TYNDP 2022

Regional Investment Plan

Northern Seas

Final Version · May 2023

CONTENTS

1. EXECUTIVE SUMMARY

1.1 Key messages of the region – decarbonisation as the main driver

The Northern Seas region will face major challenges in the energy system in the coming decades. At both a European and national level, the Energy and Climate policies have set ambitious targets to decarbonise the entire energy system by 2050. For 2030, the EU climate law enforces a cut of greenhouse gas emissions by at least 55% (compared to 1990 levels), and for 2050 the EU should be climate-neutral. The electricity sector is foreseen to lead the way with a share of the carbon neutral supply of ca. 95% in 2040 for the Distributed Energy (DE) and Global Ambition (GA) scenarios. By 2030, both scenarios reach a carbon intensity of 37 gCO2/kWh_el; whereas in 2040 the carbon intensity is 17 and 20 gCO2/kWh_el for DE and GA respectively. The bottom-up National Trend (NT) scenario only reaches 92 gCO2/kWh in 2030 and 53 in 2040. This is primarily due to the time lag associated with translating EU-wide targets into national policy.

For the Northern Seas Region, the large growth of renewables, an electrification of demand and a decrease of thermal capacity will result in a heterogeneous energy mix to cover electricity demand. This will change how the electricity system is utilised. Sector integration and demand response will be some of the key elements to integrate the large amounts of offshore wind which are foreseen. The main changes and challenges for the Northern Seas Region can be summarised as:

1. Current (geo)political developments accelerate the transition
2. A fundamental change of the power generation mix
3. Rapid expansion of offshore wind and offshore infrastructure
4. Decreased energy consumption, increased electricity consumption
5. Changed power flows across the region
6. Ensuring flexibility and security of supply in the energy system
7. A requirement for new interconnectors
8. Smart sector integration optimising the decarbonisation

1.1.1 Current (geo) political developments accelerate the transition

At the time of writing, Europe, like the rest of the world, is in an energy crisis. The price for energy carriers was already high and became even higher when Russia invaded Ukraine. Since the launch of the Green Deal by the European Commission (EC), to be implemented via the fit for 55 package, a European legal target to get to climate neutrality in Europe by 2050 has also been set (including intermediate targets in 2030 and 2040). It is not yet clear what long-term effect the current situation will have, but the main tendency is that geopolitics and energy independence will play an important role in the current decision making. An acceleration of the transition and greater diversification of power production to increase security of supply are now a major topic of discussion.

To counter the current energy crisis, the EC proposes the 'REPowerEU' plan. This aims to reduce the usage of fossil gas by 155 billion cubic metres (BCM) in 2030. Among other methods, this shall be realised by measures of energy efficiency by 13% (e.g. increased electrification rates to reduce primary energy consumption) and an increase of the average deployment rate for renewable energy. Some countries of the North Sea region have already decided to further accelerate the integration of Renewable Energy Source (RES) capacities. This will further increase the growing rate and overall capacity of RES in the region. For the member states, the result might be an additional demand of interconnection and internal network reinforcements. In this plan, the electrical demand will increase with plans for new electrical demand use cases, including additional hydrogen production, power to heat and electrical mobility.[1]

1.1.2 A fundamental change of the power generation mix

RES are the fundamental driver to decarbonise the energy system and, in all scenarios, the installed capacity will grow. A large part of the European offshore wind target will be fulfilled in the northern seas, whereas other renewables such as wind, onshore and solar photovoltaic (PV) will grow substantially. With the low or even zero marginal cost, these renewables will push (controllable) power generation out of the market. For security of supply there will be a need for CO2-low or free controllable power generation in the system. The top-down scenarios assume (fossil) fuel-fired thermal power plants with Carbon Capture and Storage; compensating for the CO2 emissions; or running the thermal power plants on CO2 free fuels, e.g. Hydrogen.

For nuclear power generation there is the overall trend of a reduction of power stations. However, in some countries there are discussions of the extension of existing plants and new plants such as in France, Belgium and the Netherlands.[2]

1.1.3 Rapid expansion of offshore RES and offshore infrastructure

The northern seas are also referred to as the powerhouse of Europe. With a shallow seabed and high wind speeds the Northern seas, consisting of the North Sea, the English Channel, the Irish Sea, Skagerrak and Kattegat, have a huge potential and can fulfil a large amount of the European Offshore wind capacity target of 300 GW. On 18 May 2022, the four governments of Belgium, The Netherlands, Denmark and Germany agreed to establish 65 GW of offshore RES by 2030 and 150 GW of offshore RES by 2050[3].

The rapid expansion of offshore and onshore infrastructure is required to integrate this energy source to the electricity system and transport it to the main demand centres. ENTSO-E will develop and publish the first Offshore Network Development Plan for the Northern Seas Sea Basin by early 2024. In this plan, the Ministries of the involved countries will deliver non-binding capacities on which ENTSO-E will develop a view on the required infrastructure needed to transport the offshore generated energy to the demand centres onshore. This ONDP is a requirement from the TEN-E regulation.

1.1.4 Decreased energy-consumption, increased electricity-consumption

Energy efficiency is one of the main pillars of the European climate plan. It presents significant potential and will lead to a decrease of overall energy demand in all sectors. Electrification of mobility, heat demand and industrial processes are a considerable opportunity for systemic efficiency increase. This will decrease the total energy demand but will increase the demand for electricity.

In addition, more electricity consumption is foreseen in new areas such as hydrogen production to decarbonise hard-to-abate sectors and data-centres driven by the increasing trend of digitisation. These developments will lead to an increase of electricity consumption and peak demand, which will require more infrastructure and a more flexible energy system.

[1] *Not all current developments are reflected in the scenarios published in April 2022.*
[2] *Not all new/current (political) developments were captured in the scenarios and therefore not all included in the results.*
[3] *The Esbjerg Declaration - Regeringen.dk*

1.1.5 Change in the power flows across the region

RES are expected to be built in vast quantities. They will be developed in optimal spatial, geographic and social areas which are generally not near to the (new) demand centres. This transformation of the energy system will significantly change the flows in the electricity system. Flow patterns may not change but the magnitude will significantly increase and will be more variable from hour to hour and over seasons. The main patterns which can today be seen are as follows:

- Norway relies on hydroelectric generation, with its associated seasonal dispatch patterns.
- Renewable generation on the Irish and British islands is dominated by wind generation, with its hourly variable output.
- Continental Europe has a mix of wind, solar and gas-fired generation.
- The generation portfolio in France includes a significant share of nuclear power.
- In addition, the offshore wind production in the Northern Seas is expected to increase considerably.

1.1.6 Ensuring flexibility and security of supply in the energy system

With the large changes in electricity generation, security of supply is one of the main challenges. Both the electricity production and demand will become more variable due to increased dependency on the weather. The production, mainly driven by solar and wind, is dependent on the variable character of the irradiation and wind speed. The demand will be increasingly impacted by the temperature due to the growing ratio of heating by electricity, e.g. heating houses by full electric heat pumps.

While the Nordics system will continue to build offshore wind and hydropower capacity including large hydro reservoirs, the rest of the region will be mainly composed of wind and solar generation along with some thermal power plants. For the Northern Seas, there is a high expectation for generation from offshore wind. Combined, this will lead to a more variable and less controllable system from the production side. A lack of production flexibility has to be avoided so as not to further challenge the security of supply, both for short term and for long term seasonal time horizons.

1.1.7 A requirement for new interconnectors

The results of the identification of system needs show that there is an economical need for more interconnection between synchronous areas and Member States in the region. There are also additional benefits of further interconnection. These include:

- Enabling maximising decarbonisation through the sharing of clean energy from the diverse renewable generation sources on a European level.
- Allowing for the integration of renewable generation by enabling cross-border exchanges and, therefore, minimising curtailment.
- Helping security of supply to be maintained as the region's generation fleet drastically changes.
- Aiding market price convergence through the sharing of cheapest available generation resources; and
- Providing the possibility for policymakers to reach adequacy through the sharing of generation resources in a more cost-efficient manner as opposed to each country acting independently.

The additional cross-border capacities are expected to generate larger power flows across Member State's internal grids. Consequently, existing transmission corridors will either need to be reinforced or new corridors identified and developed, together with future interconnectors.

In general, Europe and the Northern Seas region will need to tap into the offshore RES potential to ensure decarbonisation targets can be met. This will likely require traditional point-to-point interconnectors and radial RES connections, offshore hybrid interconnectors (also 'offshore hybrid projects') and energy hubs to be key solutions to satisfy the regions' needs and enable further steps towards a developed offshore grid.

1.1.8 Energy system Integration optimising the decarbonisation

Smart sector integration (SSI) is one of the core instruments to optimise the whole (future) energy system and decarbonise in a cost-effective manner. Electricity as an energy carrier can be used directly in sectors such as industry and transport or indirectly by converting the electricity into other energy carriers such as heat and hydrogen. With the smart operation of the sector coupling elements, SSI will support the further integration of variable renewables in the energy system. Examples of ongoing projects per country can be found in chapter 4.2.

Transmission System Operators (TSOs) are all busy facilitating the transport flows and looking beyond the 'regular' grid investment. In chapter 4.4, this report elaborates on non-wire solutions and other options to optimise the transport network.

1.2 Future infrastructure capacity needs

The changes to the generation portfolio and the resulting power flows across the region drive the need for new transmission capacity. The transmission network will require both cross-border and internal reinforcements. This Regional Investment Plan (RegIP) investigates the potential for additional cross-border capacity increases and their impact on the transmission network in general.

The identified capacity reinforcement needs for the Northern Seas Region are shown in Figure 1. The system needs for the 2040 horizon are being evaluated with respect to (1) market integration/socioeconomic welfare, (2) integration of renewables and (3) CO2 emissions. In the Northern Seas Region, substantial investments are already planned which will increase the capacity between the 3 synchronous areas of the region and with the Continental European synchronous area. These projects help close the gap between today's transmission system and the medium-term needs by 2030. However, additional needs are seen on the horizon 2040, in addition to the confirmation of earlier needs identified on horizon 2030.

