TYNDP 2022

System Needs Study

Opportunities for a more efficient European power system in 2030 and 2040

Final Version · May 2023

entsoe

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 39 member TSOs, representing 35 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 use 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.

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Ten-Year Network Development Plan 2022

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.

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

ENTSO-E System needs visualisation platform
https://needs.entsoe.eu

Questions?

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

Contents

Highlights

- Europe's power system is evolving rapidly. ENTSO-E's System Needs study shows **where opportunities exist to maximise the efficiency of Europe's power system** in 2030 and 2040, to deliver on the climate agenda and ensure security of electricity supply.

- The opportunities identified in our study exist **in a future reflecting EU Member States National Energy and Climate Plans** and long-term national strategies. In this future, significant gains in energy efficiency have already been achieved, and considerable uptake of renewable energy sources and system flexibility has taken place. System needs go beyond this point to provide a secure, cheap and decarbonised electricity at all times and in all places.

- **Opportunities for improving Europe's power system exist all over Europe**. Between 2025 and 2030, the study finds that 64 GW of additional capacity on over 50 borders would be economically efficient, a 55 % increase over the 2025 grid. In 2040, there is space for 88 GW of cross-border capacity increase after 2025 (a 75 % increase) on over 65 borders, for 41 GW of storage in 19 countries and 3 GW of CO_2-free peaking units in 4 countries.

- The study's findings are all the more relevant in the context of uncertainty over natural gas supply from Russia and rising gas prices. One of the main benefits of addressing system needs is to **replace gas-based power generation by renewables**, thus reducing Europe's dependence on gas. By connecting more consumers with more producers, grid development allows European countries to exchange electricity to replace expensive thermal generation with cheaper one, mainly renewable. **The higher the gas price, the more beneficial it is to develop Europe's cross-border grid**. Gas-based generation would decrease by 75 TWh per year in 2040 (equivalent to 14 % of the electricity generation from gas in the EU in 2021), while the avoided curtailment of renewable energy reaches 42 TWh per year in 2040.

- A more efficient use of the European generation mix translates in turn into **significant reduction in CO_2** emissions of 31 Mton / year in 2040, helping Europe to achieve its Green Deal objectives. It also **reduces generation costs** by 9 Billion euro / year in 2040, with a direct impact on consumers' electricity bills.

- **All possible solutions** should be considered by project promoters and policymakers when opportunities turn into projects. Coordinated planning will be needed **across sectors**. Identified needs can be addressed in multiple ways, including with infrastructure (new or upgraded transmission infrastructure, electricity storage, power to gas or hybrid infrastructure) and non-infrastructure solutions such as dynamic line rating.

- Project promoters are invited to propose solutions to the opportunities identified in the present study to be included in the TYNDP 2024 project portfolio. To identify the best combination of solutions, the TYNDP considers a **comprehensive assessment of projects**, looking beyond socio-economic welfare including social and environmental impact, project feasibility and refined costs.

- The energy transition is also creating **challenges for system operations**. Trends show a reduction of system inertia due to increasing integration of renewable energy sources and distributed generation, leading to higher frequency sensitivity. Flexibility options will gain in importance, both at generation, demand, and infrastructure level.

2022

Today's power system

93 GW of cross-border transmission capacity

2025

23 GW of cross-border capacity increases in construction or in advanced stages of permitting until 2025

2030

If Europe stopped investing in the grid after 2025

- **35 TWh/year** curtailed renewable energy
- **393 TWh/year** gas-based power generation
- **323 Mton/year** CO_2 emissions
- **104 Billion €/year** generation costs

With 64 GW of cross-border capacity increases after 2025

- **18 TWh/year** curtailed renewable energy
- **384 TWh/year** gas-based power generation
- **309 Mton/year** CO_2 emissions
- **99 Billion €/year** generation costs

- 17 TWh/year of avoided curtailment
- Gas-based generation reduced by 9 TWh/year
- 14 Mton/year of avoided CO_2 emissions
- 5 Billion €/year saved in generation costs

With 88 GW of cross-border capacity increase after 2025, 41 GW of storage and 3 GW of peaking units

2040

If Europe stopped investing in the grid after 2025:

- **78 TWh/year** curtailed renewable energy
- **366 TWh/year** gas-based power generation
- **175 Mton/year** CO_2 emissions
- **132 Billion €/year** generation costs

With 88 GW of cross-border capacity increase after 2025, 41 GW of storage and 3 GW of peaking units:

- **36 TWh/year** curtailed renewable energy
- **291 TWh/year** gas-based power generation
- **145 Mton/year** CO_2 emissions
- **123 Billion €/year** generation costs

- 42 TWh/year of avoided curtailment
- Gas-based generation reduced by 75 TWh/year
- 31 Mton/year of avoided CO_2 emissions
- 9 Billion €/year saved in generation costs

Q&A

What are system needs?

Needs, also referred to as system opportunities, show where new solutions are needed to contribute to reaching European decarbonisation targets and keep security of electricity supply and costs under control. This study focuses on needs beyond the next anticipated wave of cross-border grid investments of 23 GW by 2025 corresponding to projects currently under construction or in final permitting stages, additional to the 93 GW available in 2022. They use the National Trend scenarios for 2030 and 2040, which means that power system needs exist in a world where significant uptake of renewable energy sources and system flexibility already happened.

Where are there opportunities for improving Europe's power system?

Opportunities exist all over Europe. In 2030, the study finds 64 additional GW of needs on over 50 borders, a 55 % increase on the 2025 grid. In 2040, results find space for 88 GW of cross-border capacity increase after 2025 on over 65 borders (a 75 % increase on the 2025 grid), for 41 GW of additional storage in 19 countries and 3 GW of additional CO_2-free peaking units in 4 countries. The 41 GW of storage capacity add up to the 126 GW of battery storage available in 2030. All storage technologies combined, the total storage capacity in 2040 amounts to 174 GW.

The highest identified capacity increases in both time horizons are located on the UK borders to continental Europe, on German and French borders and to accommodate flows between South-Eastern and Central Europe, from Turkey through the Balkans all the way to Czech Republic. There is a significant increase in needs after 2030 on Italian borders to integrate the Italian peninsula, and on borders between Scandinavian countries and mainland Europe. In most of western and central Europe capacity increases are complemented in 2040 by storage, with highest needs in Spain, Germany, Italy, Portugal and Hungary, and to a much smaller extent by peaking units in Hungary and Poland.

How were stakeholders involved in the identification of system opportunities?

Stakeholders contributed to defining the methodology to identify system needs, with a webinar organised in October 2021 where ENTSO-E presented the main assumptions and proposed improvements to the methodology (compared to TYNDP 2020). 120 stakeholders representing among others the industry, policy-makers and projects promoters commented on the time horizons studied, on the scenarios, on the transparency and availability of the data. A detailed account of stakeholders' feedback is available in the TYNDP 2022 Stakeholders Engagement report.

This System needs report was submitted to a public consultation from 29 July to 16 September 2022 alongside the rest of the TYNDP 2022 package. Stakeholders provided many comments on the system needs study, a summary is available in the TYNDP 2022 Stakeholders Engagement report, alongside with all comments received and ENTSO-E's answers. To further engage with stakeholders, a webinar took place in early September 2022. Stakeholders wishing to discuss how the assessment of system needs could be further improved are welcome to contact ENTSO-E at tyndp@entsoe.eu.

Does the study consider the EU's goal to reduce dependency on gas imports?

TYNDP 2022 scenarios for the future of Europe's energy system, on which the system needs study is based, were developed from mid-2020 to early 2022, before the start of the war in Ukraine. The System needs study assesses the National Trends scenario, which reflects EU Member States National Energy and Climate Plans and other long-term national strategies as they were in 2020. The National Trends scenario foresees 3268 TWh and 2416 TWh of natural gas imports in 2030 and 2040 respectively.

It is to be investigated how a total energy independence from Russia would impact needs throughout Europe for transmission, storage, power-to-gas assets or any other solution, also in the light of any new target regarding energy efficiency, renewable energy or electrolysers to be adopted by the EU in the context of the Fit for 55 Package and REPowerEU discussions. Future TYNDPs will investigate such evolutions and their impacts on the power system needs considering the increasing European ambitions to integrate renewable energy and improve energy savings by 2030. However, a clear finding from our study is that one of the main benefits of addressing system needs is to reduce Europe's dependence on gas-based power generation. By connecting more consumers with more producers, grid development allows a better use of the cheapest generation. As a result, European countries can exchange electricity to replace expensive generation (gas and coal) with cheaper one (mainly renewable). Addressing system needs reduces gas-based generation by 9 TWh in 2030, and by 75 TWh in 2040. 75 TWh represents 14 % of the electricity generation from gas in the EU in 2021.

Our study's findings are therefore still very relevant in the current context of uncertainty on natural gas supply from Russia and of rising gas price. The higher the price of natural gas, the more beneficial it becomes to invest in Europe's cross-border electricity grid.

What is new in the 2022 system needs study?

ENTSO-E constantly reviews and improves its methodology from one edition of the TYNDP to the next, based on the feedback received from stakeholders, ACER and the European Commission.

- In 2020 there was general agreement that considering only one climate year was not enough. To address that concern, the 2022 needs study considers 3 different climate years in 2030 and 10 different climate years in 2040. Considering different climate conditions reinforces the robustness of the results. In addition, in 2040 it allows us to provide indicative information on needs related to security of supply, in terms of avoided energy-not-served.
- The list of investment candidates used in the optimisation has been updated with new cross-border capacity increases in TYNDP 2022. Furthermore, in 2022 we have also broadened the list of investment candidates to introduce storage and CO_2-free peaking units in the 2040 horizon (in addition to storage and peaking capacities included in the scenario).
- The zonal model approach, implemented as a pilot in TYNDP 2020 in the 2040 horizon, has been used this time to study the 2030 horizon because it provides more detailed and robust results in this time horizon most relevant for the European PCI process and EU objectives. The zonal model has been entirely reviewed to better account for grid contingencies, therefore providing a more accurate reflection of the 2030 power network.
- For the first time, stakeholders were involved early on in the study with a webinar where ENTSO-E presented the proposed methodology and the main changes compared to previous TYNDPs.
- A last main improvement introduced in 2022 is the additional perspective brought by comparing identified needs in the system needs study in the National Trends scenario, with the capacities obtained when building the Distributed Energy scenario. This comparison allows to confirm the main findings of the study.

Needs & Solutions

What are solutions to address system needs?

The System Needs study does not identify solutions. The methodology only provides an indication of where, for example, market integration could be improved, but it cannot prioritise between possible solutions to address identified needs. Different valuable solutions, or a combination of solutions, may exist to tackle any identified needs. ENTSO-E expects that addressing tomorrow's challenges will require the parallel development of diverse solutions, including with infrastructure (new or upgraded transmission infrastructure, electricity storage, power to gas or hybrid infrastructure) and non-infrastructure solutions such as dynamic line rating. Solutions to the needs will be proposed by project promoters. ENTSO-E invites promoters to propose projects for the TYNDP 2024 project portfolio in the fall of 2023, to address some of the needs identified in TYNDP 2022.

How does the System Needs study relate to the Cost-Benefit Analysis of projects?

The assessment of system needs and the cost-benefit analysis of projects are two distinct steps in the TYNDP process, that complete each other to help policy-makers identify the most relevant projects at a given time.

The System Needs study looks at where action is needed: where the flow of electricity could be improved across Europe, to reach decarbonisation targets and keep security and costs under control. It consists in an economic optimization exercise, looking at the combination of needs that maximises benefits (in terms of reduced curtailment of renewable energy, improved security of electricity supply…) while minimising system costs. The System Needs study therefore 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.

Identifying solutions to address the needs is up to project promoters, who may propose their projects for assessment in the TYNDP. ENTSO-E then performs a cost-benefit analysis, looking at how individual projects perform on multiple indicators, including how the project impacts socio-economic welfare, security of supply, impact on reduction of CO_2 emissions, integration of renewable energy sources, frequency stability.

Will TSOs plan the future grid based on identified system opportunities?

The System needs study is not a network development plan, though assessing system needs is a critical component of any network development plan. The study investigates one particular dimension of the future, which is where increases in cross-border network capacity and storage and peaking flexibilities would be economically justified from a pan-European perspective.

To plan future network development, TSOs consider a multitude of additional aspects not considered in the System needs study, including other benefits of projects (for instance in terms of frequency stability) and their environmental and technical feasibility. TSOs also consider other scenarios of evolution of the energy system. TSOs will use the study's findings as an additional input to develop future National Development Plans, in complement to national and regional planning studies.

How does the TYNDP 2022 project portfolio cover the identified needs?

Many projects able to solve system needs by 2030 are already on the table and are assessed in TYNDP 2022. 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 potential gaps. Comparing needs with ongoing projects reveals a 15 GW potential gap in infrastructure development in 2030, mainly in a corridor going from Turkey through the Balkans up to Czech Republic. A second area where investments could be higher is throughout the Baltic sea, to connect Scandinavia to mainland Europe.

The gap between needs and projects has reduced since TYNDP 2020, where only half of the 50 GW of needs in 2030 could be linked to existing projects. This shows that, based on the TYNDP, TSOs and other project promoters are working on projects to close the investment gap: of the 10 new interconnectors and hybrid projects proposed for consideration in the TYNDP 2022 portfolio, seven address needs identified in the 2020 system needs study. In some cases, infrastructure gaps reflect financing and permitting limits that TSOs face when elaborating their project portfolios, and most probably also sometimes the need for parallel development of internal grids. Infrastructure solutions will therefore need political support, including through the European Projects of Common Interest process, to become available by 2030. Non-infrastructure solutions and additional improvements in energy efficiency also require time to deliver results. Reaching Europe's Green Deal objectives in 2030 will require exploring all possible solutions to bridge the gap.

There is no system need identified on a border, does it mean that no infrastructure should be built?

The System needs study is a partial exercise that investigates one specific dimension of future system needs, which is where increasing cross-border capacity would bring the most economic benefits. Planning electricity transmission infrastructure requires to consider a whole area of indicators, including costs but also for example benefits of projects in terms of frequency system stability, reduction of CO_2 emissions and other greenhouse gases, etc. It is therefore possible that a project is globally a positive investment even though it is on a border that is not included in the optimal combination of capacity increases identified by the System Needs study, or when the benefits of investing on that border are not fully captured by the study.

Will the System needs study results be considered by the European Commission to select Projects of Common Interest?

Regulation (EU) 2022/869 makes the TYNDP the basis for the selection of Projects of Common Interest (PCIs). However, the process to select European PCIs is under the responsibility of the regional groups led by the European Commission, who ultimately decides on the material to be taken into consideration. ENTSO-E stands ready to provide the European Commission with all required information.

What's next?

What are plans for future improvements of the study?

Possible improvements for future issues will consider the feedback received from stakeholders in the public consultation as well as from ACER and the European Commission. It will also be impacted by the newly revised TEN-E [Regulation (EU) 2022/869], which puts a much stronger emphasis on the energy efficiency first principle, system integration and greater coordination of infrastructure planning across various sectors with a view to ensuring a smarter, more integrated, long-term and optimised "one energy system" view to achieve European energy targets and climate neutrality objectives. The ENTSO-E System Needs Studies (aka Infrastructure Gaps Report based on the revised TEN-E Regulation mandate) will play an even more prominent/central role in supporting these objectives.

Extensive stakeholder engagement and consultation processes will continue to be key in ensuring that all relevant stakeholders, regulatory authorities and Member States' representatives have the possibility to contribute to the infrastructure gap assessment. In addition, ACER, the European Commission and Member States will be able to provide opinions on the infrastructure gaps' reports before ENTSO-E finalises each report.

Additionally to changes introduced by the TEN-E Regulation, the TYNDP 2024 Infrastructure Gap study will for the first time include identification of needs for hybrid offshore infrastructure. ENTSO-E has launched the development of a methodology to assess these needs. A positive proof-of-concept has been developed and tested in 2021 and 2022 and will be finalised in view of its implementation for the first time in the system needs study of TYNDP 2024.

Introduction:
About the system needs study

The System needs study is carried out by ENTSO-E biannually and forms part of the Ten-Year Network Development Plan (TYNDP) 2022 package.

The present report investigates system needs and opportunities in the 2030 and 2040 horizons. For example: where could CO_2 emissions be further reduced? Where could the curtailed electricity from renewable energy sources be used? Where are there possibilities for increased price convergence between neighbouring countries? Where would additional interconnections and other flexibilities like storage improve the system behaviour and the security of electricity supply?

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

The TYNDP is a long-term plan on how the electricity transmission grid is expected to evolve in Europe to implement the EU long-term energy and climate strategy and objectives and enable the EU to reach its Green Deal objectives. Identifying the system needs is the second step in the development of the TYNDP. The TYNDP 2022 scenarios developed jointly by ENTSO-E and its gas counterpart ENTSOG are described in the TYNDP 2022 Scenarios report of April 2022. The TYNDP 2022 performs a cost-benefit analysis of 141 transmission and 23 storage projects and evaluates how they contribute to meeting the system needs for 2030 and 2040.

SCENARIOS
Range of possible futures to test infrastructure needs and projects

▶

SYSTEM NEEDS
Identify where new system assets would bring benefits in the scenarios

▶

PROJECTS ASSESSMENT
Cost-benefit analysis of transmission and storage projects in the scenarios

Figure 0.1 – The three main steps in the TYNDP process

Needs identified in the TYNDP 2022 System needs study may lead to the development of new projects addressing those needs. These projects may be developed and assessed in future national development plans and TYNDPs.

Running the System needs study every two years enables the needs behind existing projects to be monitored. As and when needs change because scenarios evolve, project promoters may redefine or even cancel projects, also considering economic profitability due to market developments. Detailed results of this study can be visualised and downloaded in spreadsheet format from our data platform.

Alongside this System needs report, ENTSO-E publishes six regional investment plans diving into details of the specific needs identified in each region and including additional sensitivity studies. For the first time, each regional investment plan includes a roadmap for further studies of the needs identified at regional level.

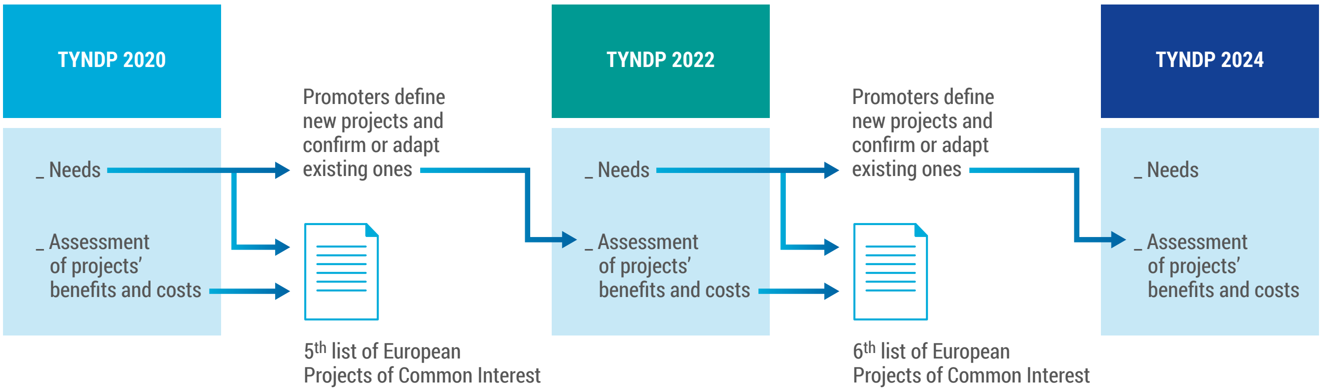


Figure 0.2 – Interrelation between system needs studies, project portfolios and project assessments in successive TYNDPs

An evolving tool to enable the energy transition

The System needs study is an evolving tool to manage increasing uncertainty in the context of the energy transition and the EU Green Deal ambitions. Its methodology and scope improve with each new edition. In 2022 we introduce flexibility assets (storage and CO_2-free peaking units) in the study in the 2040 horizon. The study also considers 10 different climate years in that time horizon, which allows to obtain information on needs related to security of supply. In the 2030 horizon, the zonal model has been entirely reviewed to consider grid contingencies.

