decrease appears differently in different areas. For example, in the Nordics synchronous area, as mentioned by the ENTSO-E report Requirement for minimum inertia in the Nordic power system "a minimum inertia value is not needed for the Nordic system in the near future. Considering socio-economic aspects, feasibility and risks, it is efficient to use frequency restoration reserve (FRR) as a complement to frequency containment reserves (FCR-D) to keep the instantaneous frequency above 49.0 Hz after a sudden power imbalance. As an additional remedial action to FFR, limiting the reference incident can guarantee the frequency stability during exceptional situations with low inertia. Considering socio-economic aspects, feasibility and risks, the new requirements for FCR-N and FCR-D will efficiently ensure transient and small signal stability after sudden power imbalances and in normal operation. Likewise, as for maintaining the instantaneous frequency, it can be necessary to utilise remedial actions to guarantee the frequency stability during exceptional situations with low inertia"[23].

Long term needs, global resilience level and distribution methodology needs to be reassessed every two years in the TYNDP System needs study to ensure a focused assessment of the inertia needs guiding the decision-making process to feasible and (cost-) effective mitigation actions on maintaining frequency stability implemented at national level.

23) Page 13 of the ENTSO-E report **"Requirement for minimum inertia in the Nordic power system"**

8 Next steps

Public consultation and ACER opinion

ENTSO-E is collecting feedback on the draft TYNDP 2024 until 14 March 2025. All interested stakeholders are invited to reply to our public consultation via ENTSO-E's Consultation Hub. Stakeholders comments will serve to improve TYNDP 2024 reports and online visualisation platforms. Comments regarding our methodologies will be taken into account in the development of TYNDP 2026.

In March 2025 ENTSO-E will release in Regional Investment Plans an analysis at regional and country level of the findings of the system needs study. The Plans will also contain information on relevant projects, including transmission projects that do not feature in the TYNDP portfolio but that are relevant from a national or regional perspective.

In Q1 2025 the entire TYNDP 2024 package will be submitted to ACER for Opinion. The Infrastructure Gaps Report will be submitted to ACER, the European Commission and EU Member States for opinion. After reception of all opinions ENTSO-E will finalise and publish the TYNDP.

Towards TYNDP 2026

Stakeholders engagement plan

ENTSO-E released the panned scope of studies and the stakeholders engagement plan of TYNDP 2026 on 13 December 2024 for public consultation until 24 January 2025. In addition to public consultations, stakeholder webinars and workshops will be organised to explain in detail the various parts of the package, gather feedback at an early stage on input data and assumptions and include the outcome in TYNDP 2026 deliverables.

Projects collection

Promoters of infrastructure projects will play a key role also in the TYNDP 2026 process. The submission window to propose projects for TYNDP 2026 will take place by mid-2025. ENTSO-E will release in early February 2025 for consultation a Guidance document that sets the exact timeline, process, and requirements to submit a project to TYNDP 2026. New and revised projects may be proposed and assessed in TYNDP 2026, potentially addressing some of the gaps identified in the present report.

Perspectives for future system needs studies

The System needs study is an evolving tool to manage uncertainty in the progress of the energy transition. Possible improvements for future issues are being investigated and will consider the feedback received from stakeholders in the public consultation, as well as the views of ACER and of the European Commission.

The TYNDP offers a view on how and how much the electricity system should increase its capacity to optimally achieve the EU and national energy policy targets and societal benefits from a socio-economic perspective. As national and EU policy frameworks become more complex and ambitious, ENTSO-E acknowledges the need to have an coordinated and comprehensive view of the infrastructure gaps on- and offshore, at European and regional level while also identifying in the TYNDP the most appropriate power transmission corridors by determining the socio-economic and technical benefits both for European, regional and project-specific performance, as support of the activities in their next planning phase. It is important to reflect the impact of sector integration on the development of the European energy infrastructure systems through a holistic approach across time, space and sectors.

TYNDP 2026 will be structured around a Central Scenario, rooted solidly in national strategies, for the target years 2035, 2040 and 2050. This Central Scenario will be accompanied by economic variants ensuring the assessment of its robustness against the variation of several input parameters, as foreseen in ACER's Framework Guidelines[24),25)]. The Central Scenario will be built on the basis of EU Member States' National Energy and Climate Plans and the national strategies of non-EU countries. This will ensure a solid basis for the assessment of the impact of these strategies on the electricity infrastructure and the subsequent development of the TYNDP.