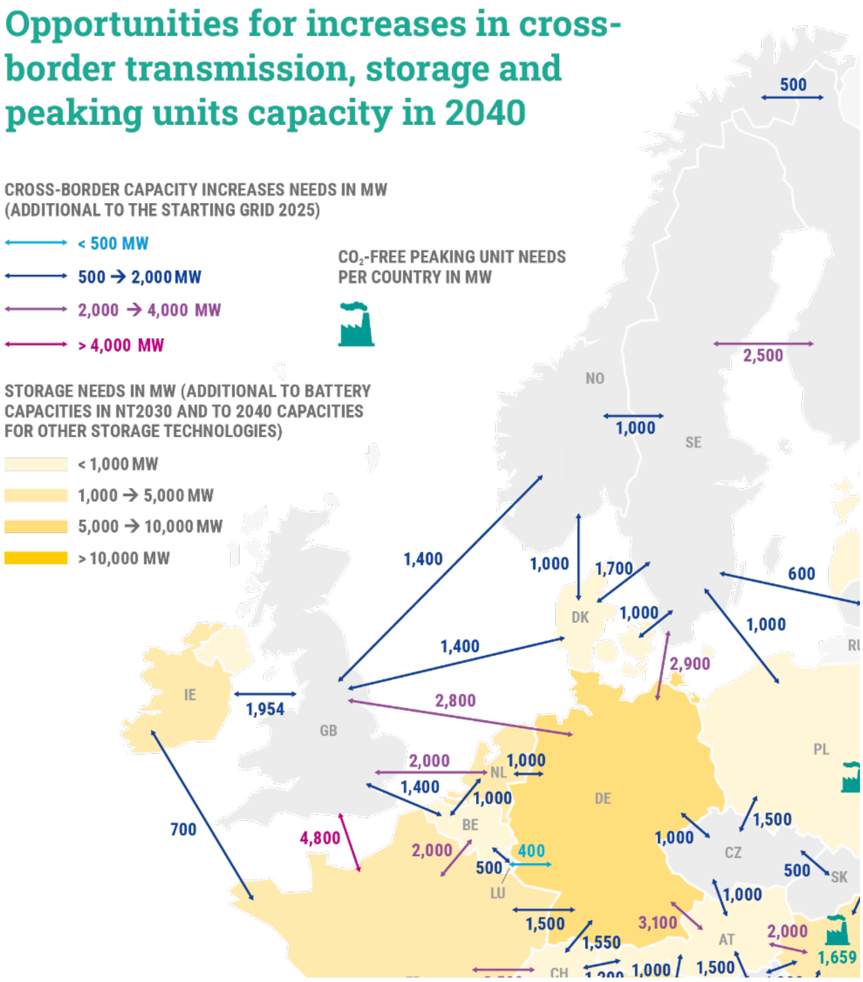


Figure 1 – Identified needs for 2040

2. INTRODUCTION AND REGIONAL CONTEXT

2.1 About Regional Investment Plans

2.1.1 Legal requirements and link to the TYNDP package

The RegIPs are part of the TYNDP package and comply with Regulation (EU) 2019/943 (Article 34 and Article 48) that requests TSOs to establish regional cooperation within ENTSO-E and publish a RegIP biennially. In addition, TSOs may take investment decisions based on that Plan.

RegIPs are part of the TYNDP 2022 package, which also includes the Scenario report and the System Needs Study. The Scenario report describes possible European energy futures up to 2050 and is used to test potential electricity and gas infrastructure needs and projects. Scenarios serve as a basis for the RegIPs to describe the future challenges of the region. The System Needs Study investigates system gaps in the mid-and long-term time horizons (2030 and 2040) in the NT scenario. The present Plan further analyses at regional and country levels the capacity increases identified in the System Needs Study.

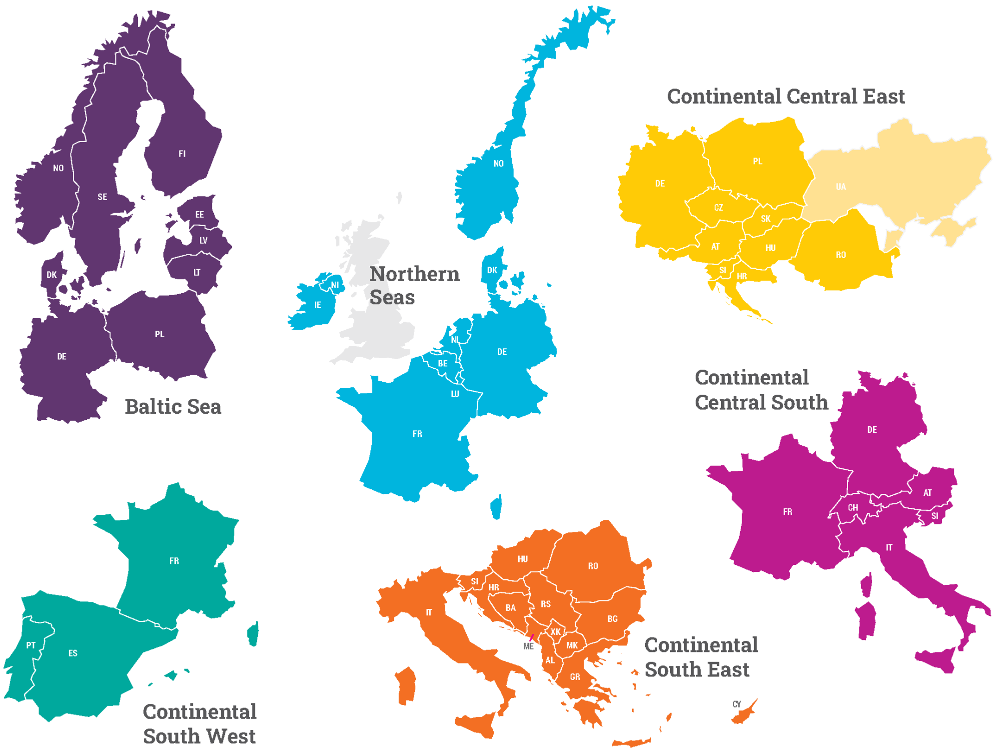


Figure 2 – ENTSO-E's six system development regions. Each region is covered by one Regional Investment Plan.

2.1.2 Scope of the RegIPs 2022

RegIPs describe the present situation in each region in addition to future regional challenges, considering 2030- and 2040-time horizons. The RegIP 2022 also investigates solutions that can help to mitigate future challenges as well as the projections regarding internal network reinforcements. In addition, this edition of the Plan includes a study roadmap for the region with ongoing and future studies that cover the priorities stemming from the 2040 System Needs Analysis.

The present document comprises the following chapters:

- **Chapter 1** gathers the key messages of the region.
- **Chapter 2** outlines the legal requirements and scope of the RegIPs. An overview of the present situation of the regions is also presented.
- **Chapter 3** covers a description of the identified regional system needs depending on the regional challenges.
- **Chapter 4** is dedicated to additional analysis specific to the region.
- **Chapter 5** presents the future challenges in the region, what the necessary mitigation steps are as well as the projections concerning internal reinforcements. The study roadmap for the region is also included.

The Appendix includes the abbreviations and terminology used in the report as well as the list of projects relevant to the region, the links to National Development Plans, the links to simulation results, and additional content depending on the region.

2.2 Overview of the region and present situation

2.2.1 The Northern Seas Region

The Regional Group Northern Seas (RG NS) under the scope of the ENTSO-E System Development Committee includes the following countries and TSOs (Figure 3 and Table 1-1). Note that since the beginning 2022, National Grid is no longer a member.

Figure 3 – ENTSO-E System Development Committee Northern Seas Region

The RG NS comprises nine countries which are listed, along with their representative TSO, in Table 1-1

Table 1-1 – ENTSO-E Regional Group Northern Seas membership

Country	Company/TSO
Belgium	ELIA
France	RTE
The Netherlands	TENNET
Germany	AMPRION, TENNET
Ireland	EIRGRID / SONI
Northern Ireland	EIRGRID/ SONI
Denmark	ENERGINET
Norway	STATNETT
Luxembourg	CREOS

2.2.2 Present situation

The RG NS comprises three separate synchronous systems and is well connected to a fourth system. The four synchronous areas are linked with High Voltage Direct Current (HVDC) interconnectors. Most of the countries in the region are part of the Continental system. Norway and East Denmark are part of the Nordic system, whereas Great Britain and the island of Ireland form their own islanded synchronous systems.

Most of the interconnectors (see map below) are comprised of 220/275/380/400 kV overhead transmission lines. Norway also makes use of 300 kV circuits. 110–150 kV circuits are extensively used in the Danish and Irish transmission systems.

2.2.2.1 Interconnection capacity in the region

Network expansion since 2010

The transmission network in the Northern Seas region has been greatly expanded since 2010. Approx. 4500 km (more than 50% of that in Germany) of lines of pan-European interest were built or upgraded. 14 new interconnectors and some PSTs have been commissioned since 2010, increasing the Region's interconnectivity by 13,400 MW in total. These new interconnectors are (status 1st July 2022):

Name	Border	Capacity (MW)	Name	Border	Capacity (MW)
Nemo Link	BE-UK	1000	**NordLink**	NO-DE	1400
Skagerrak 4	NO-DKW	700	**DKW-DE, step 3**	DK-DE	720/1000
COBRA Cable	DKW-NL	700	**ALEGrO**	BE-DE	1000
East-West interconnector	IE-GB	500	**IFA 2**	FR-UK	1000
Niederrhein – Doetinchem	DE-NL	1500	**FR-BE: PSTs Aubange-Moulaine**	FR-BE	500
Britned	GB-NL	1000	**North Sea Link**	NO-UK	1400
BeDeLux – interim phase	LU-BE	400	**ElecLink**	FR-UK	1000
Kriegers Flak	DKE-DE	400	**IC BeDELux**	LU-BE	300/180

New interconnections or interconnection reinforcements are planned to be commissioned in the region during the next five years, see the[4] ENTSO-e website.

Figure 4 shows the current level of Net Transfer Capacity (NTC) and Figure 5 the level in 2025 within the Northern Seas Region. The NTC is the maximum total commercial exchange capacity in the market between two adjacent price areas. These NTC values reflect that from a market integration perspective, the continental system is strongly interconnected via AC interconnectors, whereas there are several offshore HVDC interconnectors, linking Ireland and Great Britain, as well as the Nordic system, to the continent.

[4] The Interconnected HVAC network in the Northern Seas region including projects which are under construction (status 1.1. 2019) can be found at https://www.entsoe.eu/data/map/. The Nordic and continental systems utilise 400 kV AC as the main transmission voltage level and 220/130/110 kV AC as sub-transmission voltage levels.