Experts' corner – Our methodology

Our methodology to identify capacity increases is fully detailed in a separate **System Needs Study Implementation Guidelines**.

In a nutshell, to analyse system needs by 2030 and 2040 we determined the combination of potential increases in cross-border network capacity that minimize the total system costs, composed of total network investment (including costs of related necessary internal reinforcements) and generation costs. To do that, a panel of possible network increases was proposed to an optimizer, who identified the most cost-efficient combination. To take into account the mutual influence of capacity increases, the analysis was performed simultaneously for all borders and all countries in a single optimization process at the pan-European scale.

In the 2040 horizon the analysis also considers increases in storage and peaking units capacity in addition to increases in cross-border network capacity. The 2040 horizon was chosen for the consideration of various types of investments because the diversity of available technologies is expected to diversify with time. A second methodological difference in the study of 2040 is that the optimiser seeks to minimise energy-not-served as part of system costs.

The study was performed on a zonal model for the 2030 horizon, thus providing a finer description of the grid at the closest time horizon, and on an NTC model for the 2040 horizon. 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. The time horizons 2030 and 2040 are assessed independently from each other. This allows us to compare and confirm results.

The area covered by the study includes **all 35 European countries members of ENTSO-E**, as well as Great-Britain, Ukraine, Moldova 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 ENTSO-E area and for the EU. Results for all countries studied are available on the **online data platform**. Only the increase 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.

Starting grid of the study – Expected cross-border capacities around 2025

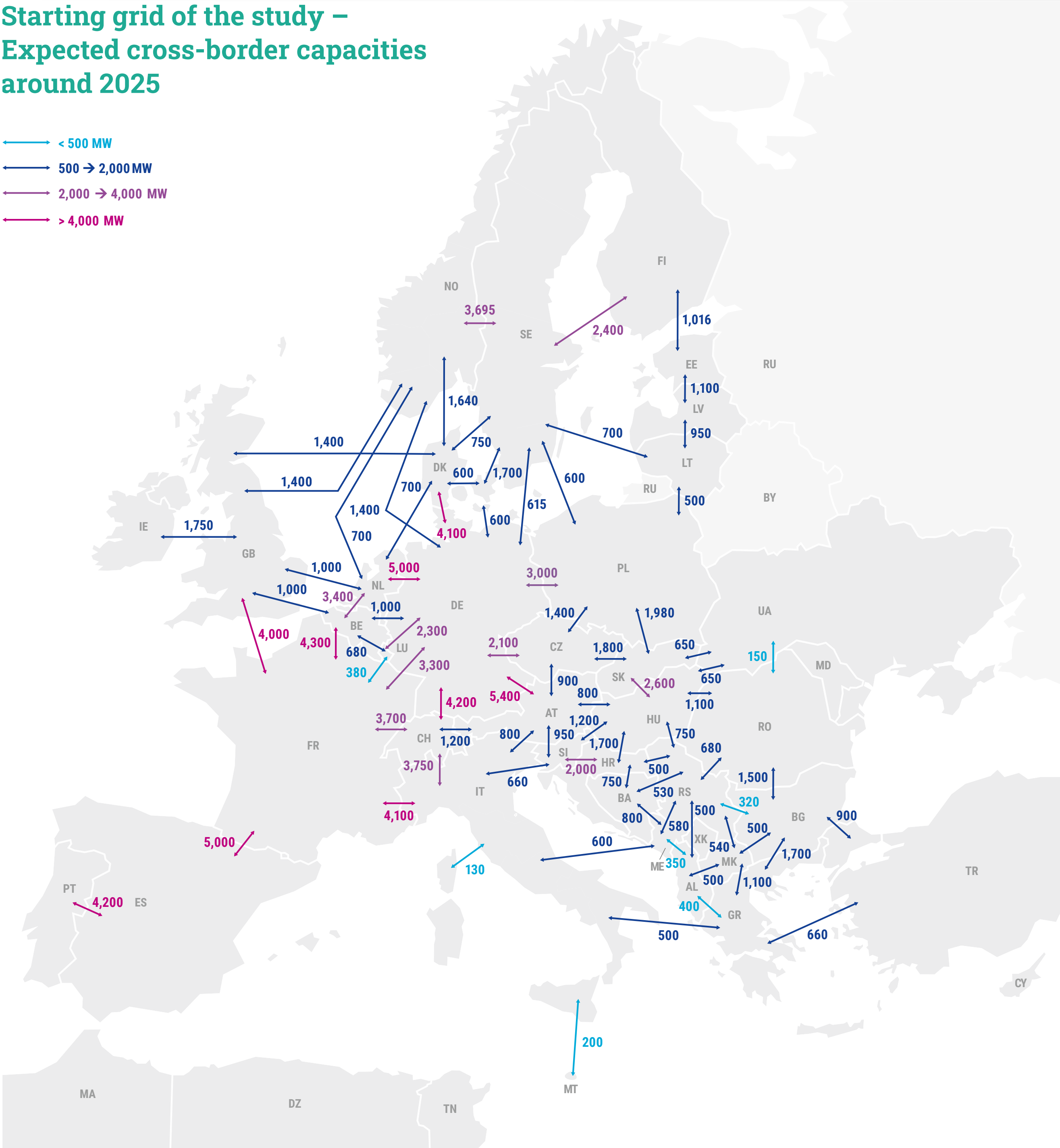


Figure 0.3 – Starting grid of the system needs study, representing ENTSO-E's estimate of available capacities in 2025. Needs identified in 2030 and 2040 are additional to the 2025 capacities.

The starting point of our study: the pan-European power system in 2025

By 2025, about 23 GW of new cross-border reinforcements are expected to be built in addition to the existing grid in 2022. These very mature projects (most of them are already under construction), already justified in previous TYNDP releases, correspond to our best view of the 2025 European transmission grid. In consequence they are not questioned in the study and serve as the starting grid for the analysis. For storage and peaking unit flexibilities the starting point is 2030 (National Trends scenario capacities for battery storage (126 GW) and for peaking units (139 GW) because they are only considered in the 2040 horizon.

All data needed to replicate the study is publicly available

- Datasets of scenarios National Trends 2030 and National Trends 2040 (Scenarios Download page)
- Starting grid (2025), published as appendix to the System needs study Implementation Guidelines
- List of investment candidates and cost assumptions, published as appendix to the System needs study Implementation Guidelines
- Network dataset: made available in aggregated form in Q4 2022 on this page.

The tool used for this study is Antares, which is an open-source tool, with an expansion module publicly available (antaresXpansion).

1 Gaps and opportunities for Europe's power system in 2030 and 2040

The pan-European power system is changing. The evolution of the generation portfolio, with increased solar onshore and offshore wind generation all over Europe, in parallel with the decommissioning of thermal units, causes higher and more variable transit flows across Europe. In parallel, new technologies will become more common such as electrolysis of electricity, electric vehicles... All these changes, as well as the EU's Green Deal ambitions, create challenges and opportunities for Europe's power system.

Identified needs in 2030 show the immediate economic interest of investing in Europe's grid

- By 2030, the study finds that 64 additional GW of cross border reinforcements after 2025 would be cost efficient to support Europe's power system. These capacity increases represent about 2 billion euro of investment per year and would deliver a yearly increase in socio-economic welfare of 5 billion euro.
- This considerable amount of reinforcement over only five years is partly explained by the fact that our starting point, the 2025 grid, is not an optimised grid. It represents ENTSO-E's best estimate of the grid around 2025 based on projects that are currently in advanced stages of development, and therefore it reflects the current delay in infrastructure development. The 64 GW of increases between 2025 and 2030 catch up on this delay in addition to accompanying the evolution of the power system occurring between 2025 and 2030.
- Needs are located all over Europe. For 2030, the highest identified capacity increases are located on the UK borders to continental Europe and on German and French borders. There are other high needs to accommodate between Eastern and Central Europe from Turkey through the Balkan countries, to integrate the Italian peninsula and to further connect Scandinavia to the rest of Europe.

Opportunities for increases in cross-border capacity in 2030

(additional to the starting grid)

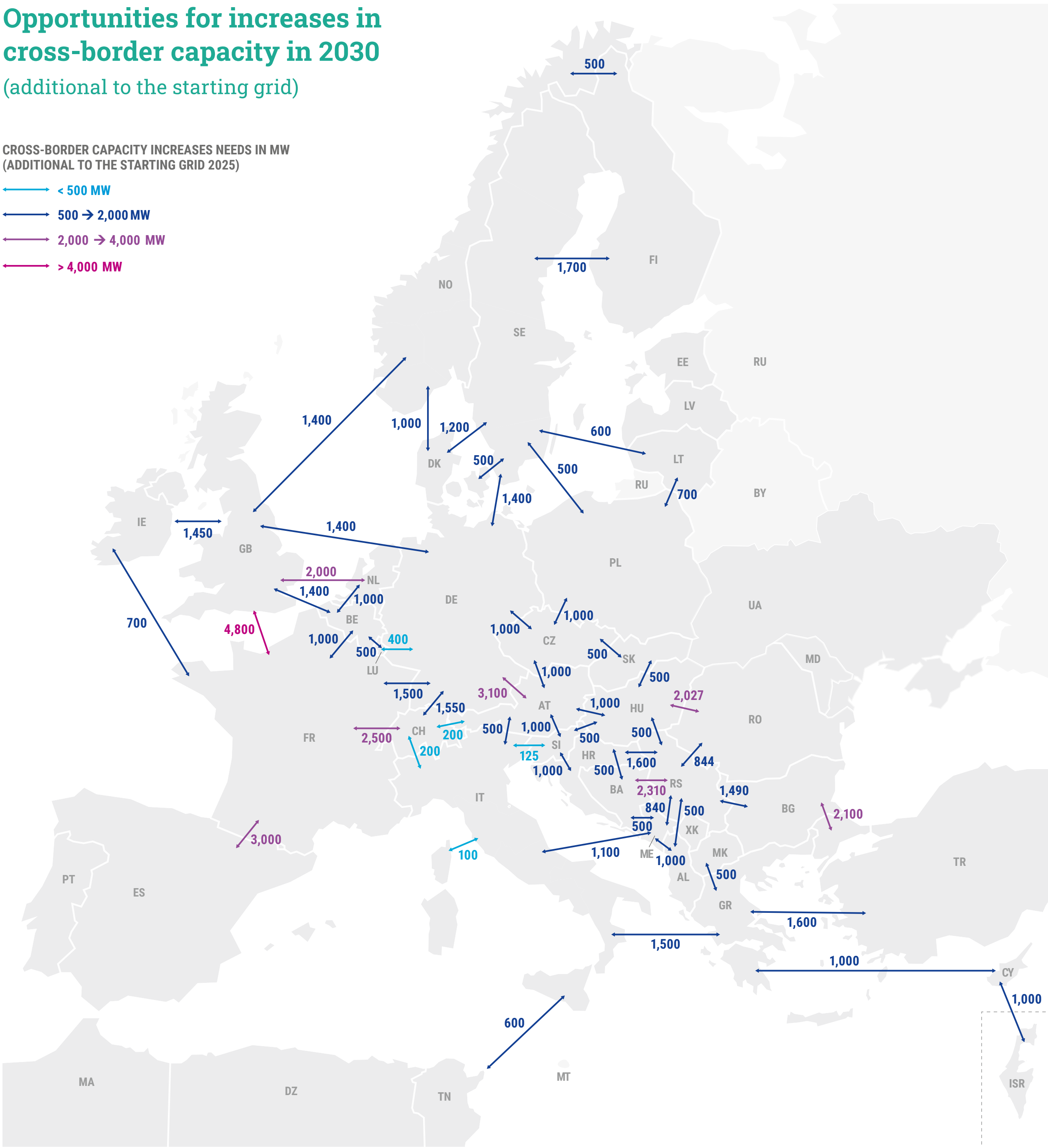


Figure 1.1 – Economic needs grid in 2030, additional to the starting grid. To not overcharge the map, only the highest value is displayed on borders where the value is not the same in both directions

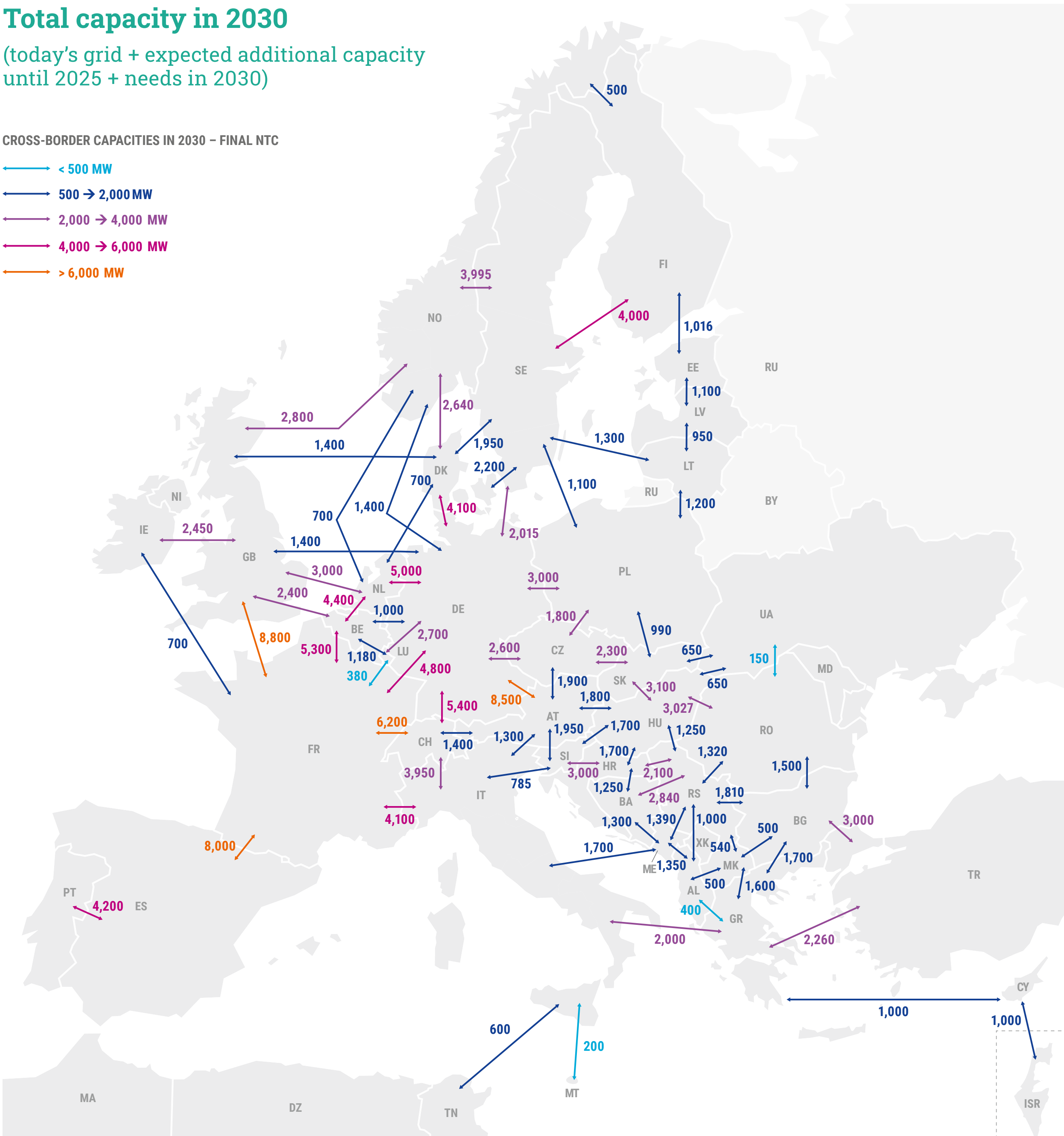


Figure 1.2 – Total cross-border capacities in 2030 (today's grid, capacities expected around 2025 plus capacity increases identified in the system needs study for the 2030 horizon). To not overcharge the map, only the highest value is displayed on borders where the value is not the same in both directions.[1]

1 For the DE-CH borders, additional to starting grid capacities of 4,200 MW and 3,000 MW, needs in 2030 equal 1,200 MW and 1,550 MW. Total capacities in 2030 are therefore 5,400 MW and 4,550 MW.

Additional capacity increases and flexibility assets by 2040 bring economic benefits and support security of supply

- By 2040, 88 GW of additional cross-border capacity increases with respect to 2025 grid, 41 GW of storage and 3 GW of CO_2-free peaking units would be needed to support Europe's move towards a carbon-free power system and ensure continuous and cost-effective access to electricity. With regards to cross-border capacity, this represents 24 GW of additional cross-border capacity increases on top of the increases identified for 2030, therefore confirming the required strong needs for cross-border capacity developments in horizons 2030 and 2040.
- The 41 GW of (battery) storage capacity needed add up to the 126 GW of battery storage available in 2030 (National Trends scenario). All storage technologies combined, the total storage capacity in 2040 amounts to 174 GW.
- Addressing the identified needs represent an investment of 6 billion euro/year between 2025 and 2040 (3.5 Bn €/year for cross-border capacity increases, 2.0 Bn €/year for storage and 0.1 Bn €/year for peaking units). The increase in socio-economic welfare amounts to 9 billion euro/year until 2040. Addressing needs would also improve security of electricity supply as energy-not-served would be cut by 1.72 TWh/year. This in turn would increase socio-economic welfare even further.
- In 2040 the highest needs for capacity increases remain on UK-continent borders, on French borders and to accommodate flows between South-Eastern and Central Europe, from Turkey through the Balkan Peninsula all the way to Czech Republic. In most of western and central Europe these capacity increases are completed by storage flexibility, with highest needs in Spain, Germany, Italy, Portugal and Hungary, and to a much smaller extent by peaking flexibility in Hungary and Poland. There is also a significant increase in needs after 2030 on Italian borders and on borders between Scandinavian countries and mainland Europe.

System needs are additional to the development of flexibility assets by 2030 and 2040

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 EU increases by 34 GW, Demand Side Response by 17 GW and Power-to-Gas by 96 GW. System needs go beyond this point in order to provide a secure, cheap and decarbonised electricity at all times and in all places.