24) Framework Guidelines for the joint scenarios for network development planning of electricity and gas

25) For information on TYNDP 2026 scenarios under development by ENTSO-E and ENTSOG together with the Stakeholder Reference group, visit https://2026.entsos-tyndp-scenarios.eu/.

TYNDP 2026			
Scenarios	Assessment of system needs		Cost-benefit analysis of projects
	Offshore Network Development Plans	System needs study / Infrastructure gaps	
What would the European energy system look like if all EU targets are met and NECPs and national strategies are implemented?	What infrastructure is needed to implement EU Member States targets for offshore RES development?	Where could the onshore and offshore power system provide societal benefits from a socio-economic perspective?	How does each individual infrastructure project contribute to the European societal benefits?

Change	Impact
The assessment of system needs becomes an integrated study of cross-border capacity, storage capacity and hybrid offshore capacity needs.	Further improved consistency
Planned early consultation of all input data and assumptions	Increased stakeholder engagement
Involvement of the Scenarios Stakeholder Reference Group from the start of the scenario-building process	Increased stakeholder engagement
Studies focused on one policy-based scenario	Further alignment with EU targets and national plans

Table 8.1 – Main planned changes in TYNDP 2026 compared to TYNDP 2024

Annex I – Stakeholder engagement in TYNDP 2024

Like for the previous editions of the TYNDP, ENTSO-E actively involved stakeholders recognising their value as a key factor to provide input at early stages to enhance collaboration and achieve sustainable outcomes.

The strategy of effective stakeholder engagement includes public consultations, webinars and workshops on key issues, and maintaining a public consultation webpage. Visualisation platforms and reports are available to ensure transparency and facilitate stakeholders information and feedback submission. Throughout the TYNDP development process, ENTSO-E has also engaged regularly with DG ENER of the European Commission and with ACER.

All relevant news and publications are available at https://tyndp.entsoe.eu/. This page centralises all relevant information throughout the TYNDP 2024 process, including the "Promoters' corner" for more specific information for project promoters.