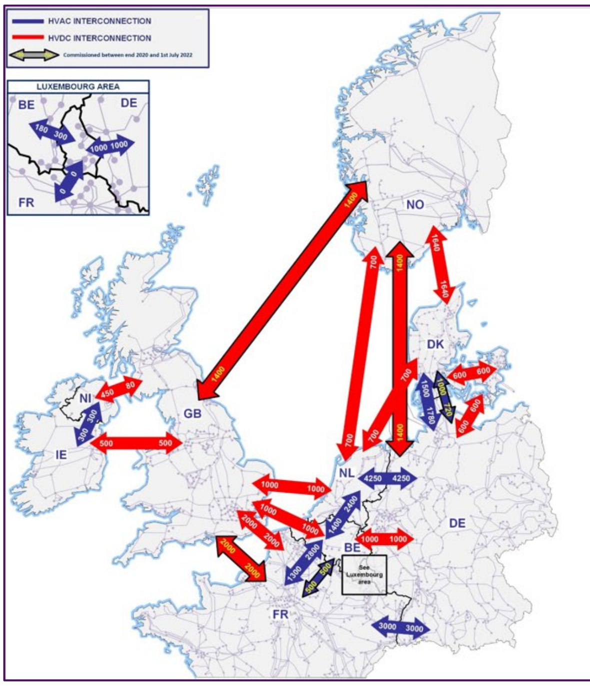


Figure 4 – Current (1st July 2022) transfer capacities in the Northern Seas Region

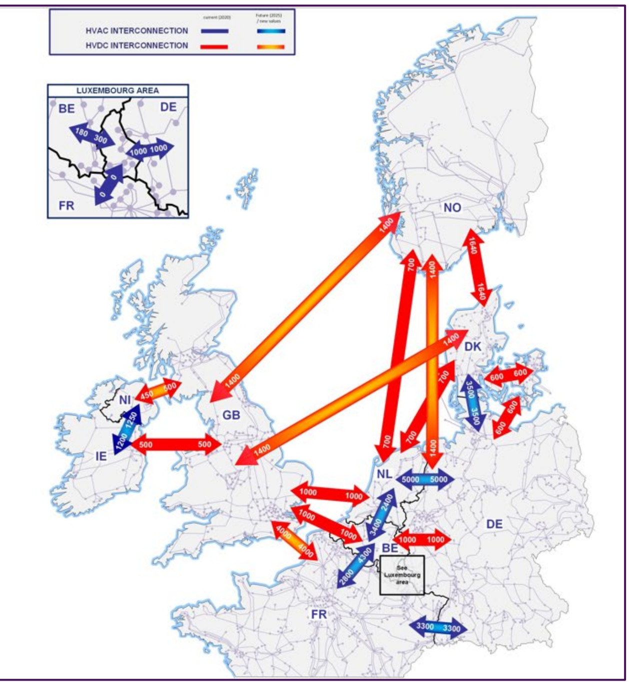


Figure 5 – Transfer capacities in the Northern Seas Region for the starting point (2025) of IoSN exercise, with identification of evolutions since end 2022

Detailed information about the TYNDP22 Reference Grid on the horizon 2027 is given in Table 2-2.

Table 2-2 – Overview of transmission projects included in the TYNDP22 Reference Grid

Project ID	Project name	Promoter(s)	TSO / Third Party	Countries	Status	Commissioning year
23	FR-BE: Avelin/Mastaing-Avelgem-Horta HTLS	Elia, RTE	TSO	FR-BE	Under construction	2022
258	Westcoast line	TenneT-DE	TSO	DE	Under construction	2022
262	Belgium-Netherlands: Zandvliet-Rilland	Elia, TenneT-NL	TSO	BE-NL	Under construction	2023
297	Brabo 2+3	Elia	TSO	BE	Under construction	2025
1063	ZuidWest380 West	TenneT NL	TSO	NL	Under construction	2022
348	NoordWest380 NL	TenneT-NL	TSO	NL	Under construction	2023
167	Viking Link	Energinet, National Grid	TSO	DK-GB	Under construction	2023
1043	Wahle-Mecklar	TenneT-DE	TSO	DE	Under construction	2024
245	HVDC Ultranet Osterath to Philippsburg	Amprion, Transnet	TSO	DE	In permitting	2026
235	HVDC SuedLink Brundbüttel/Wilster to Großgarach/Grafenrheinfeld	TenneT-DE, TransnetBW	TSO	DE	In permitting	2026
130	HVDC SuedOstLink Wolmirstedt to Isar	TenneT-DE, 50HzT	TSO	DE	In permitting	2025
309	Neuconnect	Frontierpower	Third party	GB-DE	In permitting	2022
81	North South Interconnector	SONI, Eirgrid	TSO	IE-NI	In permitting	2025
183	DKE-DE, Westcoast	TenneT-DE, Energinet	TSO	DE-DK	In permitting	2023
245	Meeden-Diele	TenneT	TSO	DE-NL	Under construction	2023
286	Greenlink	Greenlink Interconnector	Third party	IE-GB	Under construction	2024
190	Northconnect	Northconnect	Third party	NO-GB	In permitting	2027
103	Reinforcements Ring NL phase I	TenneT-NL	TSO	NL	In permitting	2025
132	HVDC Line A-North	Amprion	TSO	DE	In permitting	2027
107	HVDC Celtic (FR-IE)	Rte, Eirgird	TSO	FR-IE	In permitting	2027

2.2.2.2 Power generation, consumption and exchange in the Northern Seas region

The total annual power consumption in the Northern Seas region is approximately 1,400 TWh, of which about 70% is consumed in Germany and France. From 2010 until 2020, peak load slightly decreased to 227 GW, whereas renewable generation capacity has significantly increased, as shown in Figure 6.

Thermal fossil fuel-fired generating capacity has decreased in the Nordic countries, whereas it has slightly increased in Continental Europe. The German nuclear phase-out is already clearly visible in the graphs. The Continental and Nordic markets currently have sufficient thermal production capacity to cover demand during periods of low energy production from variable renewable sources or during dry years with low hydro production. Due to the increase of RES (mainly wind and solar) and the reduction and replacement of conventional and nuclear power plants, the region's net position will be influenced in the future. The decade of electrification, however, has only just begun, to both enable the decarbonisation of the energy system by 2050 but also enable the intermediate target of 2030, which will even further require more RES.

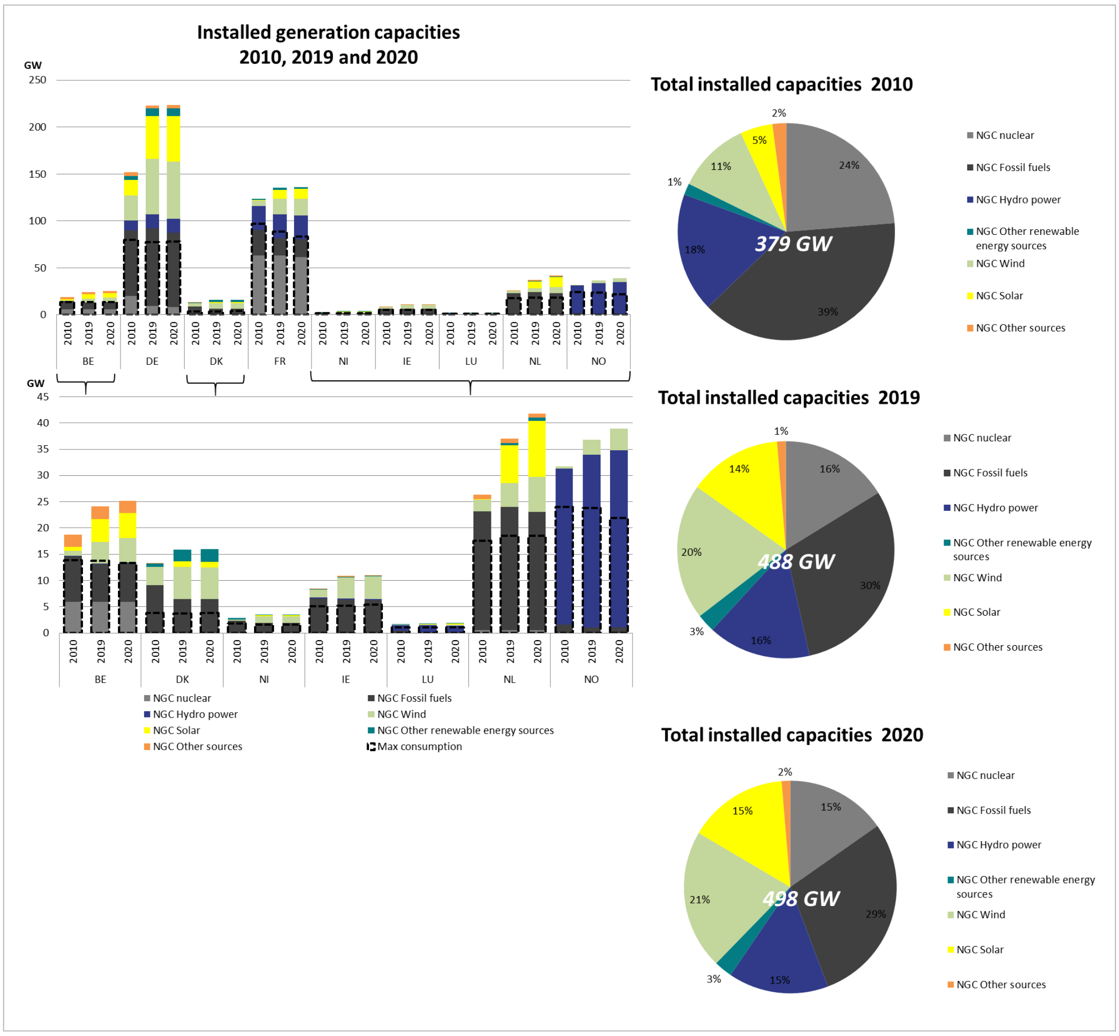


Figure 6 – Installed generation capacities by fuel type and maximum consumption in the Northern Seas region in 2010, 2019 and 2020.

The Nordic power system is dominated by hydropower, followed by nuclear, wind power and combined heat and power (CHP). Most of the hydropower plants are in Norway. During a year with normal inflow, hydropower represents approximately 100% of annual electricity generation in Norway. The total generation originating from hydropower varies between dry and wet years. Consumption in the Nordic countries is characterised by a high amount of electrical heating and energy-intensive industry.

The overall power balance in the region is positive. The Region is an energy exporter to other regions. France has a comfortable annual energy surplus and the Netherlands a small surplus, whereas Belgium, Denmark, Germany and Luxemburg show a deficit. Ireland and Northern Ireland have a neutral annual power balance during an average year. The significant increase in RES generation in Germany has replaced production from nuclear plants and fossil fuel-based generation.

The development of generation and demand in the Northern Seas region is shown in Figure 7.