Opportunities for increases in cross-border transmission, storage and peaking units capacity in 2040

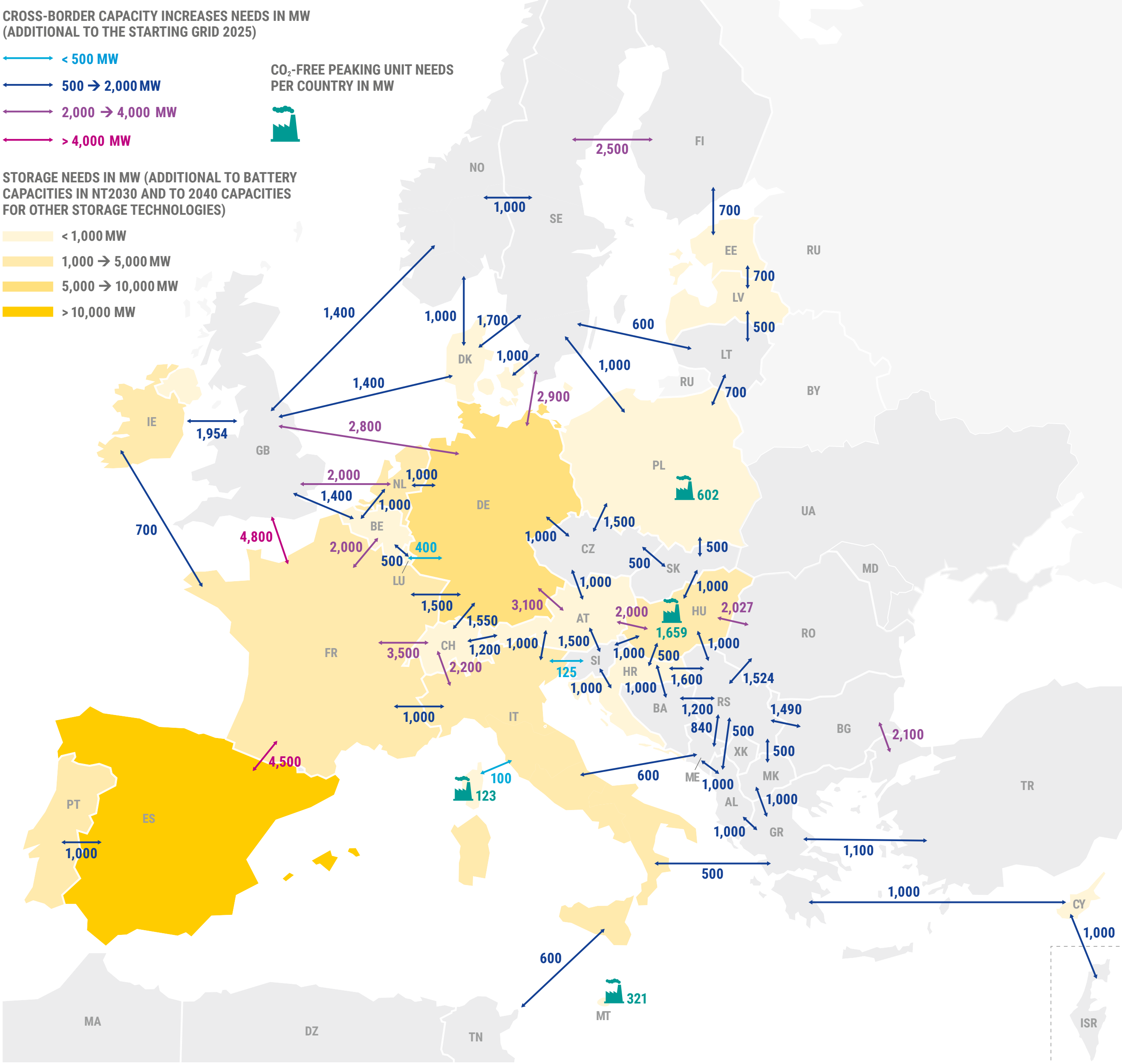


Figure 1.3 – Economic needs grid in 2040, additional to the starting grid 2025 for cross-border transmission, and to capacities in the National Trends 2030 scenario for battery storage and peaking units. To not overcharge the map, only the highest value is displayed on borders where the value is not the same in both directions

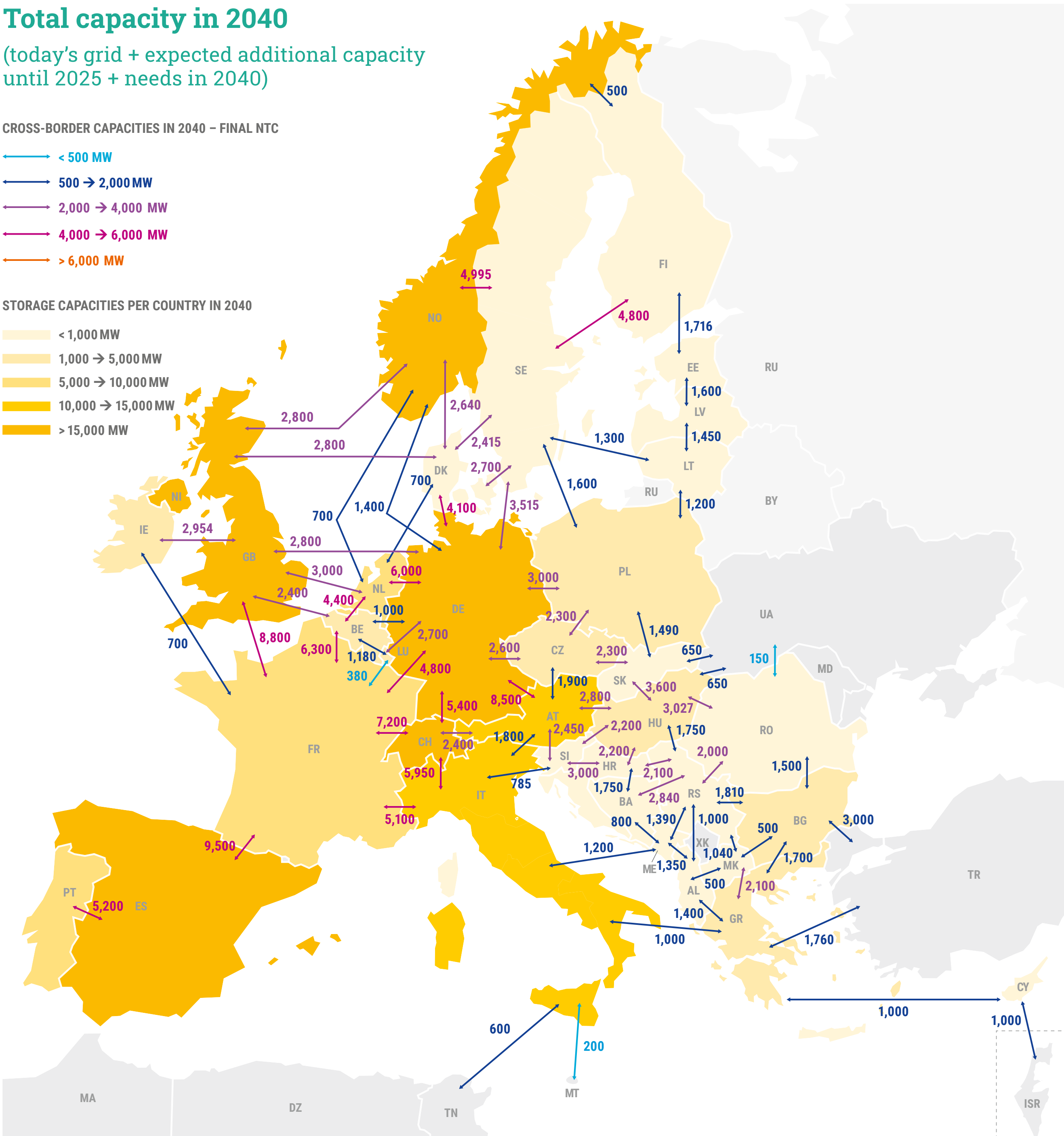


Figure 1.4 – Total cross-border capacities and storage capacities in 2040 (for cross-border increases: capacities expected around 2025 plus capacity increases identified in the system needs study for the 2040 horizon; for storage: capacities in the National Trends 2030 scenario plus capacity increases identified in the system needs study for the 2040 horizon). To not overcharge the map, only the highest value is displayed on borders where the value is not the same in both directions.[2]

2 For the DE-CH borders, additional to starting grid capacities of 4,200 MW and 3,000 MW, needs in 2040 equal 1,200 MW and 1,550 MW. Total capacities in 2040 are therefore 5,400 MW and 4,550 MW.

A diverse portfolio of technologies delivers higher benefits

Storage and peaking flexibilities add to cross-border capacity increases to form the economic needs portfolio in 2040. Inclusion of additional flexibility means is a pilot in the 2022 system needs study and was therefore implemented only in the 2040 horizon, because the diversity of available technologies to tackle the identified opportunities is expected to diversify with time. This means that, in our optimiser, storage facilities, peaking units and interconnectors are altogether considered to address the needs.

To understand how the inclusion of storage and peaking units in addition to interconnectors impacted the results, we have run the 2040 simulations with and without storage and peaking units. Results find that 87 GW of cross-border capacity increases is present in both simulations. This shows that, for the most part, storage and peaking units do not compete with interconnectors. Instead, they provide additional system benefits.

Interconnectors are generally more cost-efficient. However, storage covers needs that cannot be addressed as effectively by interconnectors. It reduces curtailed energy and CO_2 emissions even further and supports security of supply by reducing the amount of energy-not-served by about 100 GWh, which is of significant value considering the high cost of energy-not-served. A more diverse portfolio brings higher benefits to the system, justifying the increase in investments associated with the various solutions considered to cope with the identified economic opportunities.

System needs in 2040

With storage and peaking units candidates

- Cross-border capacity increases .... 88 GW
- Storage .... 41 GW
- Peaking .... 3 GW
- Investments .... 5.6 Bn€/y

System benefits

- Increase in socio-economic welfare .... 9.4 Bn€/y
- Avoided CO_2 emissions .... 44 Mton/y
- Avoided curtailment .... 68 TWh/y
- Avoided energy-not-served .... 1,7 TWh/y

System needs in 2040

With storage and peaking units candidates

- Cross-border capacity increases .... 97 GW
- Storage .... N/A
- Peaking .... N/A
- Investments .... 3.6 Bn€/y

System benefits

- Increase in socio-economic welfare .... 8.6 Bn€/y
- Avoided CO_2 emissions .... 42 Mton/y
- Avoided curtailment .... 62 TWh/y
- Avoided energy-not-served .... 1,6 TWh/y

Comparison with Distributed Energy scenario confirms needs exist in very different potential futures

The Distributed Energy scenario represents a very different future for Europe's energy system than the future represented in the National Trends scenario studied in the TYNDP 2022 system needs study. Distributed Energy pictures a pathway achieving EU27 carbon neutrality by 2050 and at least 55 % emission reduction in 2030. The scenario 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.

	National Trends 2040	Distributed Energy 2040	
Scenario overview	Based on National Energy and Climate Plans and national long-term strategies. Translates the latest policy- and market-driven developments as discussed at national level. Reflect EU targets for RES and energy efficiency.	Pathway to EU27 carbon neutrality by 2050 and at least 55 % emission reduction in 2030.	
		Driving force of the energy transition	Transition initiated at a local / national level (prosumers) Aims for EU energy autonomy through maximisation of RES and smart sector integration (P2G / L)
		Energy intensity	Reduced energy demand through circularity and better Digitalisation driven by prosumer and variable RES management energy consumption behaviour
		Technologies	Focus of decentralised technologies (PV, batteries, etc.) and smart charging Focus on electric heat pumps and district heating Higher share of EV, with e-liquids and biofuels supplementing for heavy transport Minimal CCS and nuclear
* CHP and small thermal excluded	Key numbers (in the EU, in TWh)		
Generation from wind	1,603	2,596	
Generation from solar	611	1,293	
Generation from methane*	293	343	
Generation from nuclear	453	274	
Battery generation	36	103	
Generation from hydrogen*	15	96	
Imports of natural gas	2,416	1,243	
Final methane demand	2,065	1,331	
Final hydrogen demand	426	1,063	
Final electricity demand	3,072	3,618	
Electricity demand for electrolysis	288	1,445	

The process of building the Distributed Energy scenario implied the computation of optimised cross-border capacities at pan-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 Distributed Energy 2040 confirms that there are needs on most European borders. At horizon 2040, the Distributed Energy optimization leads to an overall European cross-border final capacity of 181 GW. For the sake of comparison, one must also consider the 173 GW of battery storage foreseen in Distributed Energy. System needs in National Trends amount to 204 GW of final cross-border capacity and to 63 GW of final storage capacity in 2040.

The comparison confirms the immediate need for significant network reinforcements under any plausible scenario relying on the massive development of decentralized resources. The difference in cross-border capacity increases identified in the two scenarios amounts to only 11 %, well within the boundaries of the uncertainty margins of such future projections and hence validates the robustness of the core of the identified needs.

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

The system needs presented in the previous pages are based on the National Trends scenario, which is based on EU Member States' National Energy and Climate Plans (NECPs). When developing these plans, EU Member States were required to meet the EU's targets 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). In its 2020 assessment of the cumulative impact of the 27 NECPs, the Commission found that NECPs fall a little short of the 32.5 % target, generating reductions of 29.4 % for final energy consumption and 29.7 % for primary energy consumption. This means that the needs for capacity increase identified in our study exist in a world where significant energy efficiency gains have already been achieved.

Can the system needs identified in the TYNDP decrease by 2030? The Energy Efficiency Directive revised in 2021 goes in that direction by proposing increased targets of 39 % and 36 % of energy efficiency savings in primary and final energy consumption respectively (representing a 9 % reduction by 2030 compared to the 2020 baseline scenario). Furthermore, the RePowerEU Plan released in May 2022 proposes an increase from 9 % to 13 % of the energy efficiency target.

Besides energy efficiency targets to reduce demand for electricity, another way to reduce system needs is to improve the efficiency of existing system assets. Electricity Transmission System Operators put in place various solutions to optimise available capacity, including infrastructure (for example, RTE's RINGO project, or hybrid offshore infrastructure combining generation and interconnector) but also non-infrastructure solutions such as softwares to help address grid constraints.

However, in a European power system transitioning towards high RES and aiming at climate neutrality in 2050, reducing needs 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 border.

As detailed in the next Chapter, the main benefit of addressing system needs is to improve the overall efficiency of the power system by allowing a more efficient use of the existing generation mix (42 TWh of renewable energy saved each year until 2040). When electricity flows easily across borders, European customers get more from the same generation assets.

RTE's RINGO project

Depending on the weather conditions (high sunshine, strong winds), local wind and solar power production can peak at times and be too abundant to be transported by electricity grid. The surplus electricity would be then lost. In its role as an innovator and major player in the energy transition, the French TSO RTE is responding to this problem with the **RINGO** electricity storage experiment, approved by the French regulator. The project consists of three innovations which, together, will enable renewable energies to be fed into the network:

- Automatons developed by RTE which, capture digital network data in real time. They allow remote and autonomous control of what is happening on the high-voltage lines;
- Supplier storage batteries, connected to the grid, which will make it possible to store surplus renewable energy;
- Power electronics, i. e. large electronic chips that convert stored energy into electricity injected into the network for consumers.

RTE is then remotely and automatically controlling all the batteries connected to its network at the same time, as well as the converters that transform the energy stored in the batteries into electricity suitable for the network. The aim is to adapt the storage / unstorage times according to the electricity load on the network. With this intelligent system, RTE guarantees efficient use of the renewable electricity produced in France.

One economic needs configuration, a multiplicity of solutions

Our study uses interconnection transmission capacity and storage and peaking flexibility to express the needs because it is based on electricity TSOs' expertise, data and models, but solutions extend beyond electricity infrastructure. Addressing tomorrow's challenges will require the parallel development of a diverse range of solutions, including for example storage, the role of prosumers and generation, in addition to reinforcing the transmission grid.

The Spanish Network Development Plan 2021–2026 provides an example of how electricity TSOs select the best alternative when a need has been identified. Possible solutions with the least environmental and economic impact are assessed first, and only when no other alternative is feasible are new investments being considered. The use of the methodology presented in the flowchart in Figure 1.5 results in the improvement of 20 % of the existing network (more than 8000 km) including over 700 km of Dynamic Line Rating in the Spanish system, 300 km of change of conductor, 8 synchronous condensers, 3 STATCOM and 2 battery systems as full integrated equipment to enhance the use of the transmission system.

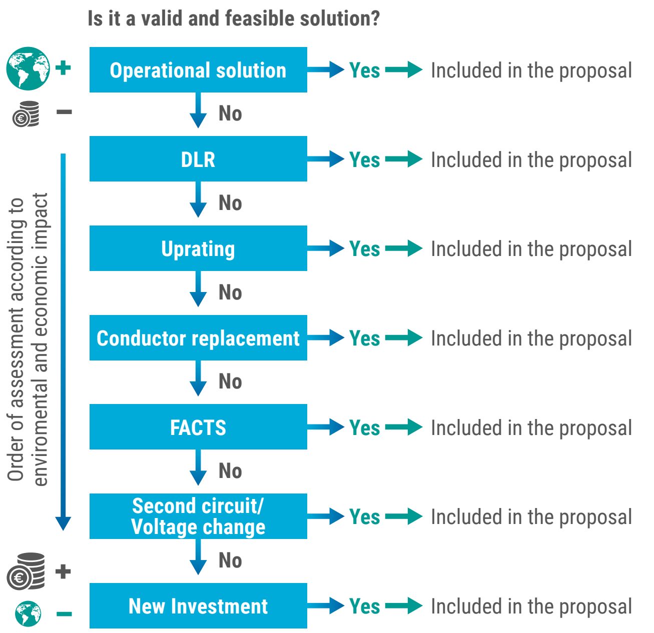
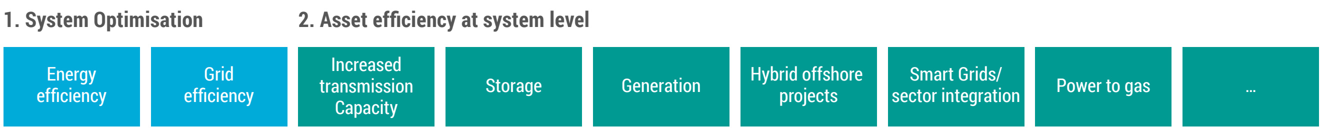


Figure 1.5 – Alternative selection flowchart for the resolution of network problems, Red Eléctrica Network Development Plan 2021–2026 (https://www.planificacionelectrica.es/en)



Existing transmission projects address only part of the needs in 2030

How do infrastructure projects currently being developed compare to the needs presented in the previous Chapter? To try and answer this question, we have looked at 2030, as a close and tangible objective horizon, and have compared identified needs with existing electricity transmission projects expected to commission between 2025 and 2030. Many projects able to solve system needs by 2030 are already on the table and are assessed in TYNDP 2022. 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 potential gaps.

Figure 1.7 shows where projects under development meet the identified needs. On 36 borders spread over whole of Europe the capacity of existing projects expected by their promoters to be commissioned until 2030 is equal to the identified needs[3]. On 13 borders, most of them in Western Europe, there are more projects than needs. There can be several reasons for that. On some borders two or more projects are competing against each other to address the same need (Belgium-UK and Germany-UK). On other borders the need addressed by projects is not identified in our 2030 study but materialises between 2030 and 2040 (Italy-Switzerland, Denmark-UK and

3 This includes borders where no need has been identified and no projects are planned for the 2030 horizon.

Romania-Serbia). On two borders the projected additional capacity that exceeds the identified needs is very small and therefore of little significance (France-UK and Austria-Italy). It can also be the case that such projects address a need that is not related to system costs and is therefore not identified in this study.

Figure 1.8 investigates the opposite situation: borders where additional capacity expected to become available for cross-border trade until 2030 is not sufficient to meet the needs. We also indicate where projects are being developed but are expected to be commissioned after 2030. The comparison reveals gaps in infrastructure development in a corridor going from Turkey through the Balkans up to Czech Republic. A second area where investments should be higher is throughout the Baltic sea, to connect Scandinavia to mainland Europe.

For over two thirds of the needs in 2030, there are transmission projects in the TYNDP 2022 project portfolio that could address them. For the remaining part there does not currently exist any corresponding transmission project in the TYNDP, though other solutions (e. g., storage, hybrid solutions) may be under development. These numbers must be compared with similar estimates in TYNDP 2020, where only half of identified needs in 2030 could be linked to existing projects. This reduced difference between needs and projects shows that TSOs and other project promoters are working on projects to close the investment gap: of the 10 new interconnectors and hybrid projects proposed for consideration in the TYNDP 2022 portfolio, seven address needs identified in the 2020 system needs study.