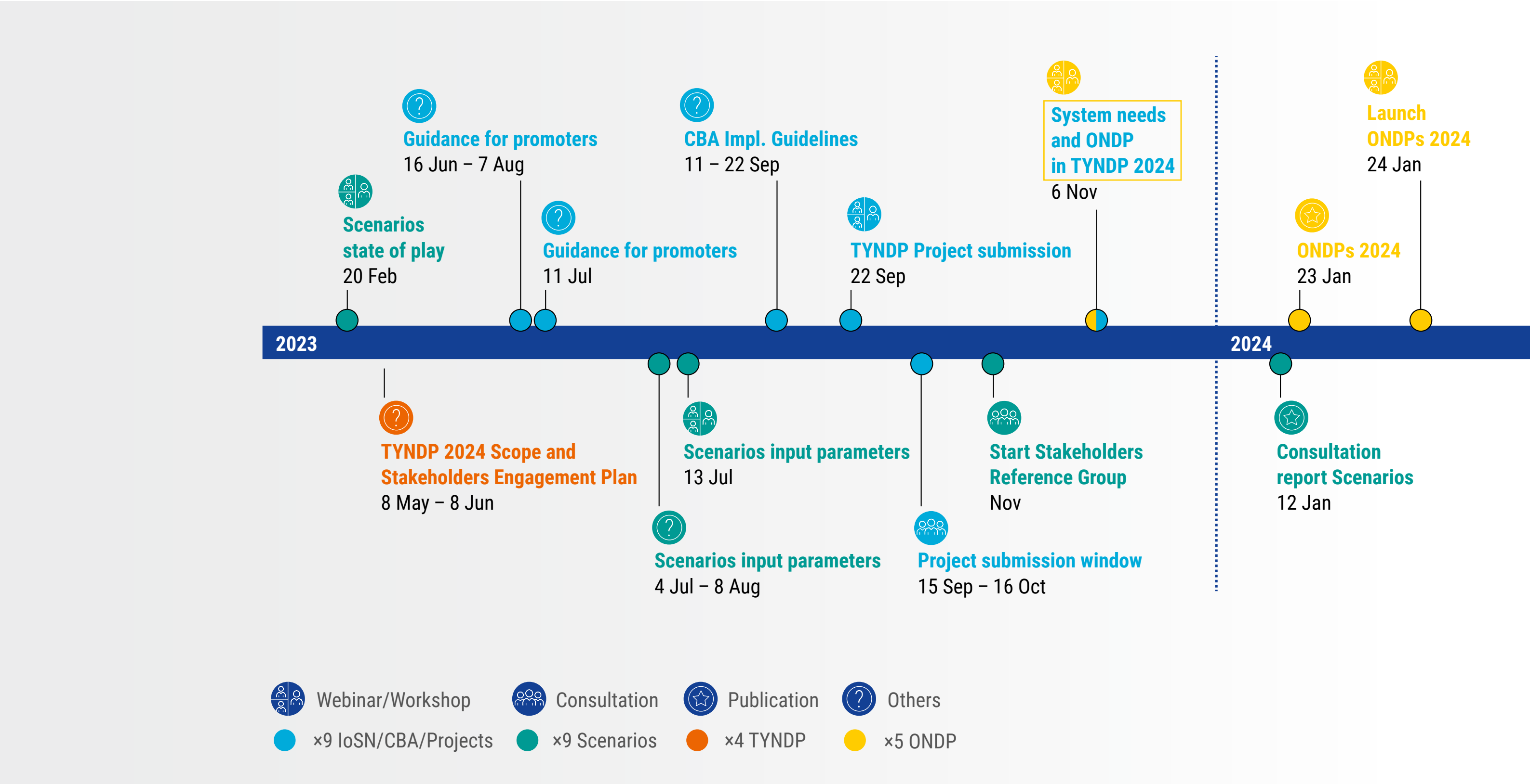
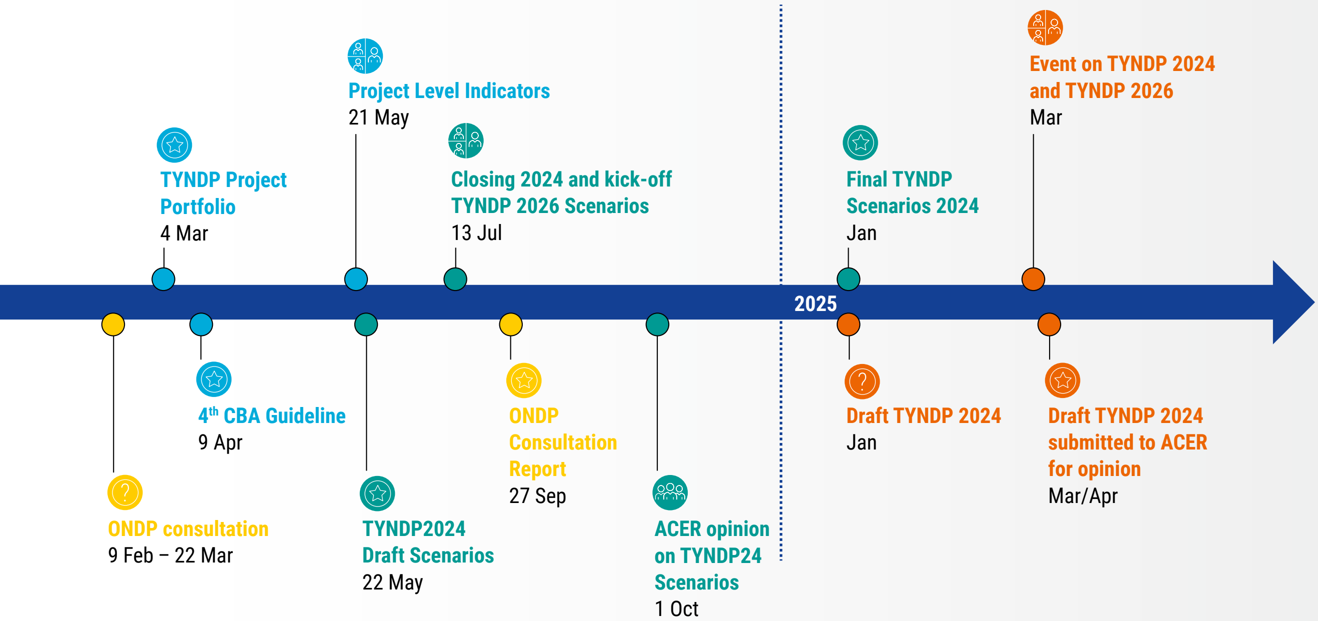