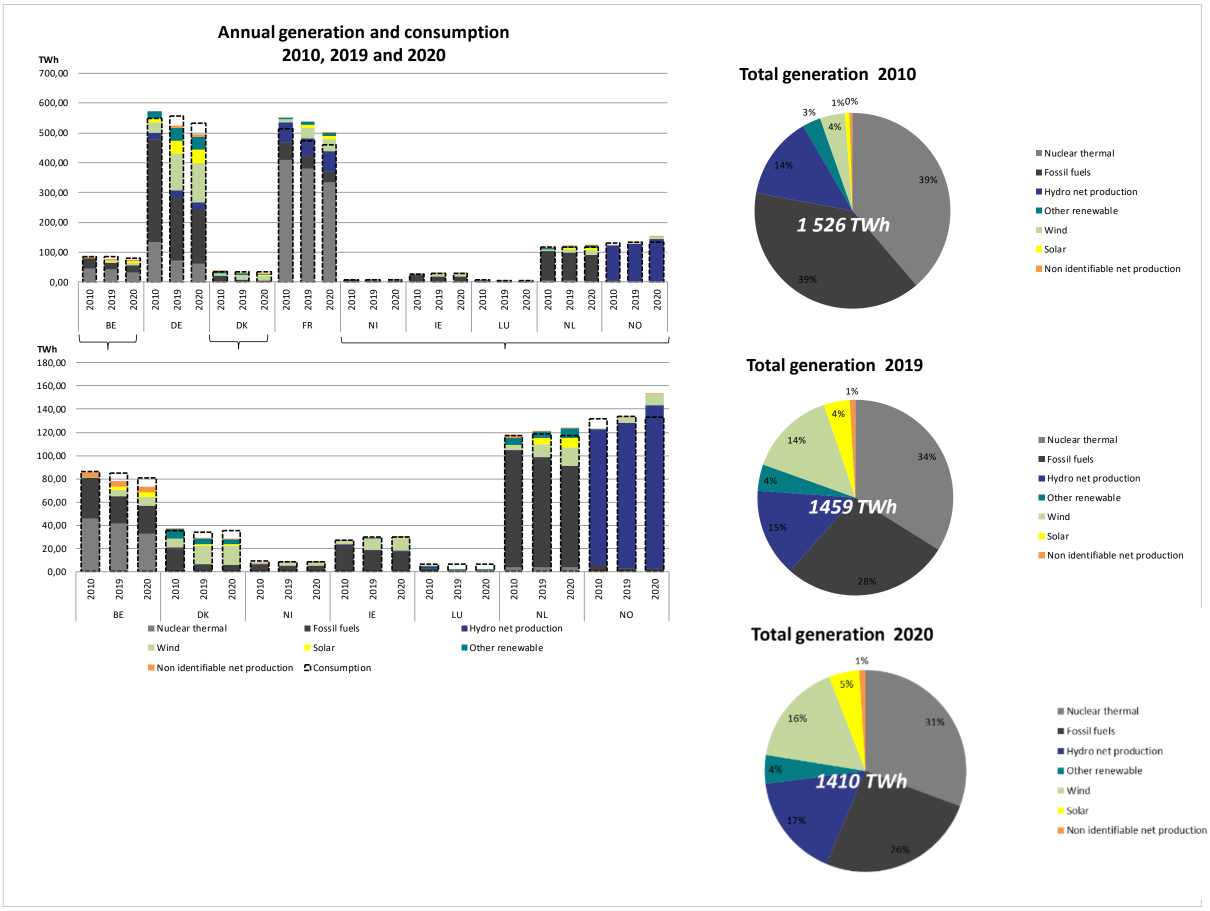


Figure 7 – Annual generation by fuel type and annual consumption in the Northern Seas region in 2010, 2019 and 2020.

Electricity production in the continental part of the Northern Seas region is dominated by thermal power except in the Danish power system, which is dominated by wind and other RES already supplying a >60% share of consumption. Consumption in the area is less temperature-dependent compared to Nordic countries.

Due to the decarbonisation of the gas system and expected increase of generation of green hydrogen based on electrolysers, an additional increase of electricity demand for the supply of the electrolysers is expected in the Northern Seas region and bordering countries. This additional increase of electricity demand will be in addition to the already scheduled increases following the electrification trends across all sectors in order to decarbonise society.

The cross-border flows in 2020 are shown in Figure 8 with some historical data in Figure 9.2020 is presented in Figure 10. The region shows important exchanges between importing and exporting countries and also power transits across countries. A large power flow from 2010 to 2020 is seen, e.g. Figure 10the Netherlands and from France to Great Britain and France to Belgium. In the Nordic countries, the flow pattern varies considerably from year to year as a result of variations in hydrological inflow (both 2010 and 2020 were dry years, but 2010 was even drier). In wet years, exports from Norway are typically much higher than during dry years. Variations in the continental system are more on an hourly basis due to weather relations of variable RES such as wind and solar energy, and from France to Great Britain and France to Belgium.

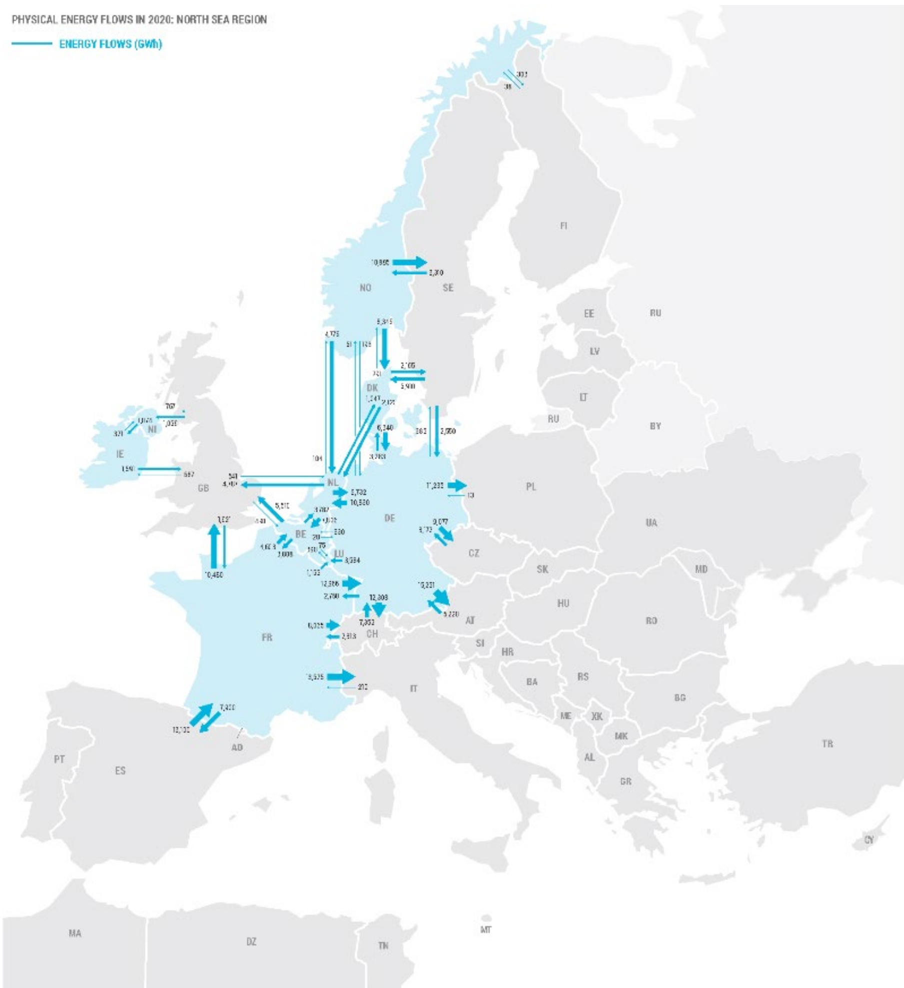


Figure 8 – Cross-border energy flows in 2020

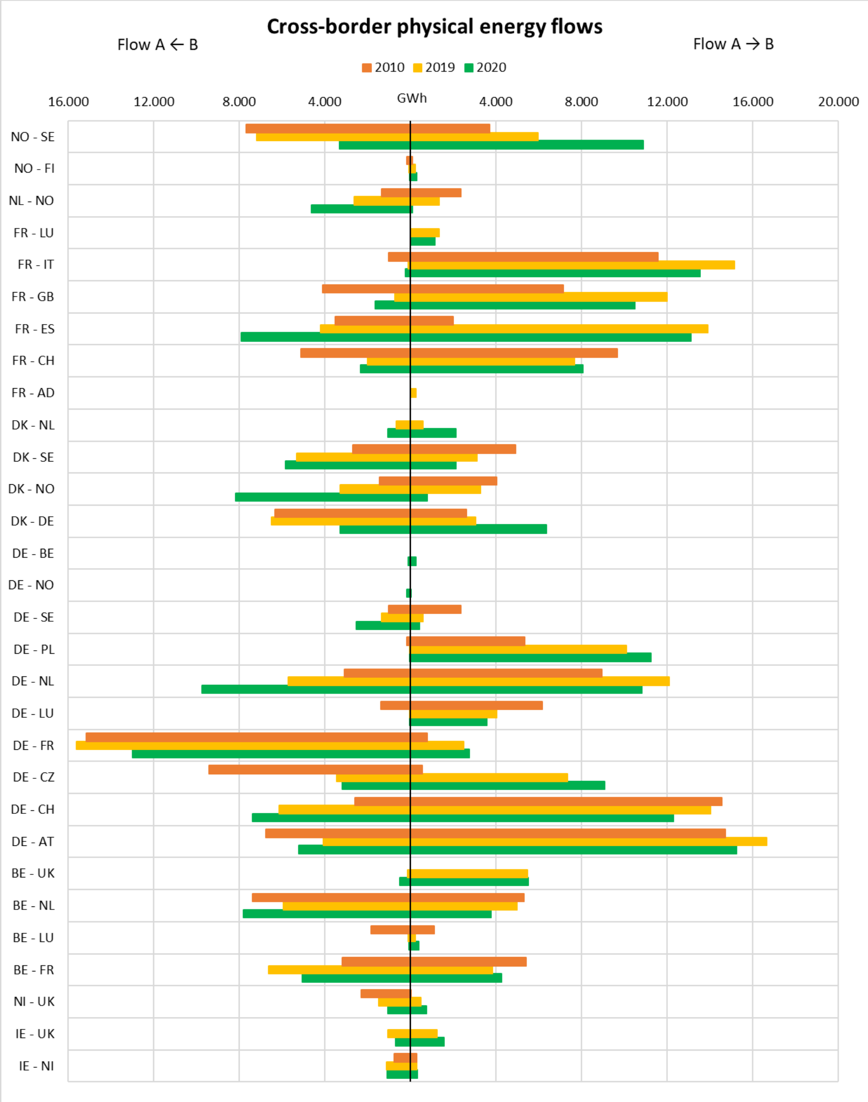


Figure 9 – Cross-border physical energy flows (GWh) in the Northern Seas region in 2010, 2019 and 2020.

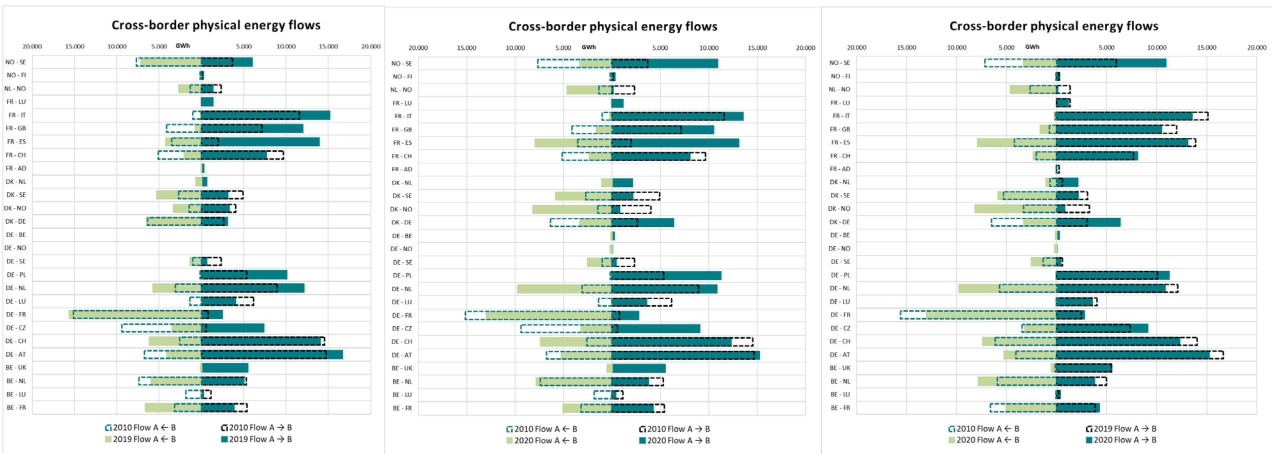


Figure 10 – Cross-border physical energy flows (GWh) in the Northern Seas region in 2010, 2019 and 2020.