Infrastructure projects take years from inception until commissioning. There is an opportunity for some very long-term projects currently foreseen to commission as late as 2040 to perhaps advance their planned commissioning date. Infrastructure solutions will however need political support, including through the European Projects of Common Interest process, to become available by 2030. Non-infrastructure solutions, such as improvement in energy efficiency, will also take years. Reaching Europe's Green Deal objectives in 2030 will require exploring all possible solutions to bridge the gap.

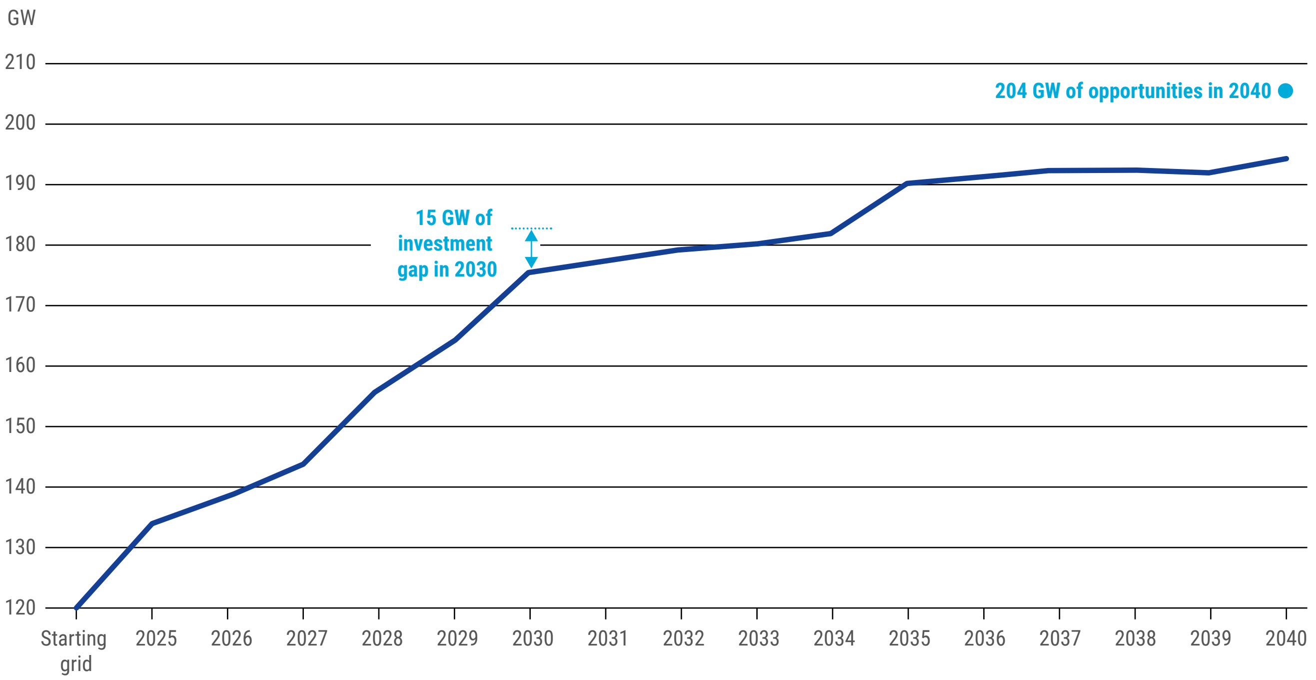


Figure 1.6 – Expected increases in pan-European cross-border electricity transmission capacity until 2040, based on the TYNDP 2022 projects portfolio

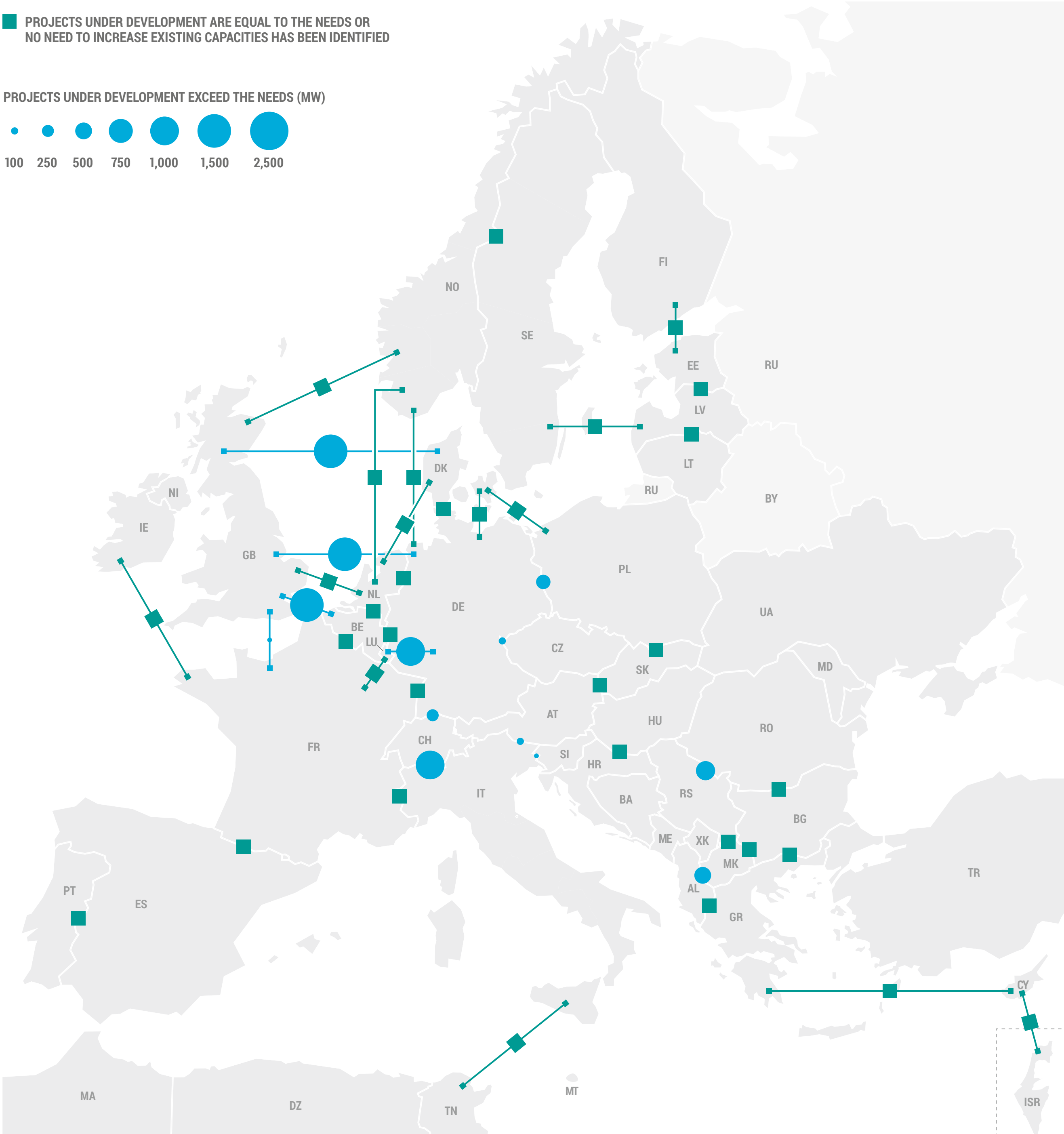


Figure 1.7 – Borders where the total capacity of projects currently under development and expected by their promoters to be commissioned until 2030 is equal or superior to the needs identified in 2030.

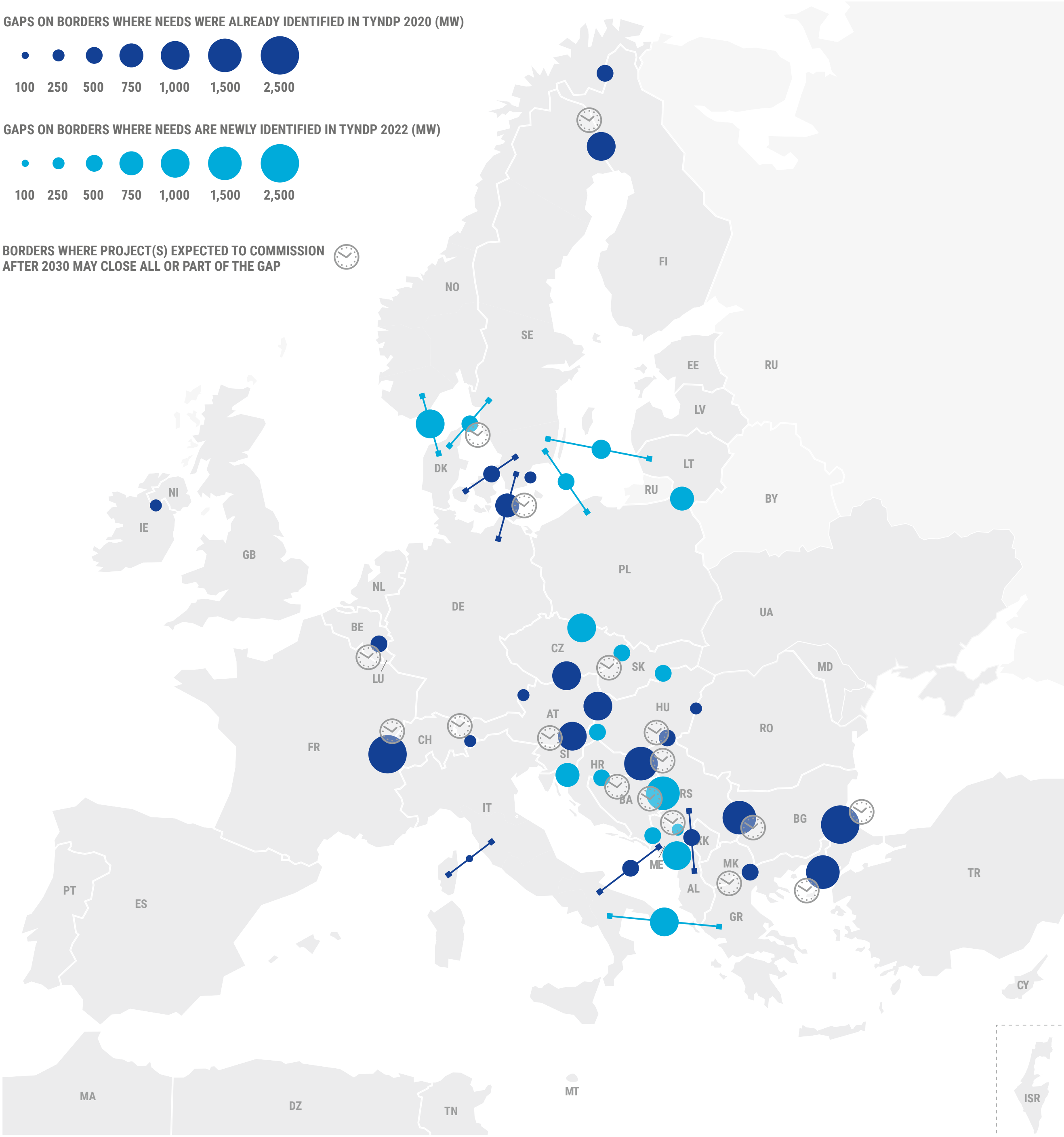


Figure 1.8 – Investment gaps in 2030. Circles represent the difference between the TYNDP 2022 electricity cross-border projects currently being developed with a commissioning date after 2025 and until 2030, and the identified needs in 2030. Clocks indicate where a project(s) is in the pipeline but foreseen to commission after 2030.

Meeting cross-border needs will require the reinforcement of national networks

Reaching the level of cross-border exchanges that result from the needs identified in the System needs study and rely on the National Trends scenario for 2030 and 2040 will create new needs for reinforcement of internal networks in the European national grids. All identified capacity increases may require some reinforcement of internal networks. Those cost approximations are taken into consideration in the costs assumed for the study. National TSOs will need to 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.

There are opportunities for new solutions all over Europe in 2040

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 ample time for policy-makers 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 few. TYNDP 2022 includes 21 transmission projects and one storage project expected by their promoters to commission between 2035 and 2040, and none after 2040. That is why we speak of opportunities in 2040, and not of gaps like in 2030.

Our study finds 132 GW of needs overall in 2040, divided in our models between 88 GW of capacity increases, 41 GW of storage and 3 GW of peaking units. Transmission projects under development today amount to 68 GW, including 50 GW between 2025 and 2030 and 18 GW from 2031 to 2040. Storage projects represent 10 GW of capacity under development by 2040.

To try and provide an indication of where policymakers and promoters should investigate potential additional solutions in 2040, we have compared needs for cross-border capacity increases and existing transmission projects in Figure 1.9. We have performed the same exercise for storage in Figure 1.10. Both comparisons show without surprise that there are opportunities for additional solutions all over Europe, with peaks, like in 2030, 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.

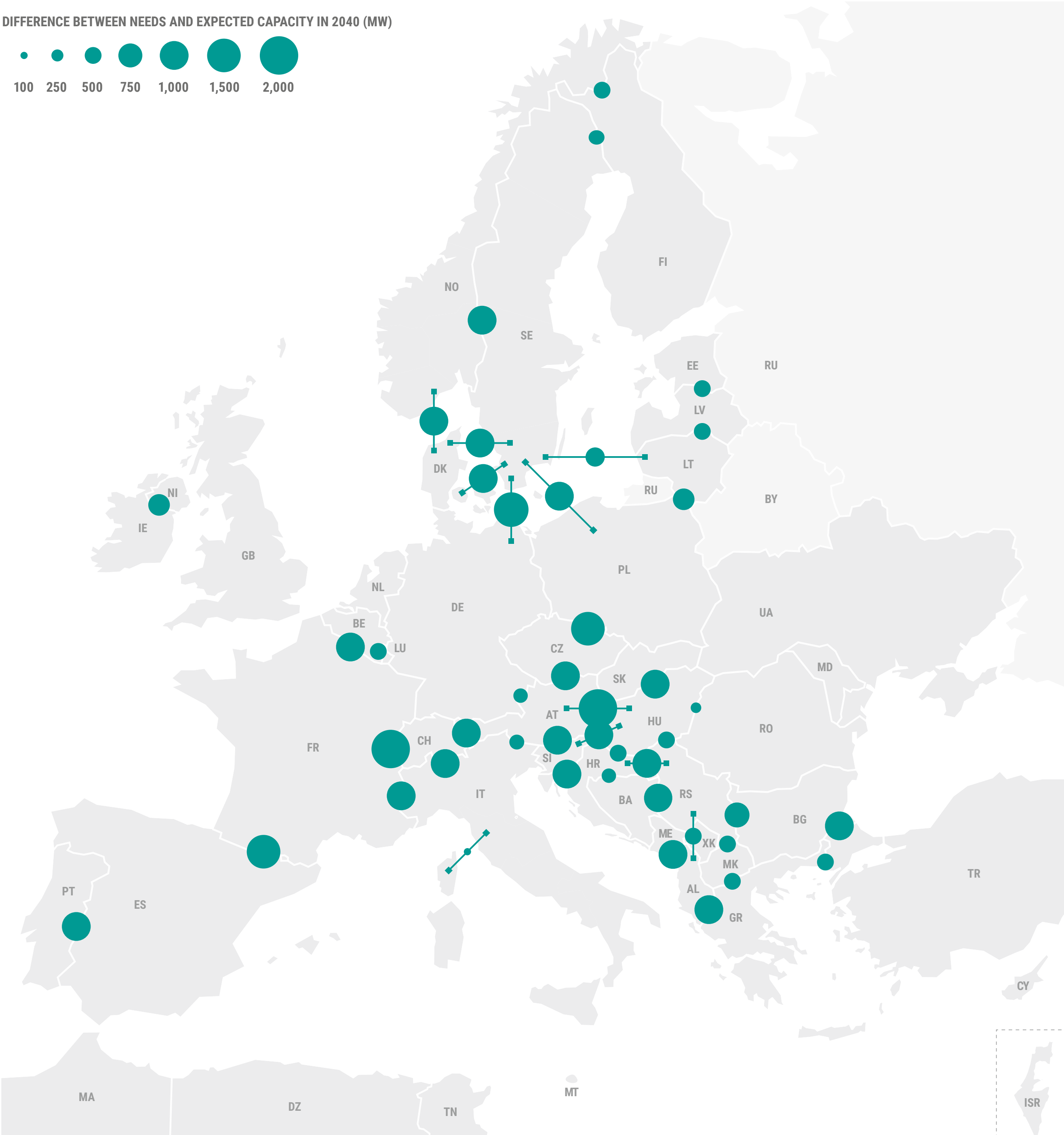


Figure 1.9 – Needs not covered by existing transmission projects in 2040. The bigger the circle, the higher the need for additional solutions.

Opportunities for increases in storage capacity in 2040

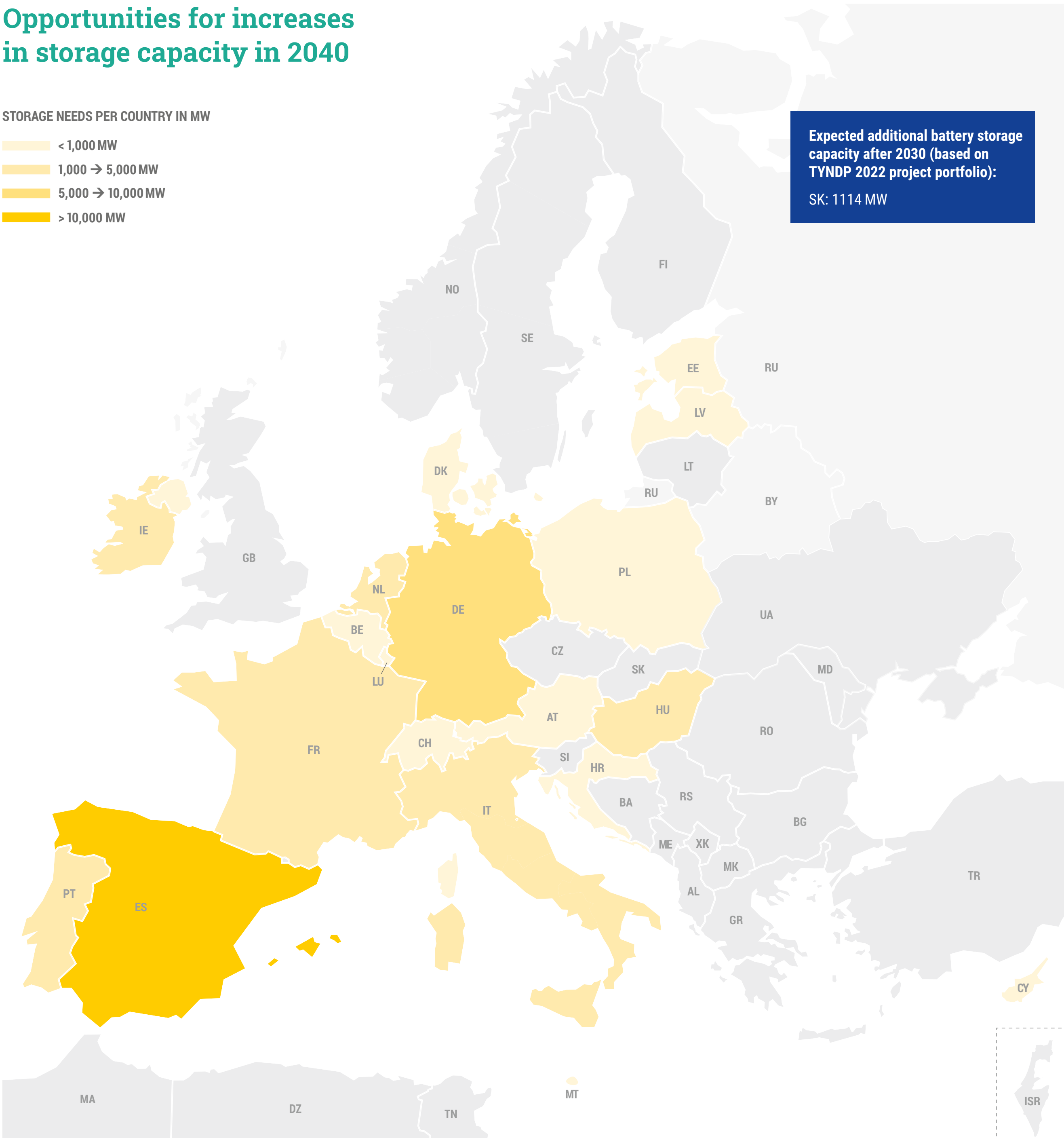


Figure 1.10 – Identified needs for storage capacity increases between 2030 and 2040. Only two of the storage projects proposed by their promoters for assessment in TYNDP 2022 are battery storage expected to be commissioned after 2030, both in Slovakia. Most existing storage projects in the TYNDP 2022 portfolio are expected by promoters to be commissioned by 2030. They can therefore be considered as included in the capacities expected in 2030 in the National Trends scenario. The capacity increases in Figure 1.10 are additional to battery storage capacities in National Trends 2030, and to capacities of other storage technologies in National Trends 2040.