Figure A.1 – Timeline of stakeholder engagement activities in TYNDP 2024


Project Level Indicators
21 May
TYNDP Project Portfolio
4 Mar
Closing 2024 and kick-off TYNDP 2026 Scenarios
13 Jul
Event on TYNDP 2024 and TYNDP 2026
Mar
Final TYNDP Scenarios 2024
Jan
2025
4th CBA Guideline
9 Apr
ONDP consultation
9 Feb – 22 Mar
TYNDP2024 Draft Scenarios
22 May
ONDP Consultation Report
27 Sep
ACER opinion on TYNDP24 Scenarios
1 Oct
Draft TYNDP 2024
Jan
Draft TYNDP 2024 submitted to ACER for opinion
Mar/Apr

A closer look at the feedback received in public consultations

The analysis of comments received for the recent public consultations reveals a nuanced spectrum of feedback from stakeholders, ranging from positive reactions to calling for improvements.

All public consultation considered, the comments received during consultations show a high representativeness of all categories of stakeholders. The general tone of feedback tends to be critical yet constructive. While respondents recognize improvements and positive elements, particularly in transparency and stakeholder involvement, they also criticize some methodological aspects of the TYNDP process.

The large number of responses coming from EU Member States show a strong regional engagement throughout the TYNDP 2024 process. Figure A.2 indicates that over 5 out of 6 responses come from Member States. EU-wide organisations have been particularly involved in the process (41 % of the answers). Alongside this large group, most responses came from Germany (10 %), Denmark (9 %), France (6 %), Italy (6 %), and the UK (7 %). Additionally, there were contributions from other Member States (13 %) and other non-EU countries (7 %). This distribution indicates a broad engagement across multiple European countries, reflecting diverse perspectives and regional interests in the consultation process.

Regarding sectorial representativeness on the answers to public consultations, Figure A.3 shows the wide-ranging stakeholder interest and input across different energy sectors. The continuous involvement of organisations involved on energy efficiency with 17 responses (25 %), energy (electricity, gas and hydrogen) associations with 16 responses (24 %), and supply-side operators with 16 (24 %) show strong interest from EU and non-EU industrial partners on the TYNDP process. Moreover, responses also showed substantial interest from civil society representatives and governmental organisations (with 9 and 4 responses, representing 13 and 6 % of total responses).

Public consultations have been particularly relevant for ENTSO-E to gather feedback from stakeholders. Figure 3 shows the outcome of the sentiment analysis based on the responses to our consultations. We have classified responses into three different categories based on their content: Positive answers (10 responses) indicate that most of the content highlights the strengths of the TYNDP studies and comments repeatedly emphasise those; Neutral comments (38) highlight the strengths, but those comments are notably balanced by constructive feedback on areas in which our processes and publications could be improved. Lastly, 20 answers ask for improvements.