2.2.2.3 Grid Constraints

The countries of the North Sea region are already quite well connected. Further interconnectors are currently under construction or planned, see Table 2-2.

The internal expansion of the transmission network is very important for avoiding future network bottlenecks, which can facilitate cross-border market trade as well as internal market flows and which ensures that the supplied electricity can physically arrive at the load demand centres. Satisfying the identified needs of this Identification of System Needs (IoSN) analysis at hand is expected to further trigger internal reinforcement needs, which have not been analysed in detail in this report.

Another motivation for the reinforcement of internal networks is to facilitate RES integration. RES are often built far away from the demand centres. With the expected required tapping into the offshore RES potential of the North Sea in line with the EU targets by 2030–2050, not only will internal grids have to be reinforced to facilitate domestic RES & market flows, but equally massive investments in offshore grid infrastructure is expected. These will be radial offshore RES connections and classical interconnections, and an increasing amount of offshore hybrid projects (or 'hybrid interconnectors') are expected, with future further offshore meshing pursued. The timely development of such offshore (hybrid) interconnectors will be complementary to required onshore reinforcements.

To achieve the Paris climate targets, it is therefore of great importance to minimise possible network constraints between renewable production and demand. As can be seen in the TNYDP 2022 project list[5] and in Appendix 1 of this report, extensive measures for the successful integration of renewables are planned, particularly in Belgium, France and Germany, as shown in Appendix 2.

[5] *https://tyndp.entsoe.eu/documents --- "TYNDP2022 project portfolio"*

2.3 Evolution compared to RegIP 2020

Since the publication of the previous RegIP 2020 that was published for public consultation in August 2020, in terms of grid development, the progress of the projects included in TYNDP 2020 is presented in the maps below – the left one shows the projects submitted to the TYNDP 2020 and the right one shows the projects being submitted to the TYND P22. Some projects have been/will soon be commissioned until end 2022, such as:

- Nordlink DE-NO (1400 MW)
- DK-DE– step 3 (720/1000 MW)
- IFA 2 FR-GB (1000 MW)
- Eleclink FR-GB (1000 MW)
- North Sea link NO-GB (1400 MW)
- PSTs Aubange (500MW) and HTLS Avelin-Horta (1000MW)

Other projects have changed their implementation status and show progress.

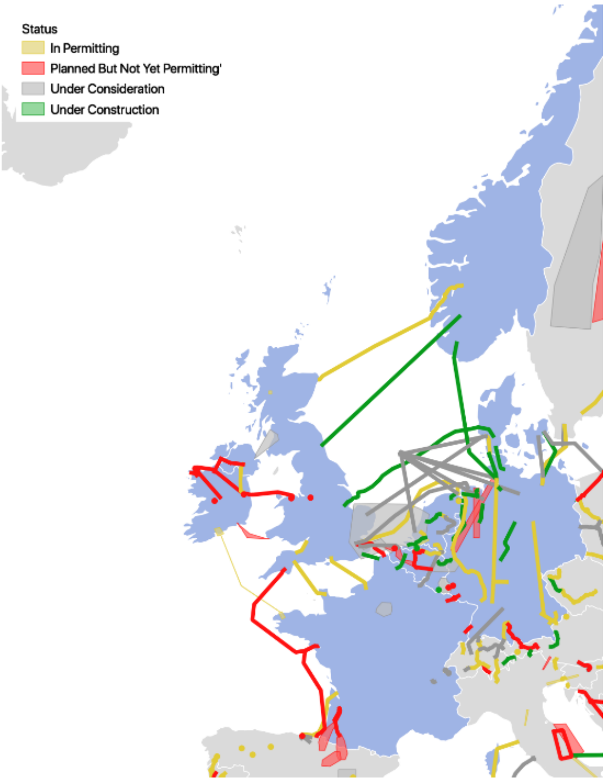


Figure 11 – Map of TYNDP20 projects

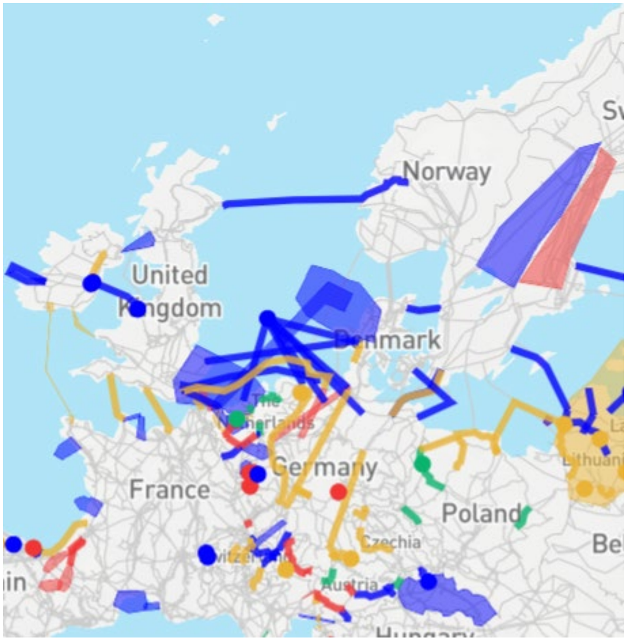


Figure 12 – Map of TYNDP22 projects

3. REGIONAL SYSTEM NEEDS

The IoSN study analyses the future needs of the energy system by determining an optimum set of new investments whereby generation and security of supply cost reductions outweigh the investment cost for new infrastructure. For the 2030 study year, only new interconnectors are considered. For 2040, both new connections, storage and peaking generation units are considered.

Electricity transmission infrastructure planning requires consideration of a large set of indicators. This includes cost benefits but also other benefits such as CO_2 emissions reductions. Based on an assessment against a large set of indicators, it is possible for an individual project to receive a positive Cost–Benefit Assessment (CBA) result even if it is not on a border included in the optimum combination of capacity increases identified by the needs study.

3.1 Regional results of the Identification of System Needs

The continued increase in RES penetration continues to drive the need for more transmission infrastructure. Although the region is already well interconnected, there is additional need for infrastructure on multiple borders. The needs of the region increased overall from 2030 towards 2040.[6]

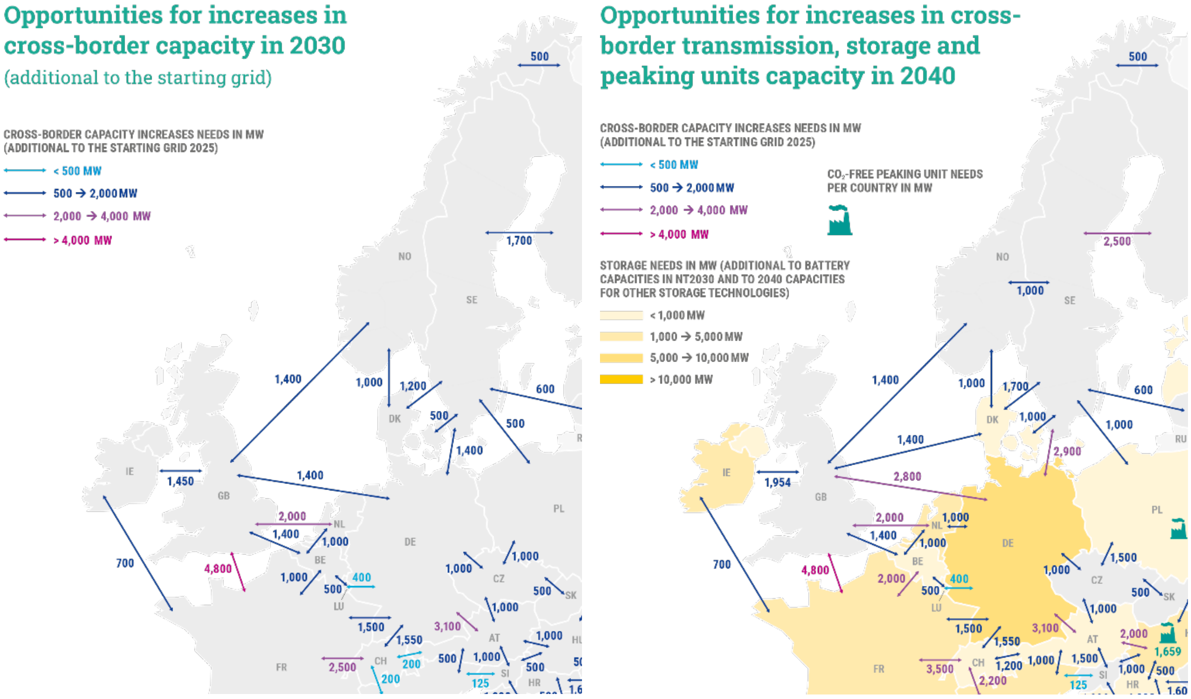


Figure 13 – Results of the IoSN results for 2030 (left) and 2040 (right)

[6] *The current System needs methodology applied in TYNDP 2022 does not identify needs for offshore 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. For more information, please refer to the main IoSN report.*

3.1.1 The need for storage and peaking units

The results for 2040 indicate storage as an effective solution option to support the integration of increased RES generation in the region. This storage is, in most cases, complementary to the needs for infrastructure. The majority of the region's countries have an additional need for storage solutions, except for Norway. This is primarily due to the fact that Norway has a significant amount of existing storage on the electricity system, via their pumped hydro storage capacity.

Peaking units are not selected for the region, assuming the countries remain sufficiently adequate following the TYNDP scenario assumptions.

3.1.2 The need for infrastructure

The islands of Ireland and Great Britain, which are both independent systems, have the need to further connect with other synchronous areas. The needs increases from 2030 to 2040 for capacity between the island systems with the Continental European and the Nordic system.

The Continental European system is more interconnected. It will be connected to the IE system via France, the UK system via France, Belgium, Netherlands, Germany, and Denmark, and to the Scandinavian system via Germany and Denmark.

Norway, embedded in the Nordic system, sees the needs for interconnection to the UK and the Continental European system.

3.2 Market results

The results of Norway present possible inconsistencies. ENTSO-E will further investigate them during the public consultation period. This especially influences figures of generation, net-balance and marginal cost.

The result of the IoSN study shows an economical optimal future grid. One for 2030 where only new interconnectors are considered and one for 2040 where new interconnectors, storage and peaking units are considered in addition to the market scenario data assumptions, the numbers of which also evolving compared to the current market scenario numbers. To put the outcomes into perspective, one can compare the results of the economical optimisation (from here on called the 'Economic grid'), to the case where there is no further extension of the current grid after 2025 (from here on called 'no grid') and to the case where only the currently projects of grid investment for TYNDP 2022 will enter the grid (from here on called 'portfolio grid').

The difference between the portfolio grid and the economical grid would be expected to be larger for the year 2040 than for 2030. For 2030, there are already projects initiated which fulfil the needs identified previously. 2040 is further away; therefore, fewer of the required projects have been initiated.