Interconnection targets confirm the needs identified in 2030

In 2017, the European Commission Expert Group on Interconnection Targets (ITEG) 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 integration of renewable energy sources 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.

Figures 1.11 and 1.12 show the results of the ITEG methodology applied for the National Trends and Distributed Energy scenarios for the 2030 horizon, taking into account the expected grid in 2025. 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 in both scenarios, which highlights the need for additional interconnection development after 2025. The security of supply and RES integration criteria show additional needs for interconnection development to be most urgent in Spain, Ireland, Cyprus, Norway and Finland in both scenarios, as well as in Germany in National Trends and in Italy, Poland and Romania in Distributed Energy..

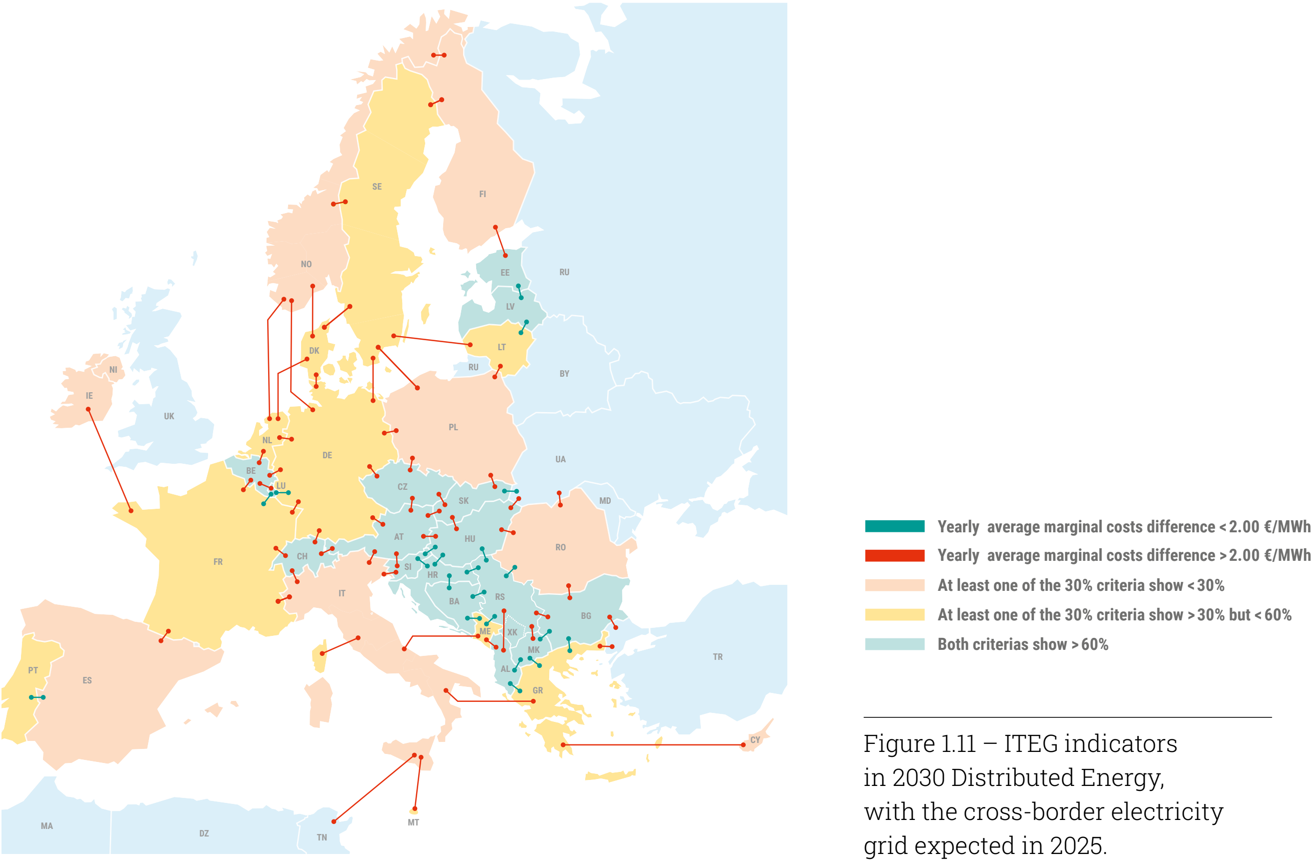


Figure 1.11 – ITEG indicators in 2030 Distributed Energy, with the cross-border electricity grid expected in 2025.

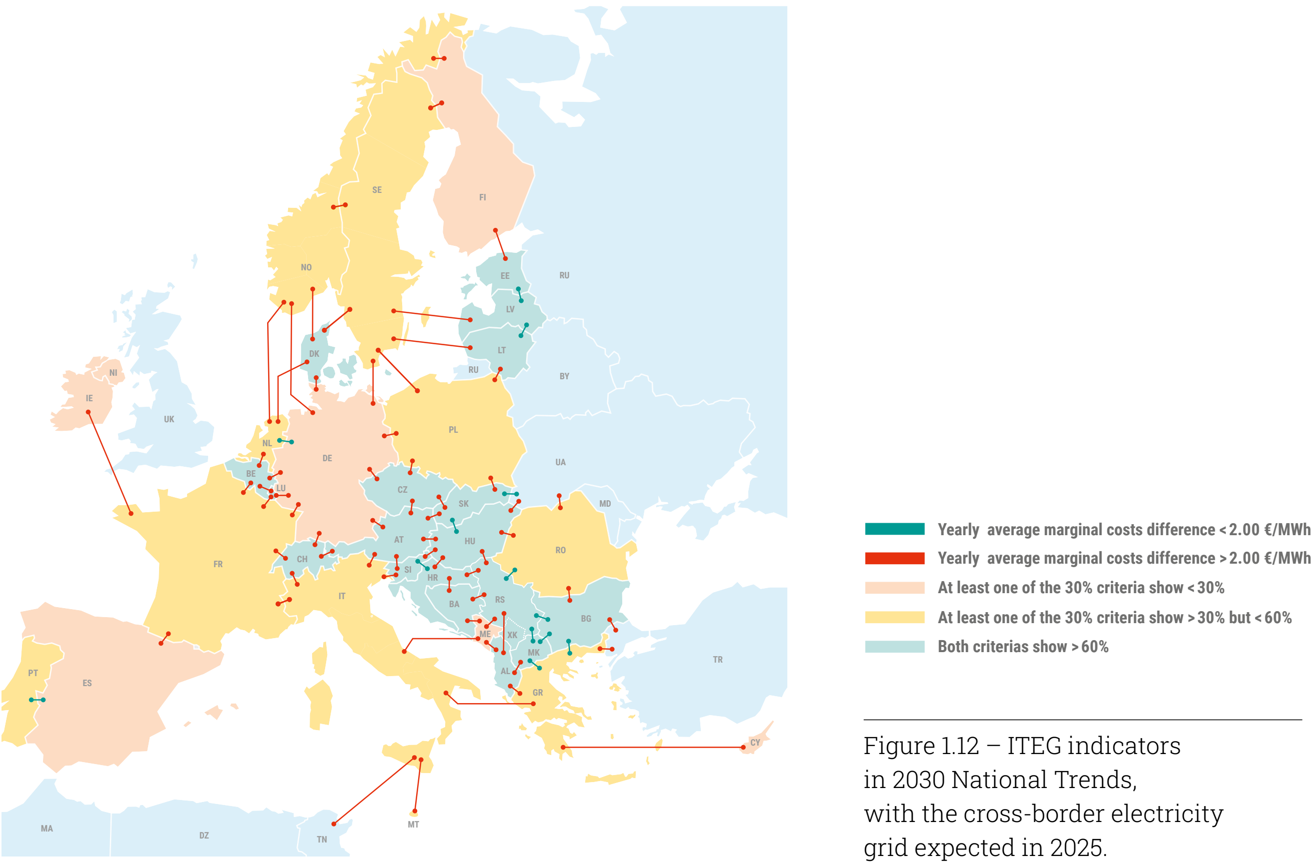


Figure 1.12 – ITEG indicators in 2030 National Trends, with the cross-border electricity grid expected in 2025.

2 How addressing system needs benefits Europe

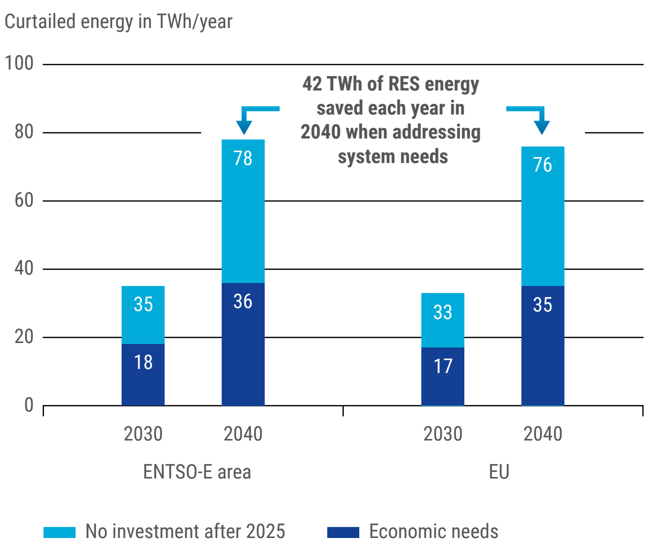
In this chapter we compare the needs presented in Chapter 1 to a hypothetical future where there would not be any further increase in transmission capacity after 2025. This comparison highlights the benefits delivered when addressing the needs on a range of indicators, in terms of reduced curtailed energy, reduced CO_2 emissions, reduced price divergence between neighbouring countries. Addressing system needs will be key for Europe to preserve security of electricity supply, deliver the Internal Energy Market and make the Green Deal a reality.

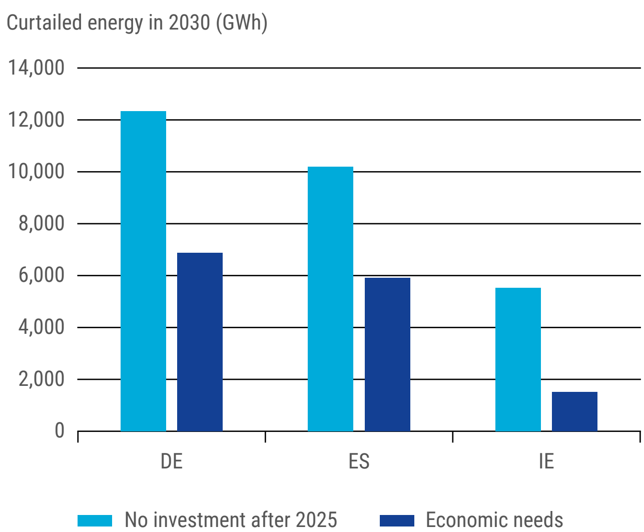
Visualise study results presented in this chapter on our interactive data platform

42 TWh of curtailed energy saved every year in 2040

Increasing exchange and storage capacity in Europe helps the integration of renewable energy by offering more opportunities to RES power plants to be used. Without network reinforcements after 2025, the RES generation would be so high at some time in some countries that some energy would have to be curtailed: by 2030, 35 TWh / year would be spilled whereas this volume increases to 78 TWh / year by 2040.

By taking advantage of the different energy mix over Europe, of the European electricity consumption profiles and the different RES peaking period between countries, the economic needs grid decreases drastically the curtailed energy. With the evolution of the energy transition, this effect increases over time: the reduction is 17 TWh / year in 2030 and reaches 42 TWh / year in 2040. Germany, Spain and Ireland are the most impacted countries due to their high national share of RES generation. The impact 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.





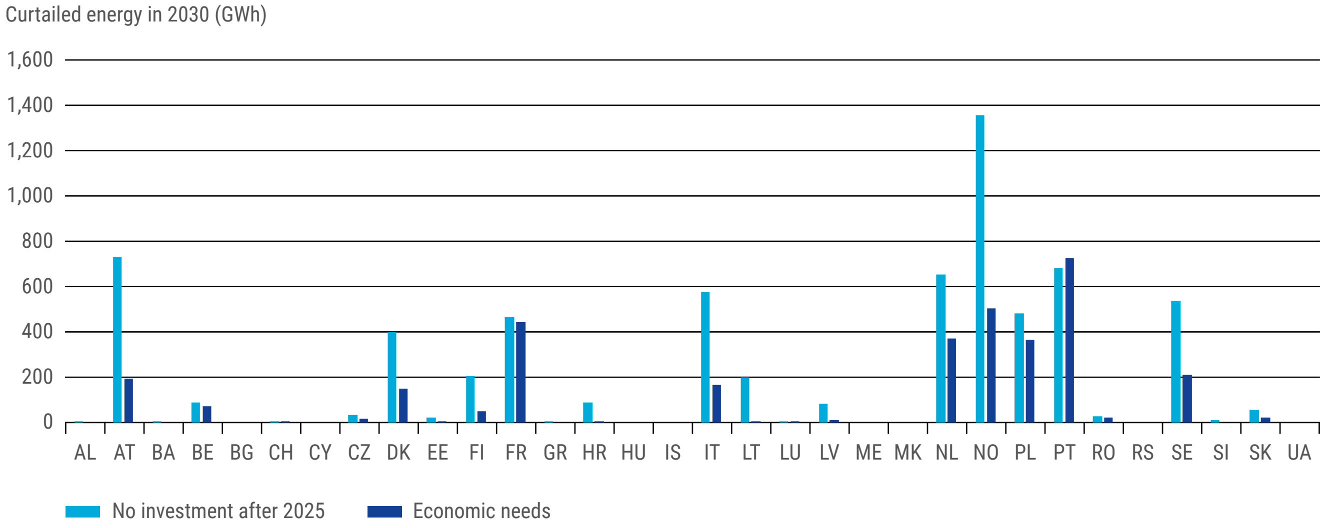
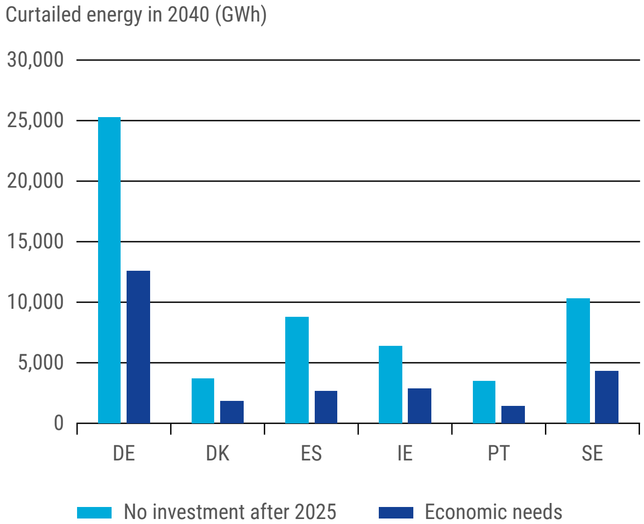


Figure 2.1 – Curtailed energy in 2030 in the ENTSO-E area, if Europe stops all investment after 2025 and with the economic needs



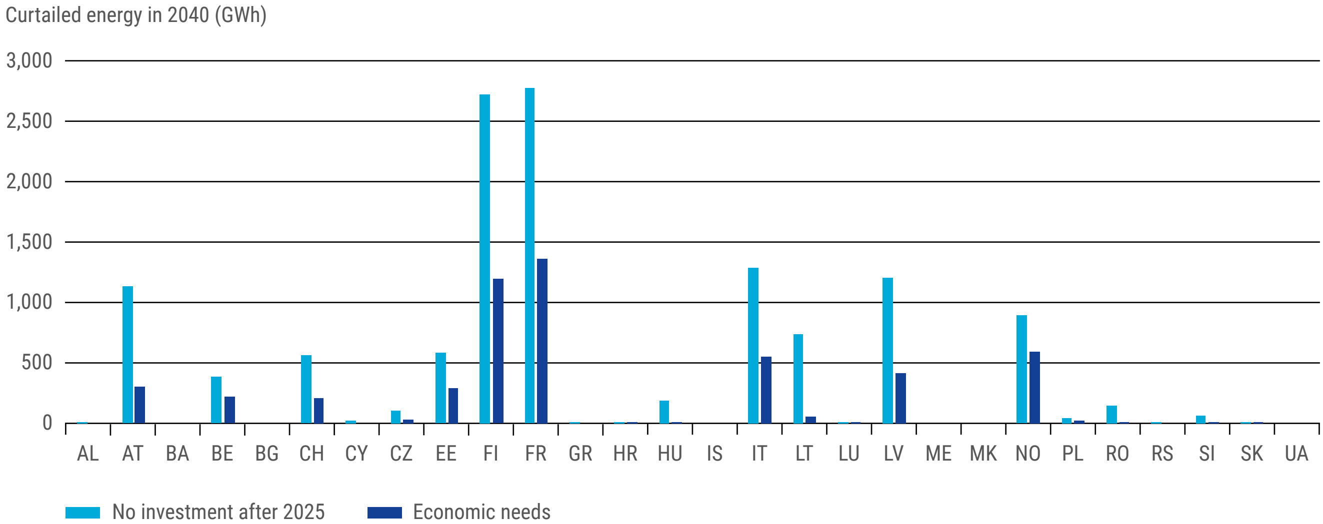


Figure 2.2 – Curtailed energy in 2040 in the ENTSO-E area, if Europe stops all investment after 2025 and with the economic needs

Reduced dependence on gas for power generation

By connecting more consumers with more producers, grid development allows a better use of the cheapest generation. As a result, European countries can exchange electricity to replace expensive generation (gas and coal) with cheaper one (mainly renewable). Addressing system needs reduces gas-based generation by 9 TWh by 2030 and 75 TWh in 2040 in the ENTSO-E area.