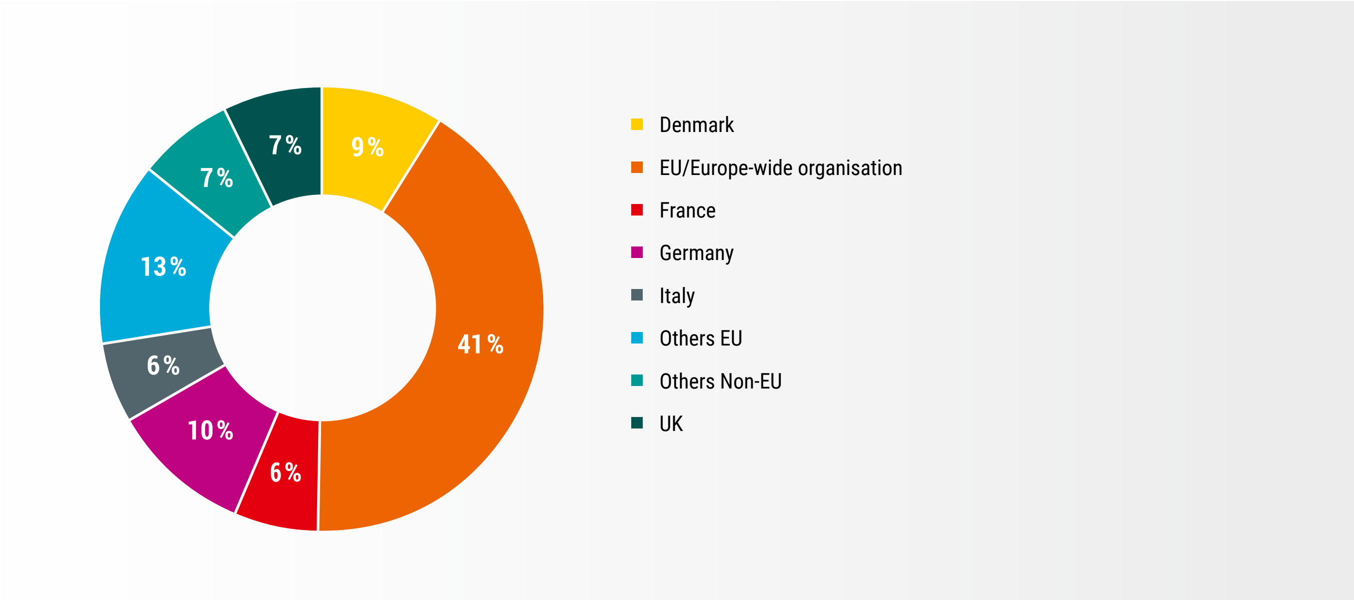


Figure A.2 – Percentage of responses to public consultations by country/area (EU corresponds to EU/Europe-wide organisations).