In this section, the results of the Economic grid, with the focus on the Northern Seas region are compared to the no grid and portfolio grid cases. This comparison examines the following indicators for 2030 and 2040:

- **System costs:** Total network investment (including costs of related necessary internal reinforcements for most borders) and generation costs.
- **Net annual balance:** The energy balance of country, meaning which country is either a net exporter or importer.
- **CO_2 emissions:** The CO_2 emission volumes in the power system due to generating energy with CO2-emitting power plant.
- **Curtailed energy:** The volume of energy curtailed (not produced energy).
- **Generation mix:** The yearly generation per fuel type (nuclear, gas, coal, oil, …) .
- **Spread of marginal costs:** The difference between marginal costs may be calculated at the borders of either member states, regions or bidding zones.

3.2.1 Key findings

The increased capacities of RES and the availability of low marginal cost nuclear generation and on the other hand the increase of demand drive the business case for increased interconnection, both within the region and externally to other regions.

New interconnectors increase the capacity for exchange between countries and new storage capacity make the more efficient use of generated energy. The difference of results between the 'no grid' and the optimal grid for 2040 are:

- The net balance between the region and other regions will increase from 56 TWh to 87 TWh.
- The energy curtailed will drop by 52% to 24,1 TWh.
- The CO_2 emissions will drop by 8% which is a reduction of 5,4 Mton CO_2
- Nuclear powerplants will produce 4% more where gas fired power plants will produce 13% less. Other non-res generation will increase by 4%
- There is a reduction in both power-to-gas of 8% and pump storage utilisation of 12%.
- The differences in marginal costs are, reduced for most countries. The reduction ranges from 4–16%
- The total system costs are reduced by 11%.

In general, the analysis shows that there are benefits for the region, increasing the interconnection above the current grid and increasing the storage to levels higher than in the scenario assumptions. The following section includes more in-depth commentary on the results of several of the indicators.

3.2.2 Net annual balance

The results of Norway present possible inconsistencies. ENTSO-E will further investigate them during the public consultation period. This especially influences figures of generation, net-balance and marginal cost.

With the increase of RES and increasing electricity demand for all countries, the imports and exports of countries change significantly over the two reference years. The key findings are:

- Exports from the region increase:
    - For 2040: from 56 TWh in the 'no-grid' case to 66 TWh in the portfolio grid and to 87 TWh in the economic grid.
    - For 2030: the results follow similar trends, with a net export of 67 TWh, 62 TWh and 72 TWh for the 'no-grid', portfolio grid and economic grid respectively.
- France is a large exporter of electricity with annual values of 95, and 92 TWh for the 2030 and 2040 economic grid. This due to the vast amounts of nuclear energy and increased RES in the system.
- Belgium, assuming a full nuclear phase out, is the largest importer of electricity in the region for both reference years with annual values of 32 and 35 TWh for the 2030 and 2040 economic grid
- Germany will transform from a net importer in 2030 (12 TWh) to an exporter in 2040 (33 TWh). This due to the high volume of RES which will be integrated in the German system towards 2040.

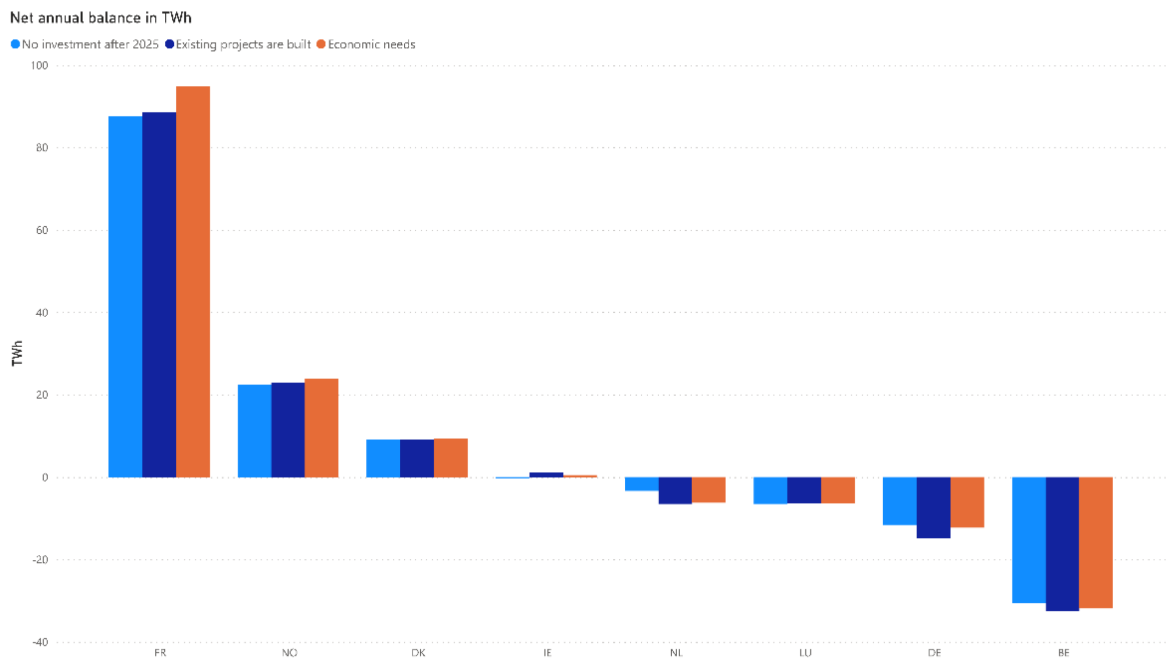


Figure 14 – Net annual balance for 2030

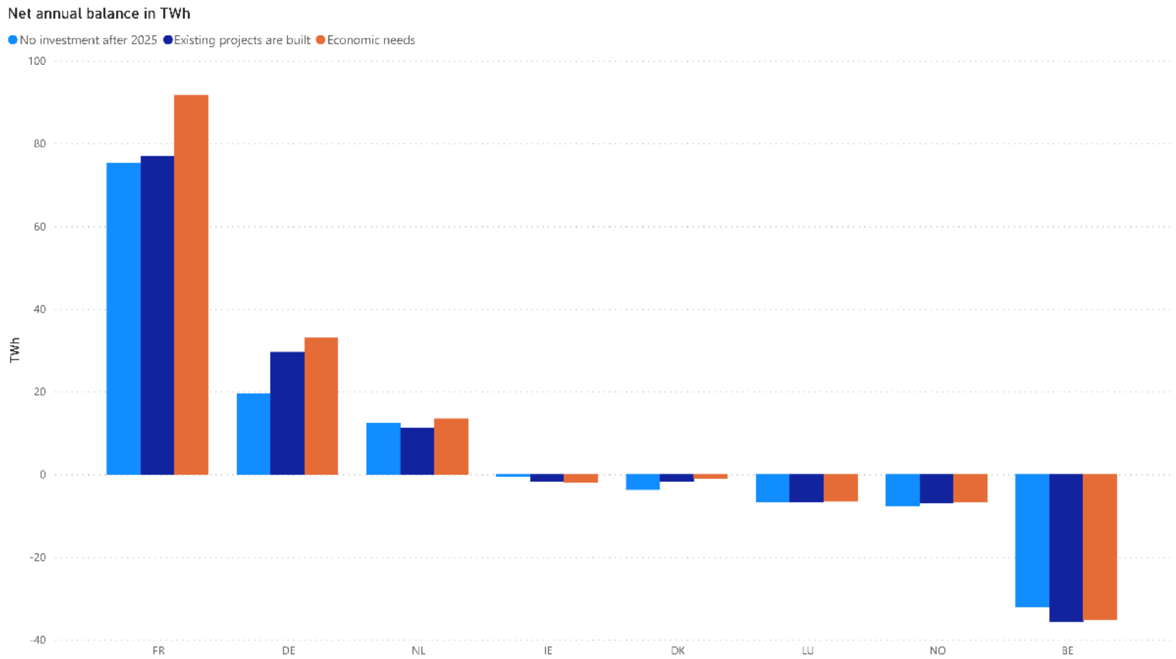


Figure 15 – Net annual balance for 2040

3.2.3 System costs

The total network investment, including the costs for related necessary internal reinforcements, storage and generation costs can be found in Figure 16 and Figure 17.

The increase of the interconnections for 2030 and the increase of interconnection and storage for 2040 will lower the total systems cost for the region although for some countries the system cost does rise. In the case of France, additional interconnection increases exports, which results in an increase in the system marginal costs. This is due to the availability of low marginal cost nuclear generation.

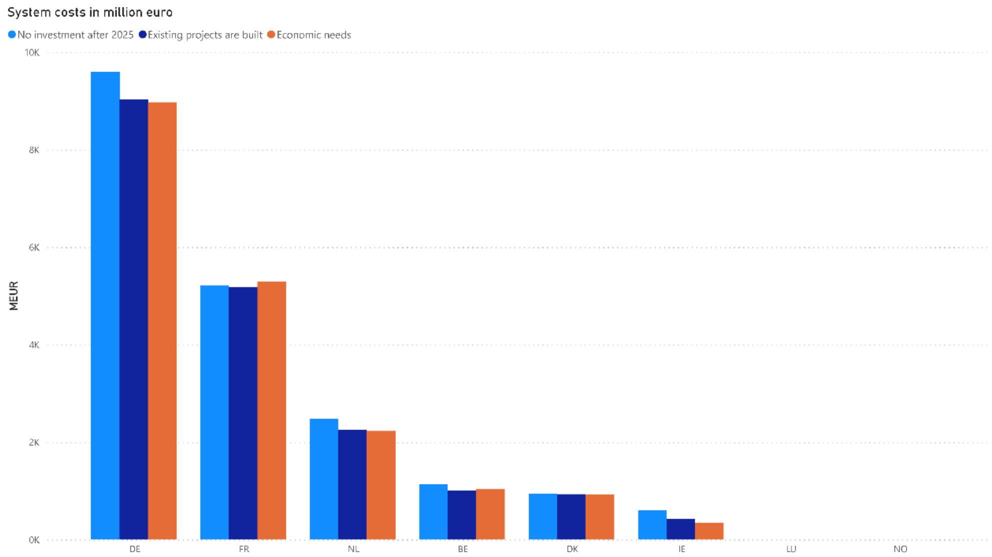


Figure 16 – System costs for 2030

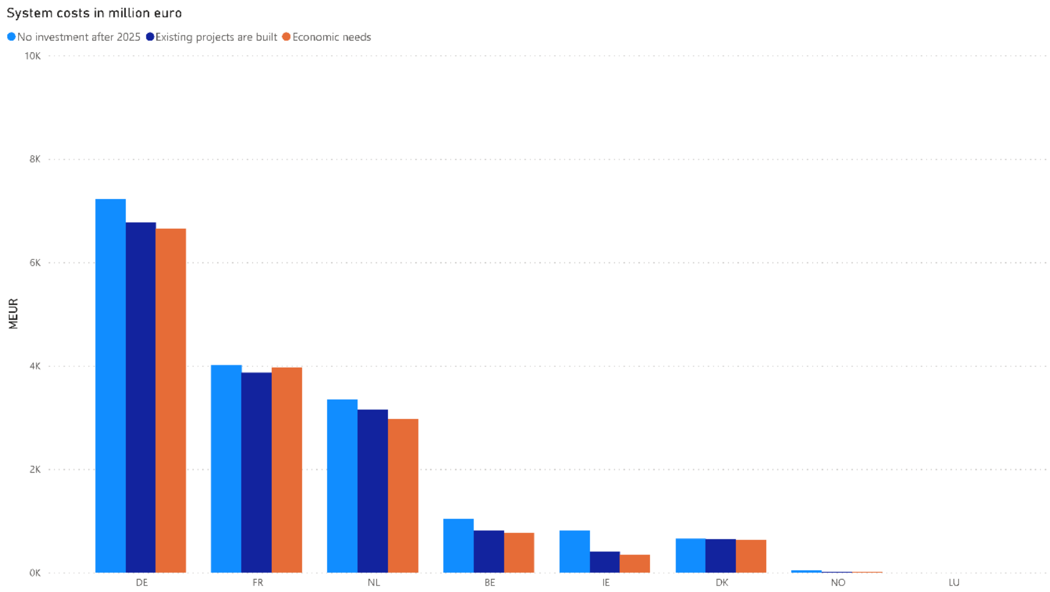


Figure 17 – System costs for 2040

3.2.4 Curtailed energy

With the increase of variable RES such as wind and solar, curtailment levels increase . This is clearly visible between 2030 and 2040. The Economic grid, and to a lesser extent the Portfolio grid, reduce significantly the energy which needs to be curtailed in comparison to a 'no grid' situation. This reduction is between 30 and 55% for the region in 2040.