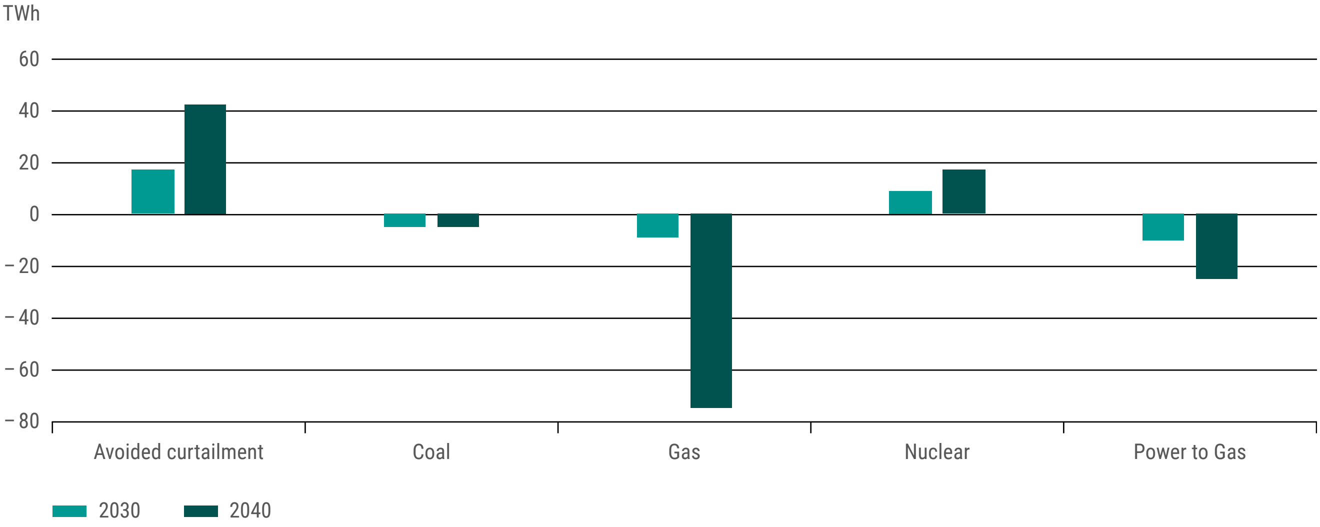


Figure 2.3 – Difference in the generation mix in the ENTSO-E area, between the No investment after 2025 case and the Economic needs (in TWh)

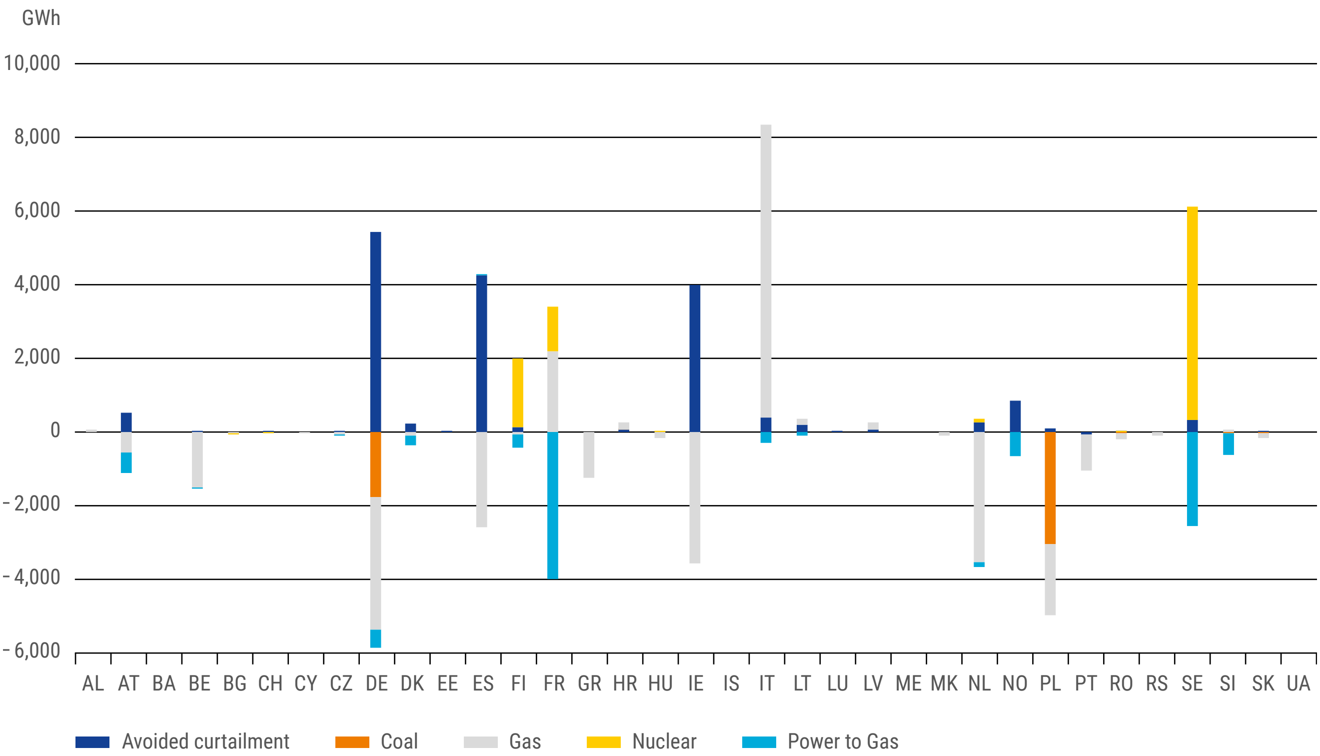


Figure 2.4 – Difference in the generation mix in 2030 in the ENTSO-E area, between the No investment after 2025 case and the Economic needs (in GWh). This figure shows the impact of increasing cross-border electricity exchange capacities on the European power generation mix.

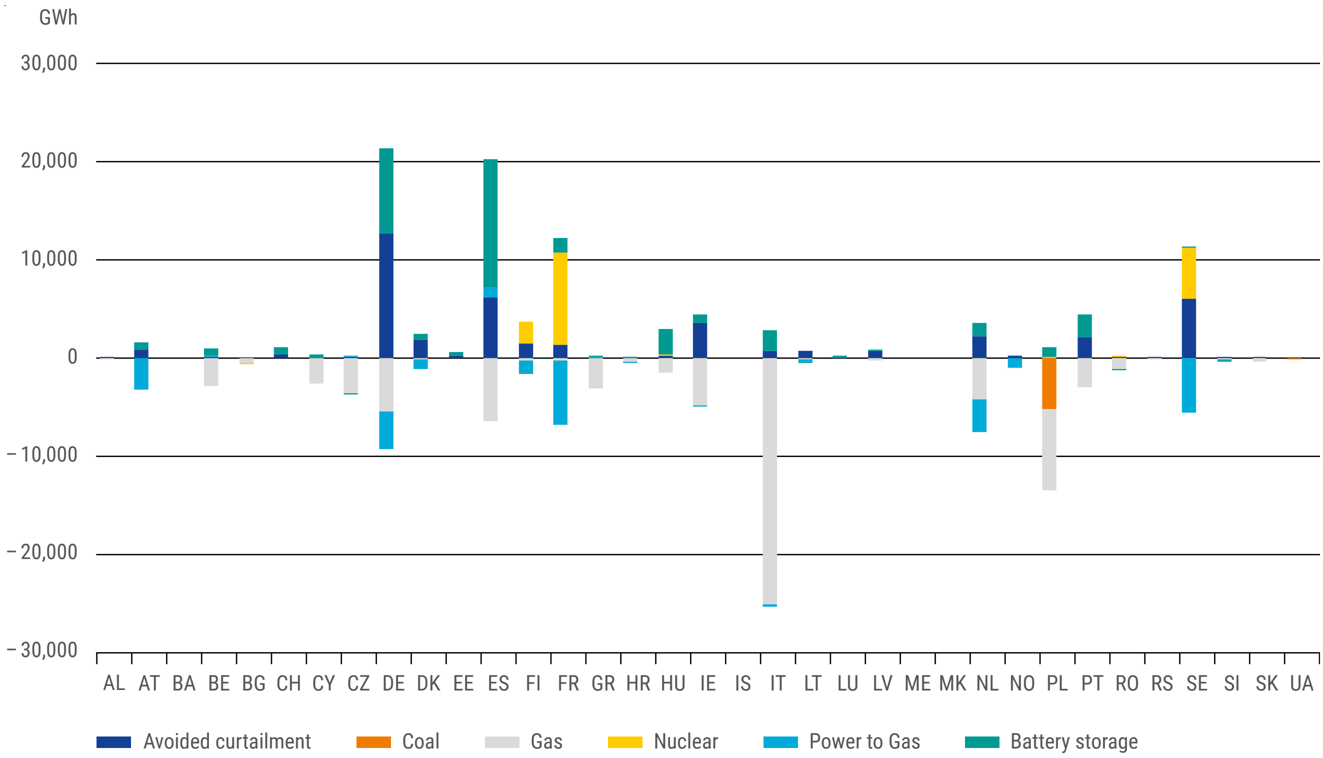


Figure 2.5 – Difference in the generation mix in 2040 in the ENTSO-E area, between the No investment after 2025 case and the Economic needs (in GWh). This figure shows the impact of increasing cross-border electricity exchange and battery storage capacities on the European power generation mix.

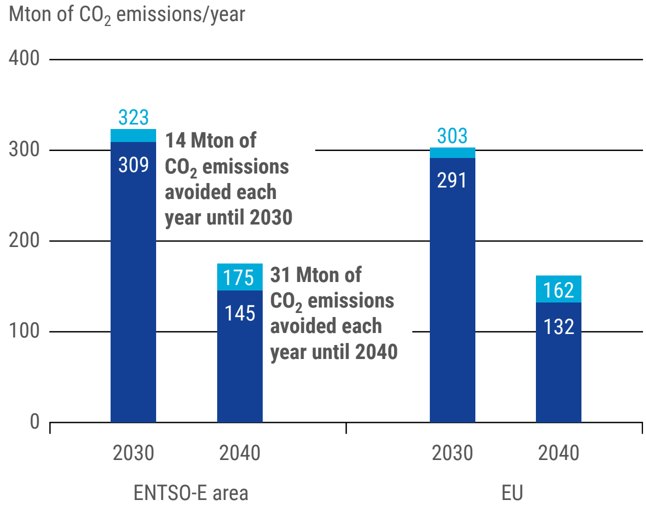
In 2030 the main driver of investments are the better access to RES generation (avoided curtailment mainly in Germany, Spain and Ireland) and nuclear generation (mainly in Sweden, Finland and France) that replaces expensive thermal generation (gas in Spain, the Netherlands, Germany and Ireland; coal in Germany and Poland).

In 2040, the main driver remains better access to RES generation, with the highest avoided curtailed energy in Germany, Spain and Sweden, and nuclear generation mainly in France and Sweden. RES and nuclear replace thermal generation from gas mainly in Italy, Spain, Poland and Germany, and from coal in Poland. Battery storage reinforces the generation mix mainly in Spain and Germany.

The higher the price of natural gas, the more beneficial it becomes to invest in Europe's cross-border electricity grid. Our study's findings are therefore still very relevant in the current context of uncertainty on natural gas supply from Russia and of rising gas price.

31 Mton of CO_2 emissions avoided each year in 2040

By allowing a better integration of non-CO_2 emitting generation, an optimised system leads to a significant reduction of European CO_2 emissions. This highlights the important role of the network in the path toward carbon neutrality. Compared to a path with no investment after 2025, CO_2 emissions of the power sector decrease by 14 Mton per year in 2030 and 31 Mton per year in 2040 to reach in Europe 309 Mton / year in 2030 and 145 Mton / year in 2040.



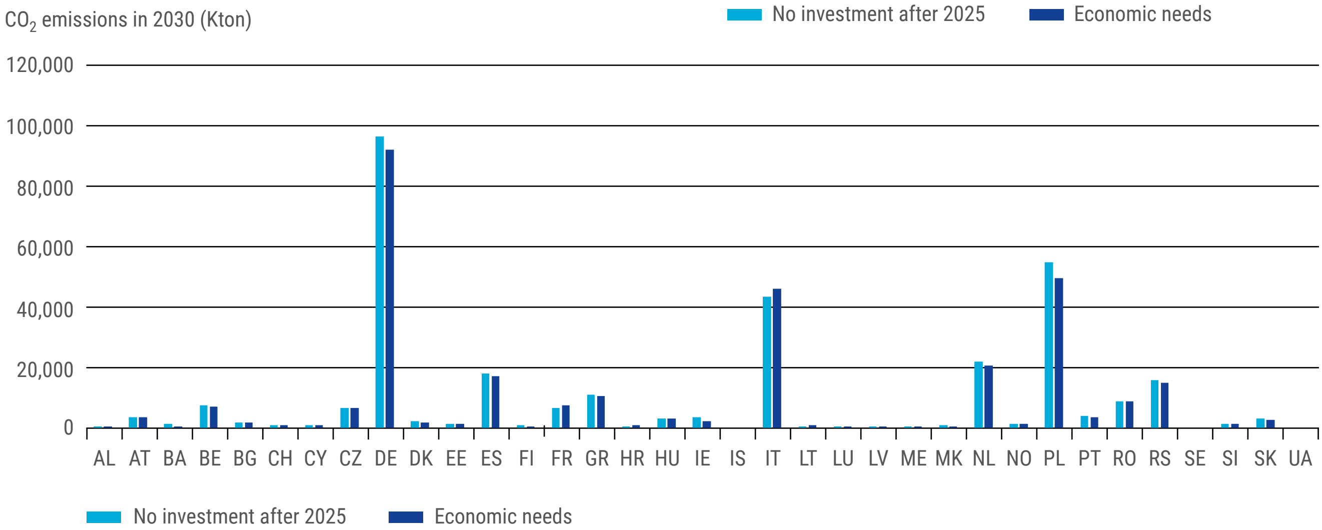


Figure 2.6 – CO_2 emissions in 2030 in Kton in the ENTSO-E area, in the No investments after 2025 case and in the Economic needs case

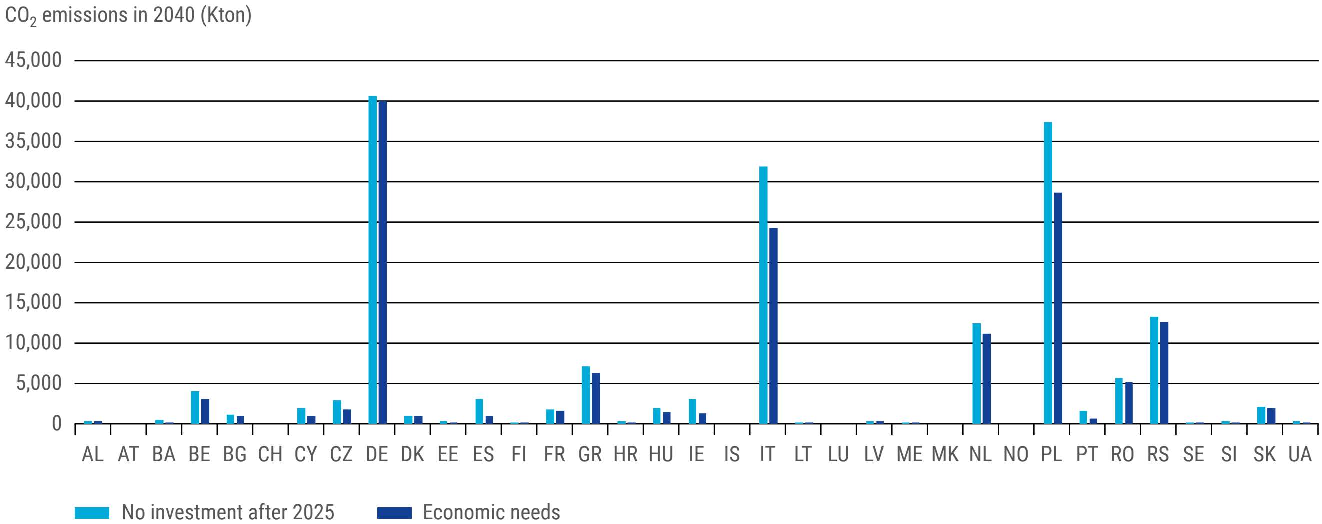


Figure 2.7 – CO_2 emissions in 2040 in Kton in the ENTSO-E area, in the No investments after 2025 case and in the Economic needs case

Generation costs decrease by 9 billion euro per year in 2040

The better use of the European generation mix translates into an important decrease in generation costs. 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.

Addressing system needs leads to a reduction of costs of about 5 bn €/year in 2030 and 9 bn €/year in 2040. These gains far outweigh the cost of investing in Europe's grid and power system, of 2 bn €/year for 2030 and 6 bn €/year for 2040[4]. Reduction in generation costs are largely related to decrease in thermal generation, mainly gas.

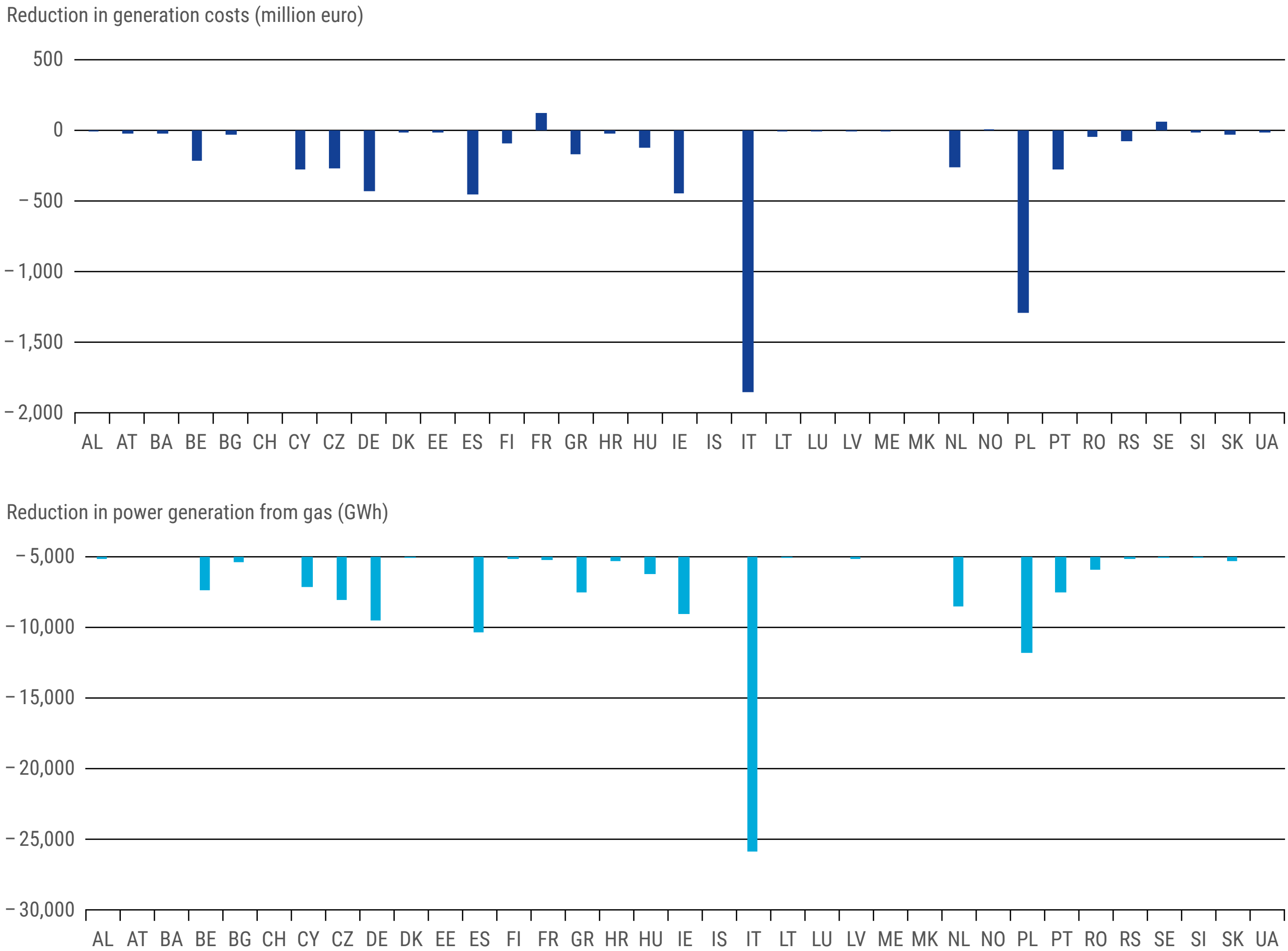


Figure 2.8 – Avoided generation costs and reduction in gas-based generation in 2040 (economic needs grid compared to the No investment after 2025 case)

4 Values for avoided generation costs and investments are provided for the entire area covered by the study, which extends beyond the ENTSO-E area. The reason is that increases in socio-economic welfare, and the related investments costs, are not available per country but only an output of the optimisation for the entire area studied.