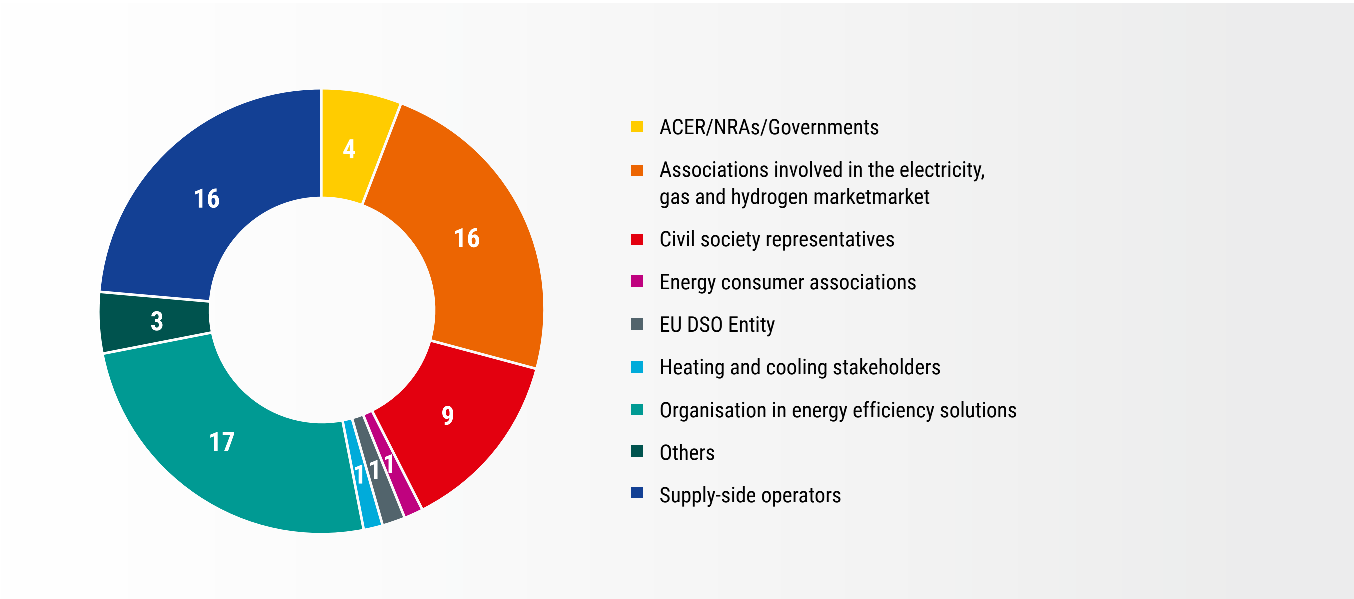


Figure A.3 – Number of responses by (TEN-E) stakeholder category

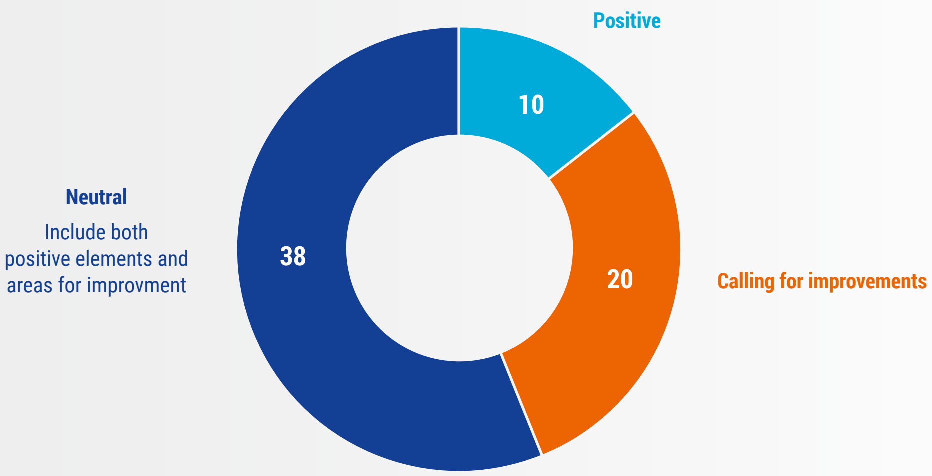


Figure A.4 – Number of responses per tone of response

Exhaustive accounts of all comments received to all public consultations performed in the development of TYNDP 2024 are available online.

Consultation
TYNDP 2024 Scope and stakeholders engagement plan
Guidance for promoters
TYNDP 2024 Scenarios input parameters
ONDP consultation

Engagement plan for project promoters

Project promoters are key stakeholders in the TYNDP process, and ENTSO-E has put in place dedicated communication activities to ensure a smooth bi-directional sharing of information.

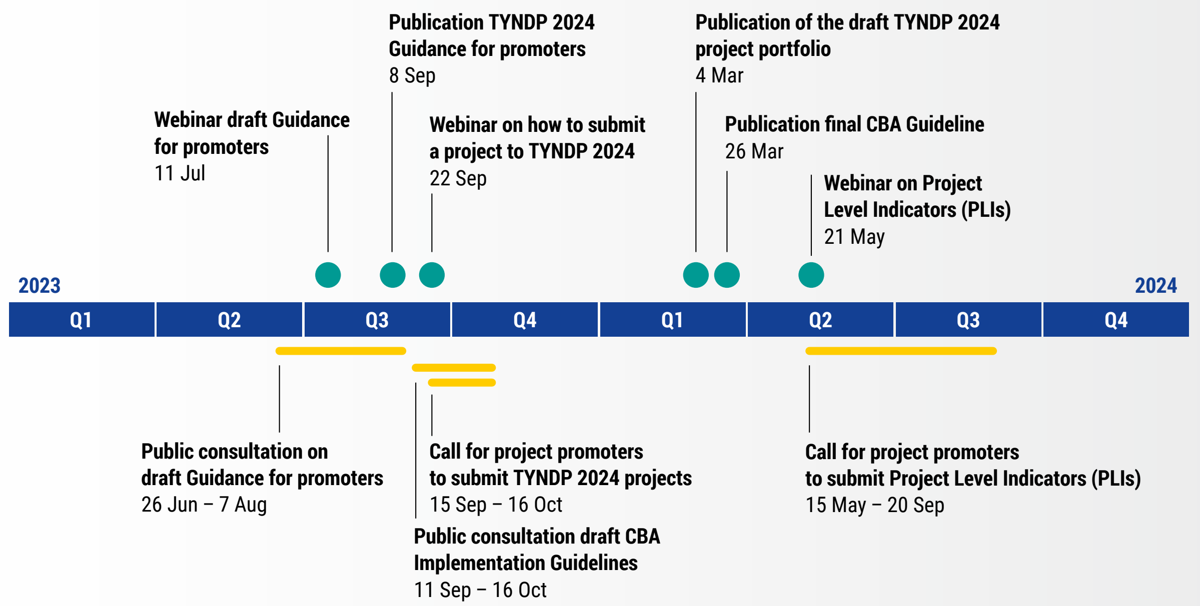


Figure A.5 – Communication to promoters: Release of key documents, webinars and data collection windows.