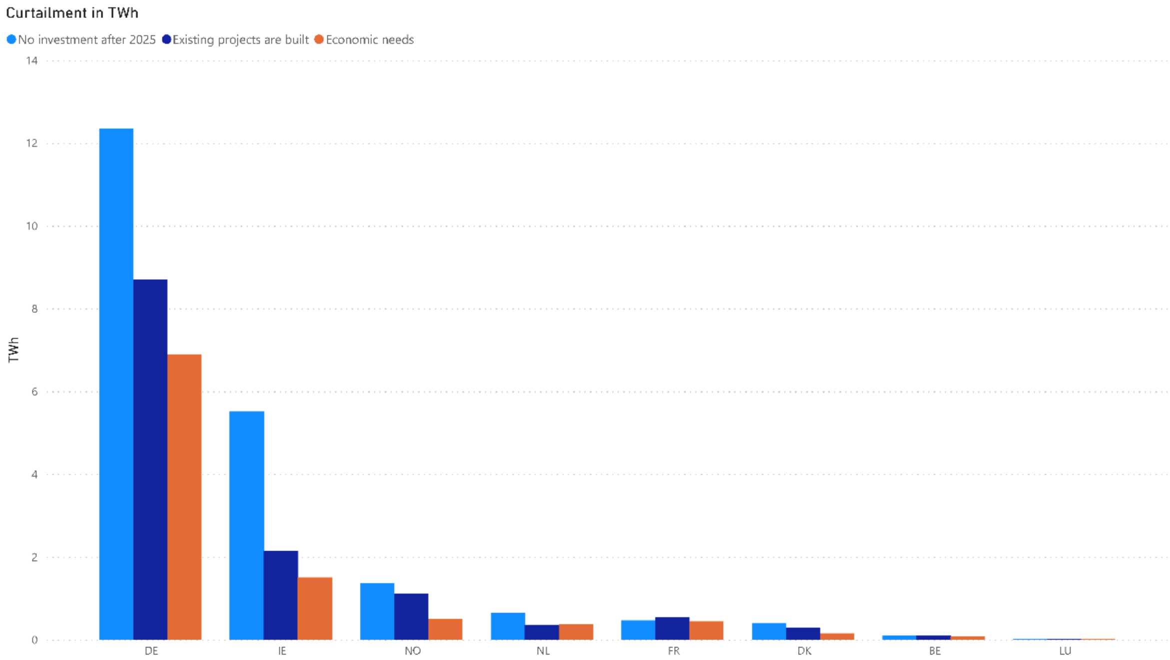


Figure 18 – Curtailment for 2030

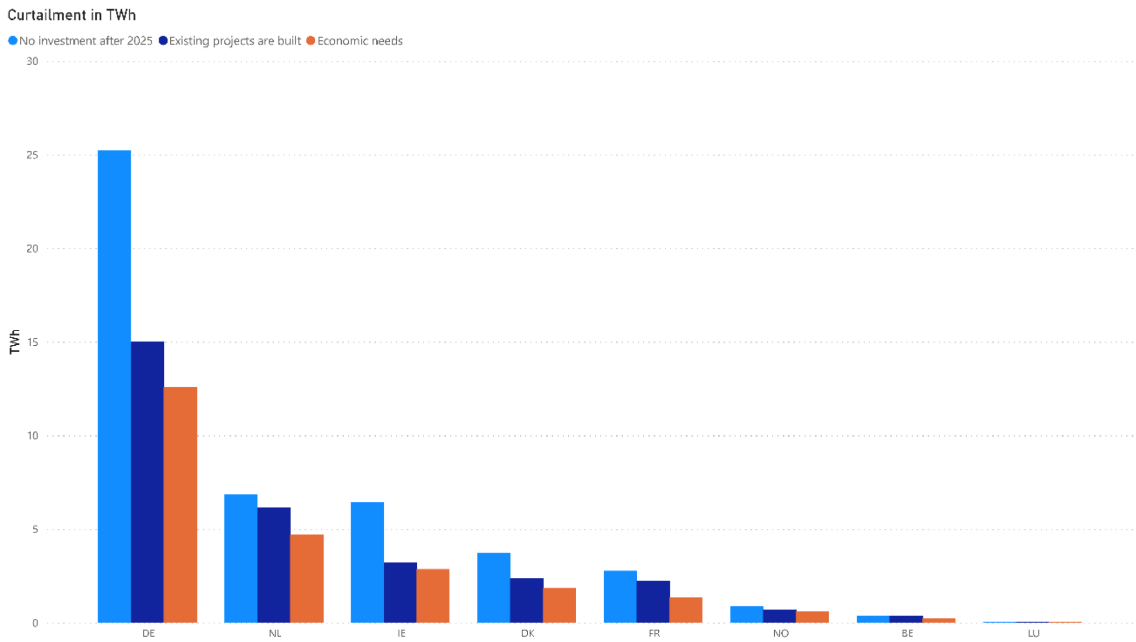


Figure 19 – Curtailment for 2040

3.2.5 CO2 emissions

There are measured reductions in CO_2 emissions in the region when comparing the economic and no grid cases. In 2030, there is a 7.2 Mton reduction due to the economic grid whereas in 2040 there is a 5.4 Mton CO2 reduction. In 2040, there is higher RES generation on the system which results in fewer CO_2 emissions. This contributes to why there is a smaller reduction in 2040 compared to 2030.

Finally, with the economic grid there is a reduction of 75.6 Mton of CO_2 emissions (-57%) from 2030 to 2040. reduction.

For some countries, FR and BE, there a slightly increased CO_2 emissions in the economic grid compared to the portfolio grid or even the no grid, which can be seen in FFigure 20. It is likely that optimisation has displaced more polluting and expensive thermal generation from other Regions with both RES and, at times, more efficient thermal generation in these countries. This CO_2 increase effect on these counties seems temporary when examining Figure 20 to Figure 21, which cover the 2040 horizon. These CO_2 increases in these countries lead to a more optimal European energy system, which supports and enables CO_2 reduction already in the short-term as well as in the long-term.

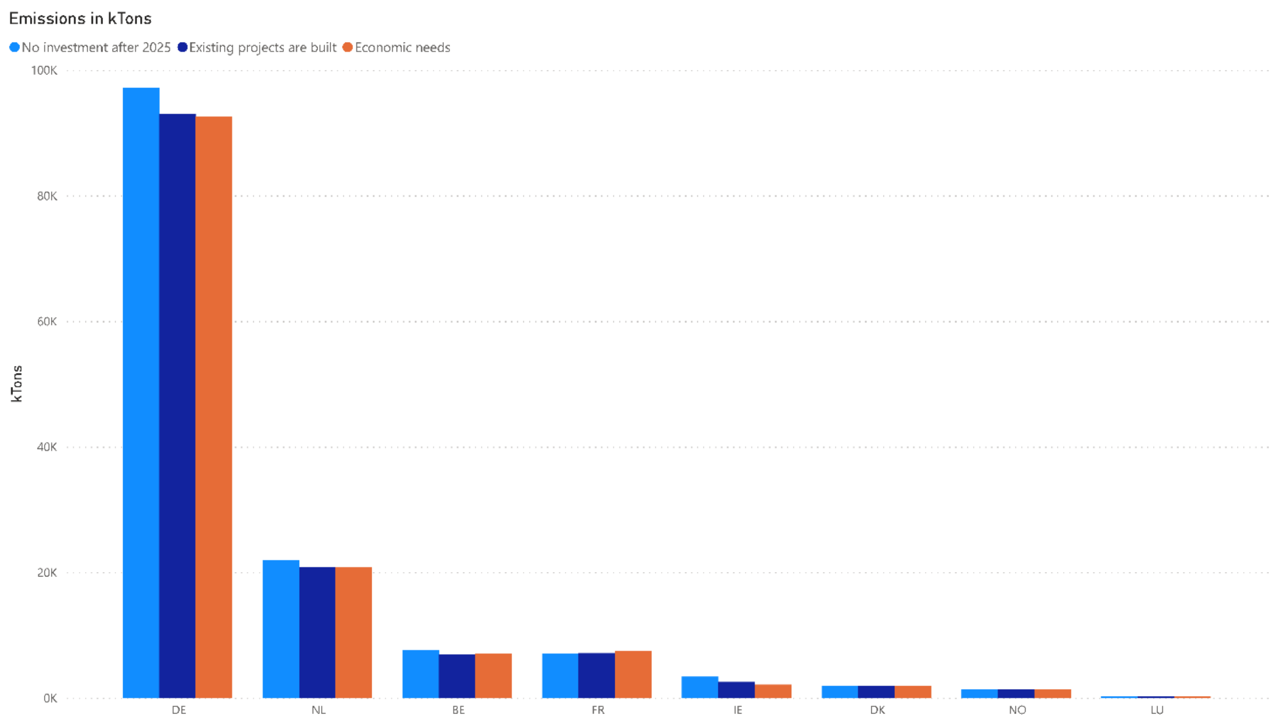


Figure 20 – CO_2 Emissions for 2030 (ktons/y)