Higher electricity exchanges and price convergence between countries

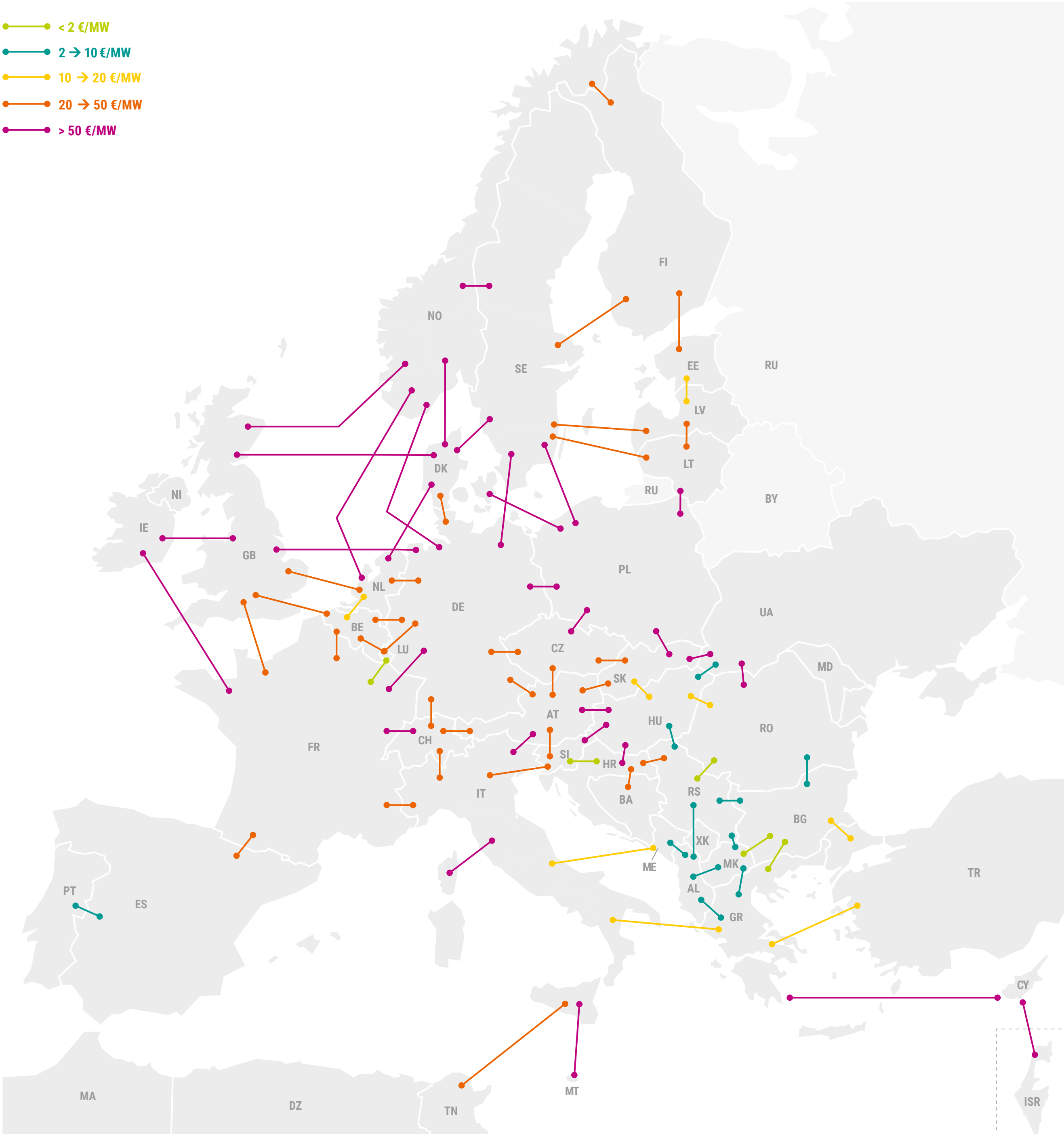
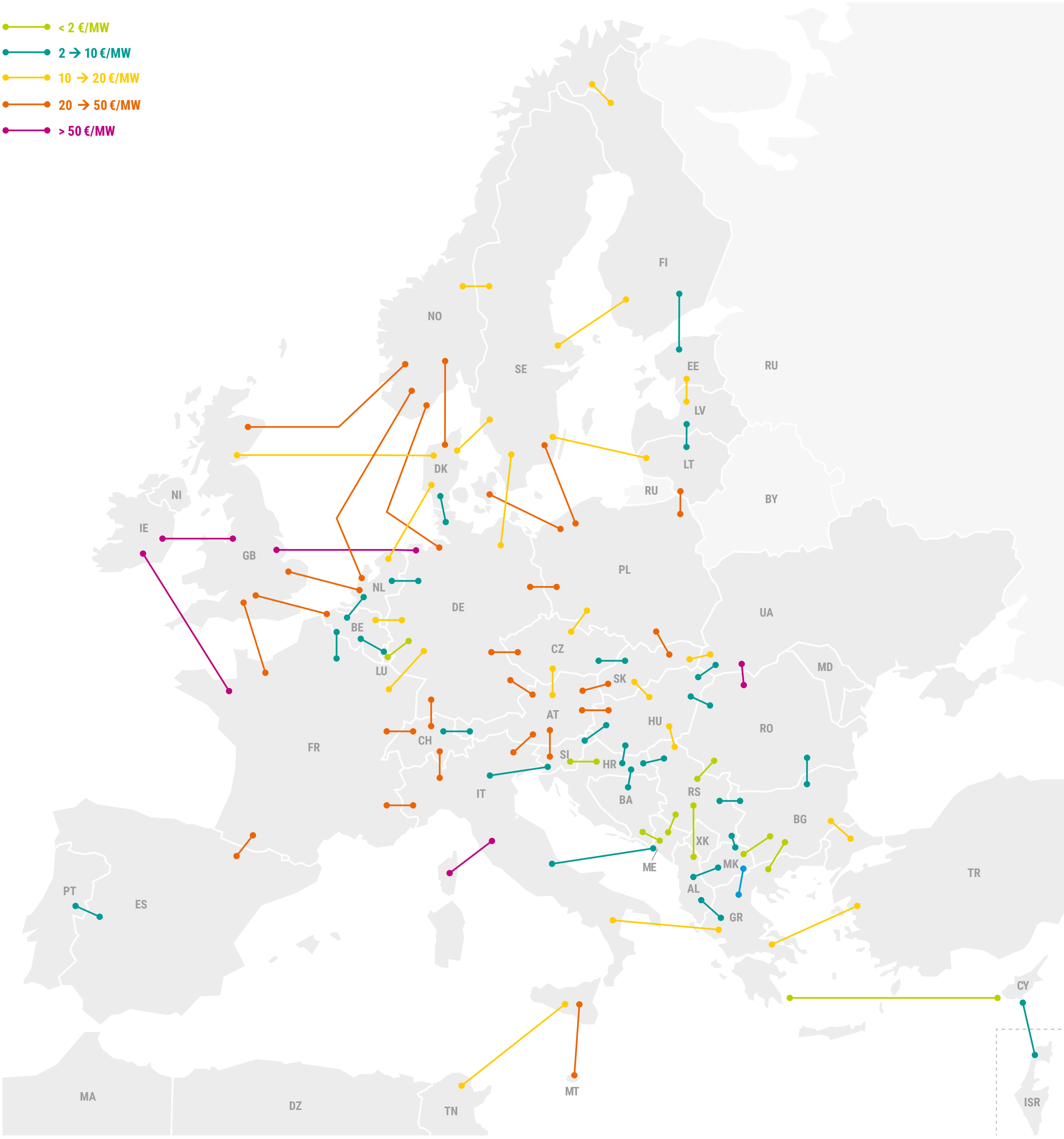


Figure 2.9 – Difference in the marginal cost of electricity between neighbouring countries in 2040, in the No investment after 2025 case (left) and in the economic needs (right)

Cross-border capacities increases allow European countries to exchange more energy: in total an additional 321 TWh/year and 485 TWh/year would be exchanged in 2030 and 2040 respectively, relative to the situation where Europe would not invest in the grid after 2025. This brings the total exchange volume to 1182 TWh/year in 2030 and 1267 TWh/year



in 2040. In addition, increasing cross-border capacities converges European marginal costs to an average spread of 10 €/MWh and 7 €/MWh in 2030 and 2040 respectively.

For example, with no investments after 2025, the Bosnia-Croatia border would be congested 32 % of the time in 2030 with an average price difference of 11 €/MWh. The identified optimal cross-border capacity increases reduce annual congestion to under 1 % and reduce the average annual price difference to an absolute value of 3 €/MWh. By 2040, without any investment after 2025 the Bosnia-Croatia border could face an average marginal cost difference close to 34 €/MWh. With investment, this price difference would decrease by 95 % bringing it close to 2 €/MWh. Nevertheless, zeroing electricity market differences between neighbouring countries is not an objective in itself, as local conditions and grid development costs must be taken into account.

Ensuring security of electricity supply throughout Europe

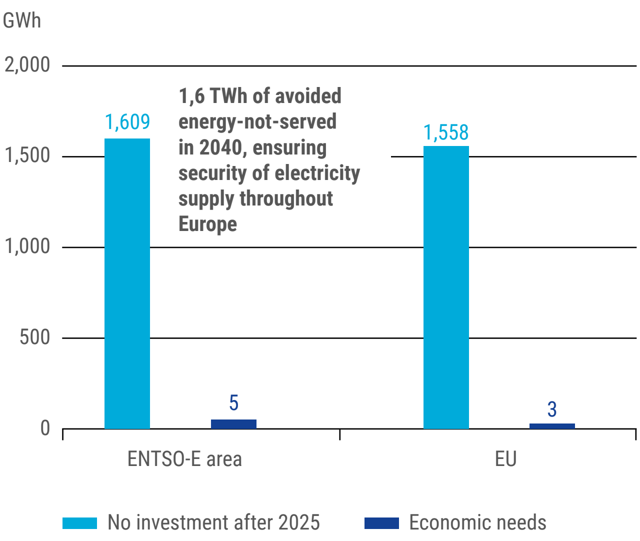
Connecting generation and demand in a reliable manner at reasonable costs is one of the main tasks of TSOs. Exchange capacities play an important role in this task as they allow countries to help each other during stressed periods of time, for example a cold wave or a low wind generation period.

Not addressing system needs would have a tangible impact on Europeans' economy and quality of life by putting at risk the reliability of access to the electricity infrastructure. If renewable energy sources and new electricity uses keep developing as foreseen, failure to deliver on grid investments could lead to unacceptable levels of load shedding, meaning that the final demand could not be supplied at some time. This could result in damaging business operability. To avoid these consequences, some additional generation would have to be built leading to higher costs for European consumers.

Our study investigates amounts of Energy Not Served, meaning the amount of final demand that cannot be supplied within a region due to a deficiency of generation or interconnector capacity. Results show that addressing the identified opportunities would cut Energy Not Served by 1604 GWh in the ENTSO-E area, to reach only 5 GWh in 2040. Energy not served could only be investigated in 2040 because this time horizon was assessed with 10 different climate years, a necessary condition to obtain a first insight into energy not served. A more complete analysis on many more climate years remains however necessary for a thorough assessment.

Our 2040 study also considered interconnectors, storage and peaking units among investment candidates. The results of a sensitivity performed without storage and peaking units find 1681 GWh of avoided Energy Not Served. This tends to show that a diverse portfolio of technologies including storage and peaking units in addition to interconnectors allows to go a little farther towards securing electricity supply at all times for all Europeans.

High intermittent weather-dependent generation raises challenges that will not be tackled by increased cross-border transmission capacity alone, from the viewpoint of system stability, voltage control and adequacy. ENTSO-E's ERAA investigates adequacy between generation in demand in the next decade. In TYNDP 2022, the report **"System dynamic and operational challenges"** offers further insights into needs related to ensuring security of supply in a power system with high integration of variable renewables.



3 The rise of offshore RES and offshore grid infrastructure development

The EU's energy system is undergoing an unprecedented transition at an unprecedented pace. Today, over 22 GW of offshore wind capacity is installed in European waters. A huge boost in investment in offshore RES is expected: the "EU Strategy to harness the potential of offshore renewable energy for a climate neutral future" anticipates at least 60 GW of offshore wind and 1 GW of ocean energy in 2030, and 300 GW of installed offshore wind and 40 GW of installed ocean energy in 2050.

Offshore investments come with their own set of challenges regarding regulatory frameworks, market design and research and innovation, which must all be addressed to accelerate the integration of offshore renewable energy generation. Offshore wind will play a major role in decades to come, because it has high availability rates, high full-load hours and higher public acceptance than onshore wind, together with falling cost-curves. However, time pressure is high, as not providing the offshore wind generation and necessary infrastructure will lead to missing the European carbon-neutrality targets.

217GW of offshore wind generation capacity in 2040

The resource potential for offshore wind in Europe in several areas is very high. Furthermore, the cost of offshore wind has declined substantially in the last decade, making it an attractive contributor to the European Green Deal. In fact, the National Trends scenario expects reaching 107 GW and 217 GW in 2030 and 2040 respectively in the EU.

The results of the present System needs study, merged with detailed information of offshore power plants, will allow project promoters to define new potential hybrid projects or adapt existing ones, thus proposing new steps towards future modular offshore grid infrastructure. An offshore "hybrid infrastructure" is an infrastructure combining two functionalities, namely:

1. Connection of two EU member states or bidding zones (and their respective energy markets) to each other;
2. Connection of RES or any other type of generation/load to the onshore system.

In addition to the above "dual purpose" configuration, the future offshore grid infrastructure could see the development of multi-terminal offshore hubs, connecting multiple platforms and two or more member states or bidding zones (with or without offshore wind) into a meshed network.

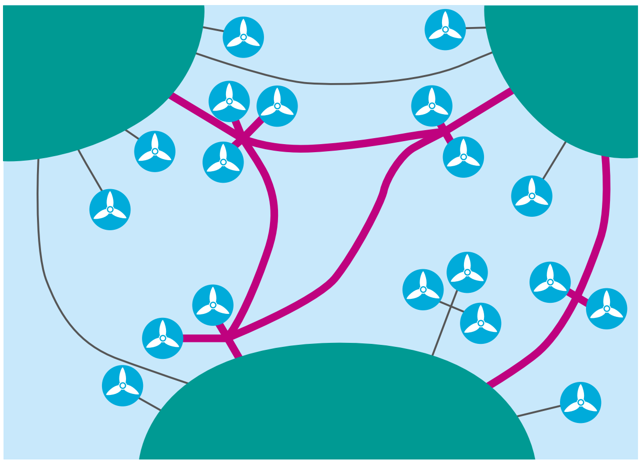


Figure 3.1 – Example of possible hybrid offshore infrastructure configurations

This kind of projects could help to decrease the cost of exchange capacity in marine areas (submarine transmission projects tend to be expensive), hence making new capacities cost-effective, which they may not have been by themselves.

Indeed, there are some benefits to be gained by new exchange capacities as the differences in marginal costs on these borders tend to be high.

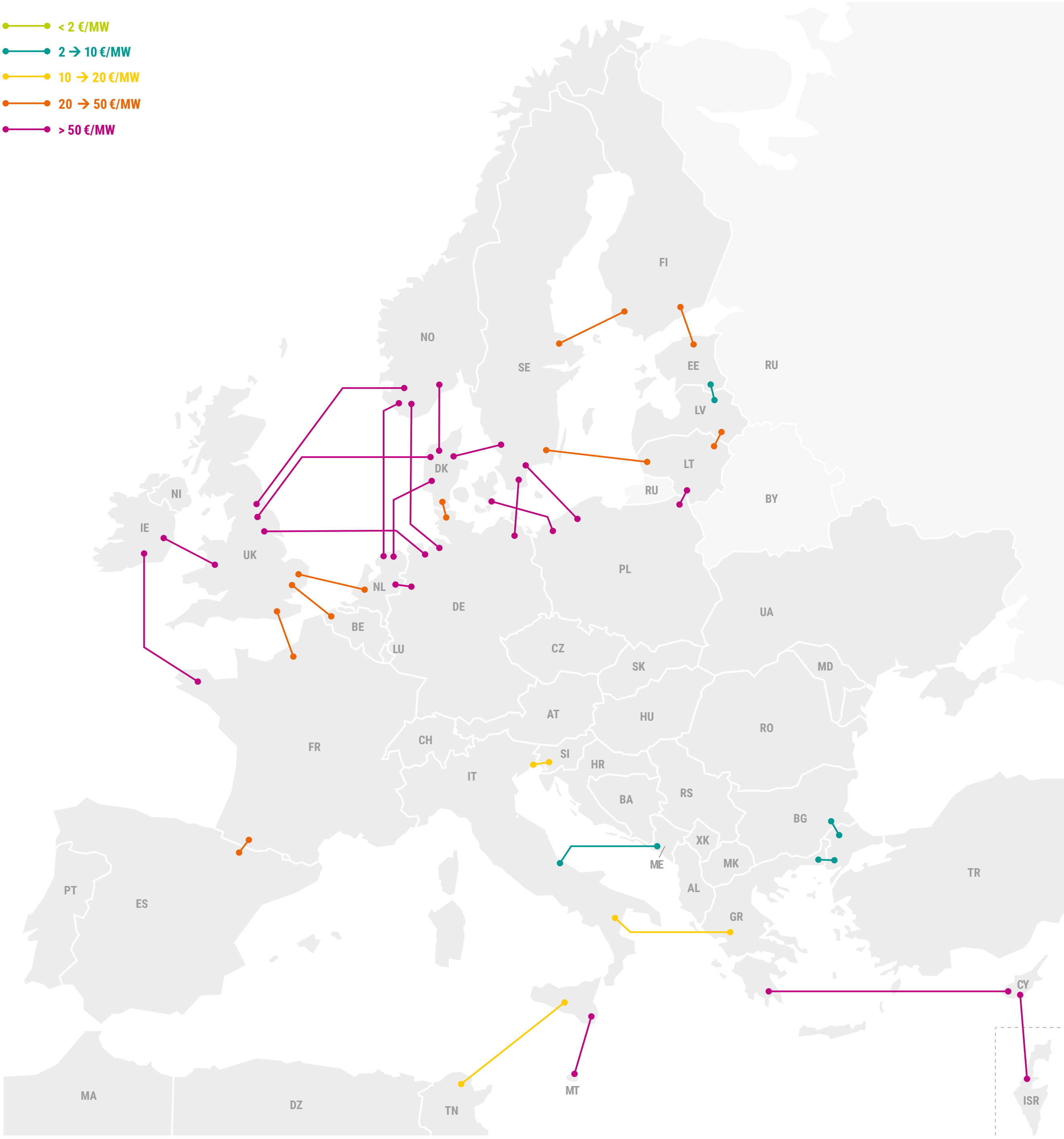


Figure 3.2 – Difference in the marginal cost of electricity between neighbouring countries in 2040, on maritime borders, if Europe were to stop all investments in the grid after 2025. Most borders show a cost difference well above 10 €/MWh.