Acknowledgements

ENTSO-E would like to thank all the experts involved in the Ten-Year Network Development Plan 2024 for their commitment and enthusiasm in building this unique coordinated pan-European plan. In particular, ENTSO-E would like to thank the following experts who contributed to the TYNDP:

Authors of this report – TYNDP Editors team

Léa Dehaudt (Convenor) .... ENTSO-E
Clément Grouthier .... RTE
Katerina Macos .... IPTO
Michael Heit 50Hertz
Michela Perrino .... Terna
Tommi Asp .... Fingrid
Xosé María Vega Arias .... ENTSO-E

TYNDP Project Management

Francesco Celozzi .... ENTSO-E
Giulio La Pera .... ENTSO-E
Rodrigo Barbosa .... ENTSO-E

TYNDP Steering Group

Patricia Labra (Convenor) .... Redeia
Katerina Macos .... IPTO
Andrew Kasembe .... ČEPS
Domenico Iorio .... Terna
Michael Heit 50Hertz
Mirela Mustavic .... Svenska Kraftnät
Ralph Pfeiffer .... Amprion
Stephan Osterbauer .... APG

Quality Control Board

Aaron Keyes .... Eirgrid
Andrew Kasembe .... ČEPS
Antonio Conserva .... Terna
Arno Haverkamp .... TenneT
Belén Segura Díaz .... Redeia
Katerina Macos .... IPTO
Michael Heit 50Hertz

WG ACB

Belén Segura Díaz .... Redeia
Bertrand Vosse .... Elia
Bjorn Slettan .... Statnett
Fabiola Aravena .... RTE
Franck Dia Wagoum .... ENTSO-E
João Pedro Castro .... REN
Nils Schindzielorz .... TenneT
Philipp Fortenbacher .... Amprion
Stefano Massimo Spiga .... Terna

Planning Study Team

Andriy Vovk (Convenor) .... ENTSO-E
Ahmad Usman Khan .... Eirgrid
Alexandra Andor .... Tennet
Ali Pourimani .... APG
András Kádár .... MAVIR
Andrzej Tymorek .... PSE
Arthur Burlin .... RTE
Balázs Turoczi .... MAVIR
Bartosz Zagórowicz .... PSE
Chittesh Chandran .... Eirgrid
David Böhm .... APG
Fabiola Aravena .... RTE
Fabrice Guy .... RTE
Fernando Postigo .... Redeia
Francesca Ferretti .... Terna
Gaetan Schoore .... RTE
Gerjan Emsbroek .... TenneT
Giorgiana Giosanu .... Transelectrica
Giulia Antonini .... Terna
Guillaume Malingue .... RTE
Gustave Sobek .... RTE
Iason Dizes .... ENTSO-E
István Márk .... MAVIR
Jean-Michel Berton .... RTE
Jörg Leonhardt .... APG
Jose Cerda-Arias .... TenneT
Laura Lopez Garcia .... Redeia

Louise Ansart .... RTE
Lukas Ingenhorst .... Amprion
Maria Giovanna Russo .... Terna
Mikko Koskinen .... Fingrid
Mirza Sarajlic .... Amprion
Mónika Németh .... MAVIR
Natalie Ebersbach .... TenneT
Nicolas Dominguez .... RTE
Ondřej Hladík .... ČEPS
Orhun Selcuk .... TenneT
Pedro Javier Sanchez Gonzalez .... ENTSO-E
Peter Van Roy .... Elia
Radek Vrábel .... ČEPS
Reuban Samikkannu .... Eirgrid
Rimantas Rutkauskas .... Litgrid
Robert Raczkowski .... PSE
Rohit Trivedi .... Eirgrid
Romain Bouguillon .... RTE
Ruben Lopez Sanz .... Redeia
Santiago Barbero .... ENTSO-E
Sebastian Spieker 50Hertz
Simon Bouchillou .... RTE
Simon Deschanvres .... RTE
Tamás Decsi .... MAVIR
Thibault Le-Gac .... RTE
Thomas Rzepczyk .... Amprion
Thomas Schwarz .... RTE
Thomas Haydn .... APG
Timothy Hofmann .... APG
Vasilis Banos .... IPTO

Special thanks to

ENTSO-E's Data & Models team
TSOs data correspondents
Anna Butenko .... ENTSO-E
Branislav Pilat .... SEPS
Emil Tan .... ENTSO-E
Joao Moreira .... REN
Christelle Verstraeten .... ENTSO-E

Design
DreiDreizehn GmbH, Berlin . www.313.de

Cover Image
© iStock

Images
Cover: ©pexels, kellyisfancy
page 17: courtesy of TenneT
All others: © iStockphoto.com

Publication date
January 2025

ENTSO-E . Rue de Spa 8 . 1000 Brussels . Belgium