New methodology to identify needs for hybrid offshore infrastructure

The current System needs methodology employed in TYNDP 2022 does not identify needs for hybrid infrastructure. It does not focus on the optimal connection of generation. Instead wind and solar capacities are part of the scenarios, meaning that connection costs are treated as an externality.

However, in response to the aforementioned challenges, ENTSO-E has launched the development of a new methodology to assess needs for hybrid offshore infrastructure. A positive proof-of-concept has been developed and tested in 2021 and 2022 and will be further detailed in view of its implementation for the first time in the system needs study of TYNDP 2024.

In a similar way as the current system needs identification study, the methodology proposes investment candidates including direct interconnectors and hybrid infrastructure to an optimiser. For each border, the result may include only interconnector, only hybrid infrastructure, both types of infrastructure or none at all. The way of working is described in **Identification of Offshore Hybrid Needs in the TYNDP's IoSN phase – Methodology**, a report part of the TYNDP 2022 package.

Next step: Offshore Network Development Plans

Art. 14 and Art. 15 of the revised TEN-E regulation set out the legal framework for ENTSO-E's new legal mandate related to the development of offshore systems. As per art. 14.2 ENTSO-E is expected to publish the first edition of the offshore network development plans (ONDP) by January 2024, as separate reports part of the TYNDP. There will be one ONDP per sea basin. ONDPs must be based on the goals developed by EU member states for offshore renewable generation in 2050 and be in line with National Energy and Climate Plans and agreements between Member States related to offshore.

ONDPs will aim at providing a high-level outlook on offshore generation capacities and offshore grid needs, including needs for interconnectors, hybrid projects, radial connections, reinforcements of national grids and hydrogen infrastructure, in 2030, 2040 and 2050. The development of the plans will take into account the inputs coming from the Maritime Spatial Planning data delivered by the Member States, allowing the inclusion of the spatial constraints when defining the potential solutions for the development of offshore systems. Additionally, the ONDPs will consider all relevant technical solutions and technological capabilities in the different timeframes, with the aim of giving visibility to the complete portfolio of innovations. ENTSO-E is in the process of building a methodology to develop the sea basin reports that will be part of the ONDP 2024.

4 High consistency with needs identified in TYNDP 2020

Comparing the results of the 2020 and 2022 system needs studies tends to show the robustness of the identified needs. Needs identified in TYNDP 2022 are slightly higher than those identified in the previous TYNDP, therefore confirming the economic space for optimising the European electrical system through additional cross-border capacities, storage installations, CO_2-free peaking units or any other innovative solution to tackle the identified needs.

Indeed, the identified needs for additional cross-border capacity between 2025 and 2030 increased from 50 GW in TYNDP 2020 to 64 GW in TYNDP 2022. In 2040, the various typologies of needs considered in TYNDP 2022 (interconnection, storage and CO_2-free peaking units) lead to a small reduction of the cross-border capacity needs increase between 2025 and 2040, which was 93 GW in TYNDP 2020 and 88 GW in TYNDP 2022 (and of 97 GW in the sensitivity analysis performed without storage and peaking units).

	In 2030, for the entire area studied		In 2040, for the entire area studied	
	TYNDP 2020	TYNDP 2022	TYNDP 2020	TYNDP 2022
Identified needs	50 GW	64 GW	93 GW	88 GW of cross-border capacity increases 41 GW of storage 3 GW of peaking units
Increase in socio-economic welfare	4 bn €/year	5 bn €/year	10 bn €/year	9 bn €/year
Avoided curtailment	47 TWh/year	32 TWh/year	110 TWh/year	70 TWh/year
Avoided CO_2 emissions	60 Mton CO_2/year	38 Mton CO_2/year	55 Mton CO_2/year	44 Mton CO_2/year
Avoided energy not served	Not assessed	n/a (the NT 2030 scenario is adequate)	Not assessed	1.7 TWh/year

Figure 4.1 – Comparison of key results of the System needs study in TYNDP 2020 and TYNDP 2022. To ease the comparison, results for avoided curtailment and CO_2 emissions are presented for the entire area covered by the study (extending beyond ENTSO-E to include Great-Britain, Ukraine, Moldova and Med-TSO countries bordering the Mediterranean Sea (Morocco, Algeria, Tunisia, Libya, Egypt, Palestine, Israel and Turkey)).

Unlike the scenarios used in TYNDP 2020, the TYNDP 2022 National Trends 2040 scenario includes much more flexibility, in particular Power to Gas. More renewable energy is stored or transformed with electrolysis and as a result there is less curtailment in the scenario. This explains why the avoided curtailment enabled by addressing system needs, and in turn the avoided CO_2 emissions, are lower in TYNDP 2022 than in 2020.

Although results show some differences, they are overall very consistent, especially considering the differences in methodology and assumptions between 2020 and 2022. These include in particular the modelling methodology: while in 2020 a zonal model was used in 2040 and an NTC model in 2030, in 2022 a zonal model was used in 2030 and an NTC model in 2040. Other differences include the use of additional climate years (3 climate years in 2030, 10 in 2040) while the 2020 study relied on only one climate year, and of course the scenarios.

5 New needs in a new setup – Dynamic study

Beyond the necessity to efficiently ensure a balance between production and demand at any time, the future system must also be operable in real time by TSOs. The integration of a very large amount of distributed renewable energy sources radically transforms the way this will be done, leading to new technical needs for the system.

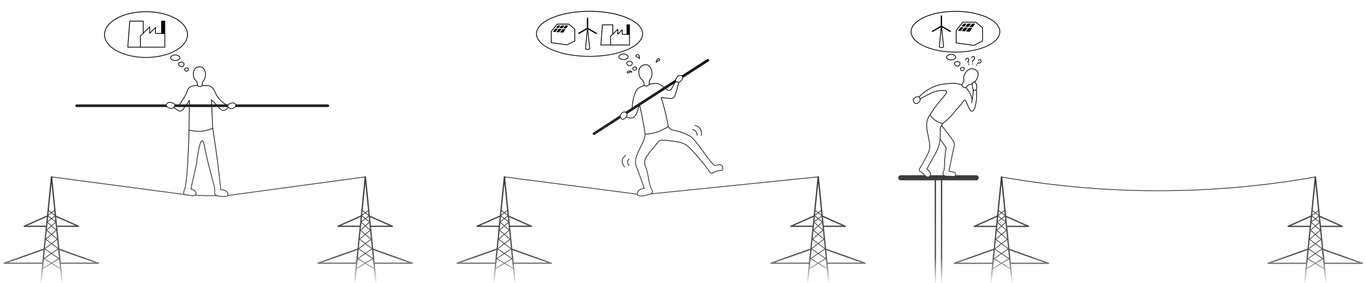
Transmission systems in Europe are increasing in complexity. The future system will have more renewables at all voltage levels, more power electronics either in generation or HVDC connections, a very variable mix of generation and also large and highly variable power flows along with more interconnections between different synchronous areas. This combination of trends, observed in all European synchronous areas, will make it more challenging for system operators to manage in real time aspects such as frequency (maintaining system inertia and preventing system split events), voltage or congestion management control.

These grid synchronisation and stabilisation mechanisms are currently provided by design by the large rotational synchronous generators of conventional thermal plants. As those are gradually phased out from the electricity system, these tasks will have to be performed by other technical and operational solutions. Some of the needs may be addressed by redefining responsibilities and services that grid participants (generation or demand) are expected to provide as part of their connection. The needed technological solutions, such as grid forming Converters (GFC) new types of fast response storage already exist with different levels of maturity. It is urgent to accelerate their development and to make them effectively usable by system operators. Until these new stability management technologies are available, costly but temporary additional measures, such as limiting RES or power flows or slowing down the phase out of thermal units, might be necessary to ensure system security.

- A constructive dialogue between all involved parties, TSOs, DSOs, research institutes, manufacturers, system users and policy makers, should start now to define the relevant technical requirements and develop a roadmap to make the new tools available to the system in time.

Additionally to new technologies at all voltage levels, the changing environment will increase the need for regional and European cooperation of system operators whose processes will become more interdependent. Nationally and regionally defined network reinforcement projects can also be expected to address the specific dynamic stability needs.

- The TYNDP system needs includes a comprehensive range of studies and analysis on key future system operation challenges performed on the TYNDP 2030 and 2040 scenarios: frequency analysis (system inertia, system split events), flexibility needs, transient and voltage stability. They are presented in the dedicated Identification of System Needs 2022 – System Dynamic and Operational Challenges report, along with a detailed overview of the possible system design, operational, regulatory and technological solutions.



PREVIOUSLY
Inertia of the generators immediately compensated deviations (long balancing pole)

TODAY
the synchronous generators are less and less often connected to the grid – Inertia decreases (balancing pole gets shorter and shorter)

IN THE FUTURE
very low levels of inertia will occur (without balancing pole)

Focus: maintaining system inertia

In normal state of operations, the value of the system frequency (normally 50 Hz) measured in Warsaw at a given time is, in theory, the same as the value measured in Lisbon because these cities are located in the same "synchronous area".

However, the electricity system is constantly exposed to a variety of events, of different scale, which do result in a change in the local values of frequency, and the consequences of these changes can ignite a reaction chain propagating its effects at a very large distance, sometimes even at continental level.

Frequency variations occur in power systems due to **mismatches between active power generation and demand**.

Currently the energy stored in the rotating masses of the very large generators of thermal units, by virtue of their intrinsic mechanical inertia, provides means of instantaneously balancing any mismatch. This is essential for instantaneously balancing any small mismatch until frequency reserve response providers are able to restore the balance between generation and demand.

As these units disappear from the electricity mix, the system will see a significant decrease of this inertia. In turn, the system will become more vulnerable to experience high frequency excursions and even blackout as result of a relatively low imbalance between generation and demand. The impact of this inertia reduction is especially significant in small synchronous areas.

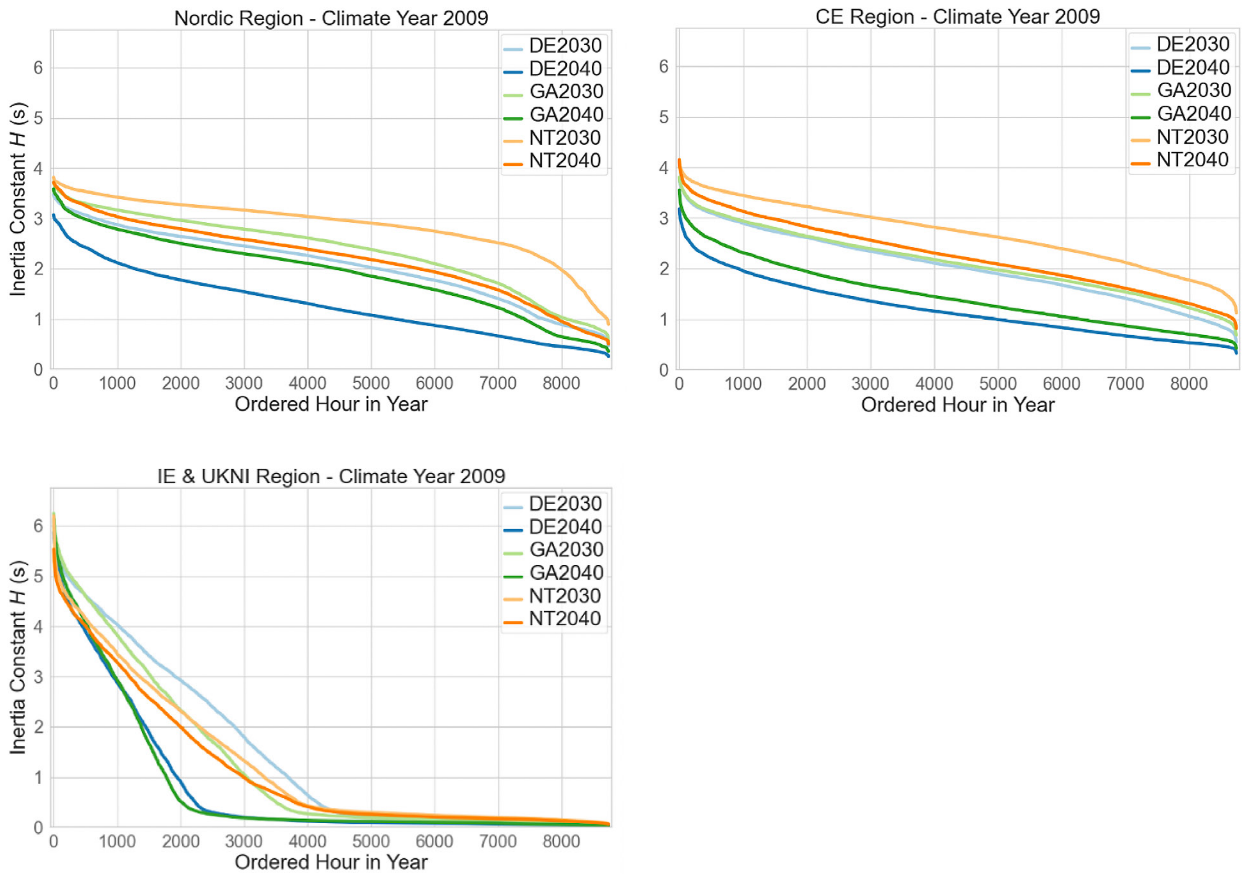


Figure 5.1 – System inertia visualised[5] in the different TYNDP scenarios for 3 European synchronous areas, Nordic region, Continental Europe and UK and the island of Ireland. The scenarios with a higher share of renewables clearly offer lower available inertia (curves are lower and lower).

5 Duration curve: each point of a curve shows the number of hours in the year (horizontal axis value) for which the system inertia is higher than a certain value (vertical axis)

6 Next steps

Public consultation

ENTSO-E has collected feedback on this System needs study from 29 July to 16 September 2022 via ENTSO-E's Consultation Hub. Many comments were received, among which a few have allowed us to correct minor mistakes in the present report and in Regional investment plans. Most comments, including those regarding the methodology itself will be taken into account in the development of the next edition of the System needs study, because time does not allow to re-run the study.

A summary of the feedback received, and an exhaustive account of all comments, is available in the TYNDP 2022 Stakeholders engagement report.

Stakeholders feedback on the draft methodology to identify needs for hybrid infrastructure were also collected before the methodology is finalised and implemented in TYNDP 2024.

Cost-benefit analysis of transmission and storage projects

The TYNDP 2022 performs a cost-benefit analysis of 141 transmission and 23 storage projects and evaluate how they may contribute to meeting the system needs in 2030 and 2040. The CBA considers a wide range of indicators and will assess projects in Distributed Energy scenario in addition to National Trends. Assessment results are available in online project sheets.

ACER opinion

By early 2023 the entire TYNDP 2022 package will be submitted to ACER for Opinion. ACER's comments will be implemented as far as possible in this edition of the system needs study, or alternatively considered for implementation in future studies.

Identified needs may give way to new projects and adaptations of existing projects

ENTSO-E expects that system needs study results will allow promoters to study new projects for the mid to long-term addressing the newly identified needs. Promoters may also review and possibly adapt existing projects based on the study's findings. New and revised projects may be assessed in TYNDP 2024. The submission window to propose projects for TYNDP 2024 will open in September-October 2023.

Perspectives for future System needs studies

The System needs study is an evolving tool to manage increasing uncertainty in the context of the energy transition. Possible improvements for future issues are being investigated and will consider the feedback received from stakeholders in the public consultation previously mentioned, from ACER and the European Commission. The TYNDP 2024 Infrastructure Gap study, as it is referred to in the revised TEN-E Regulation (EU) 2022/869, will for the first time include identification of needs for hybrid offshore infrastructure. It is expected to be released a few months after, and will be closely coordinated with, the release of the first pilot Offshore Network Development Plan, expected in early 2024.

Glossary

Term	Acronym	Definition
Agency for the Cooperation of Energy Regulators	ACER	EU Agency established in 2011 by the Third Energy Package legislation as an independent body to foster the integration and completion of the European Internal Energy Market both for electricity and natural gas.
Congestion		A situation in which an interconnection linking national transmission networks cannot accommodate all physical flows resulting from international trade requested by market participants, because of a lack of capacity of the interconnectors and/or the national transmission systems concerned.
Cost-benefit analysis	CBA	Analysis carried out to define to what extent a project is worthwhile from a social perspective.
Curtailed electricity		Curtailment is a reduction in the output of a generator from otherwise available resources (e. g. wind or sunlight), typically on an unintentional basis. Curtailments can result when operators or utilities control wind and solar generators to reduce output to minimize congestion of transmission or otherwise manage the system or achieve the optimum mix of resources.
Demand side response	DSR	Consumers have an active role in softening peaks in energy demand by changing their energy consumption according to the energy price and availability.
Energy not served	ENS	Expected amount of energy not being served to consumers by the system during the period considered due to system capacity shortages or unexpected severe power outages.
Internal Energy Market	IEM	To harmonise and liberalise the EU's internal energy market, measures have been adopted since 1996 to address market access, transparency and regulation, consumer protection, supporting interconnection, and adequate levels of supply. These measures aim to build a more competitive, customer-centred, flexible and non-discriminatory EU electricity market with market-based supply prices.
Net transfer capacity	NTC	The maximum total exchange programme between two adjacent control areas compatible with security standards applicable in all control areas of the synchronous area, and taking into account the technical uncertainties on future network conditions.
National Energy and Climate Plan	NECP	National Energy and Climate Plans are the new framework within which EU Member States have to plan, in an integrated manner, their climate and energy objectives, targets, policies and measures for the European Commission. Countries will have to develop NECPs on a ten-year rolling basis, with an update halfway through the implementation period. The NECPs covering the first period from 2021 to 2030 will have to ensure that the Union's 2030 targets for greenhouse gas emission reductions, renewable energy, energy efficiency and electricity interconnection are met.
Power to gas	P2G	Technology that uses electricity to produce hydrogen (Power to Hydrogen – P_2H_2) by splitting water into oxygen and hydrogen (electrolysis). The hydrogen produced can then be combined with CO_2 to obtain synthetic methane (Power to Methane – P_2CH_4).
Project of common interest	PCI	A project which meets the criteria defined in the TEN-E Regulation and which has been granted the label of PCI project according to the provisions of the TEN-E Regulation.
Regional investment plan	RegIP	6 regional reports released by ENTSO-E every two years and investigating system needs at regional level, legally mandated by the TEN-E Regulation.
Scenario		A set of assumptions for modelling purposes related to a specific future situation in which certain conditions regarding gas demand and gas supply, gas infrastructures, fuel prices and global context occur.
Ten-Year Network Development Plan	TYNDP	The Union-wide report carried out by ENTSO-E every other year as (TYNDP) part of its regulatory obligation as defined under Article 8, para 10 of Regulation (EC) 714/2009.
Trans-European Networks for Energy	TEN-E	Policy focused on linking the energy infrastructure of EU countries. It identifies nine priority corridors (including 4 for electricity) and three priority thematic areas.

Code	Country	Code	Country
AL	Albania	IS	Iceland
AT	Austria	IT	Italy
BA	Bosnia Herzegovina	LT	Lithuania
BE	Belgium	LU	Luxemburg
BG	Bulgaria	LV	Latvia
CH	Switzerland	ME	Montenegro
CY	Cyprus	MK	North Macedonia
CZ	Czech Republic	NL	The Netherlands
DE	Germany	NO	Norway
DK	Denmark	PL	Poland
EE	Estonia	PT	Portugal
ES	Spain	RO	Romania
FI	Finland	RS	Serbia
FR	France	SE	Sweden
GR	Greece	SI	Slovenia
HR	Croatia	SK	Slovakia
HU	Hungary	UA	Ukraine
IE	Ireland		

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