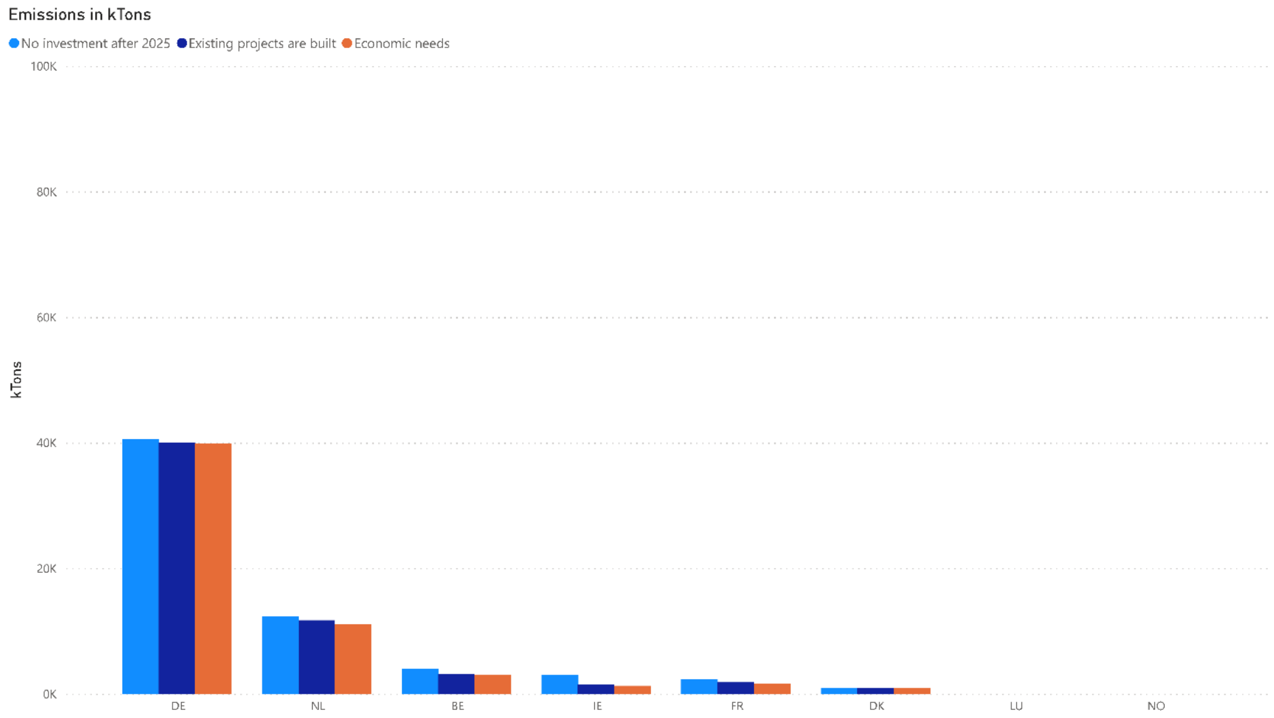


Figure 21 – CO_2 Emissions for 2040 (ktons/y)

3.2.6 Generation mix

The results of Norway present possible inconsistencies. ENTSO-E will further investigate them during the public consultation period. This especially influences figures of generation, net-balance and marginal cost.

The shift from fossil fuel power plants towards RES can be clearly seen in the main finding between 2030 and 2040 for the economic grid:

- Coal phased will be completely phased out between 2030 and 2040[7].
- Decrease of nuclear due to phase out in France, Belgium and Netherlands.
- Increase of electricity produced by RES, especially wind and solar. Wind onshore, offshore and solar PV together will show an increase of more than 460 TWh between 2030 and 2040.

These observations can be seen in the figures below.

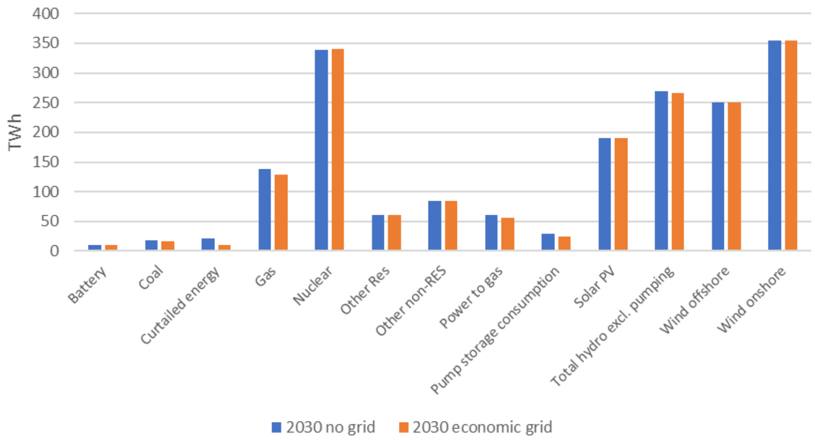


Figure 22 – Energy mix for 2030 for North Seas countries

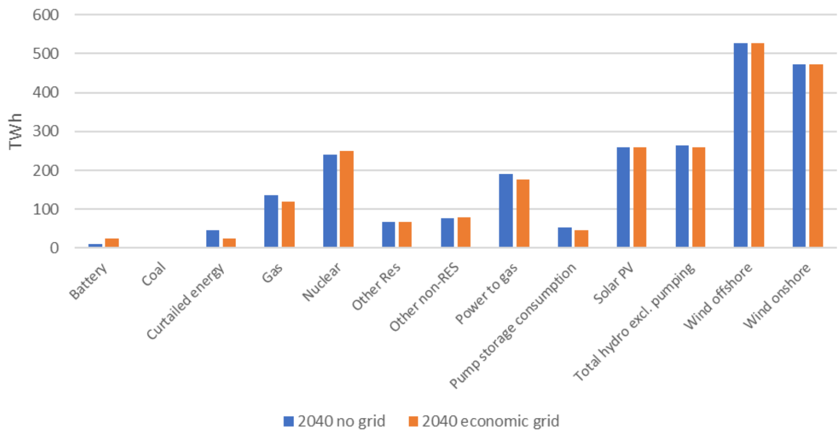


Figure 23 – Energy mix for 2040 for Northern Seas countries

[7] *Assumptions (on coal, nuclear, ...) defined for scenarios before Ukrainian crisis and repowerEU communication*

3.2.7 Marginal costs

The results of Norway present possible inconsistencies. ENTSO-E will further investigate them during the public consultation period. This especially influences figures of generation, net-balance and marginal cost.

It can be seen from figures 24 and 25 that marginal costs have increased from 2030 to 2040. Although there is more RES in the system and coal and nuclear are phased out in some countries, in the hours with low RES, availability and high demand, the more expensive fuel type (e.g. gas) might be selected and set the price.

The average marginal costs are expected to decrease and converge within the Region with the 'Economic Grid' in place, as shown in Figure 25 for 2040.

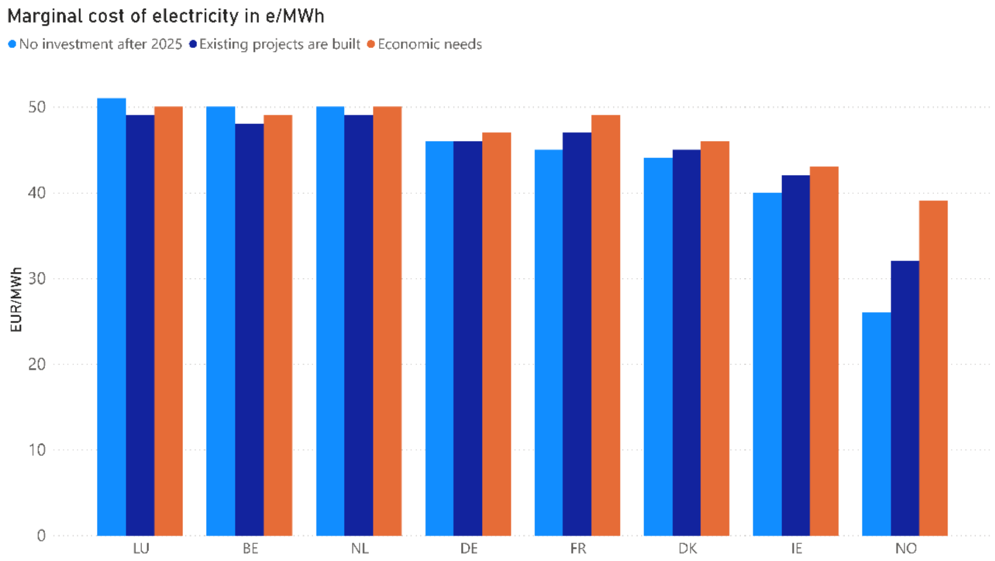


Figure 24 – Marginal cost for 2030

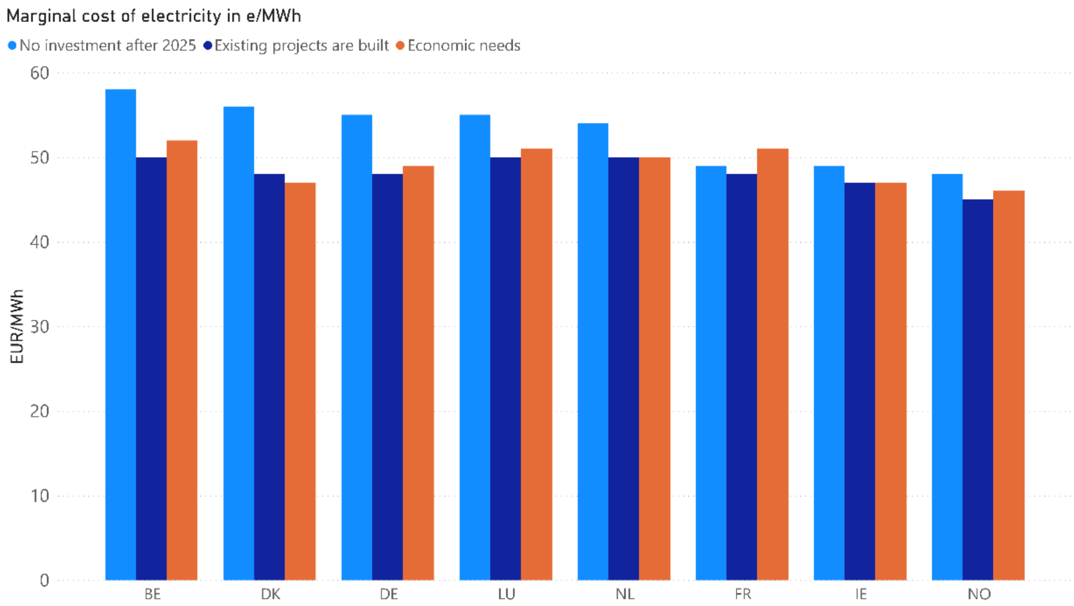


Figure 25 – Marginal cost for 2040

Figure 1Figure 26 a and Figure 26 b below show the average hourly marginal cost difference across the borders in the Region, enabling the conclusion that satisfying the 'Economic' needs leads to significant reductions in price spreads.

Not all reductions are clearly visible in the maps, as e.g. the spread between Norway and the Netherlands seems to remain high – but is actually reduced significantly from a level of about 102 €/MWh to a level of about 17 €/MWh. The same is valid for the spread between Ireland and France, which reduces from 302 €/MWh down to 14 €/MWh. Nevertheless, zeroing electricity market price differences between neighbouring countries and respecting the ITEG target in general is not an objective in itself as local conditions and grid development costs must be considered.

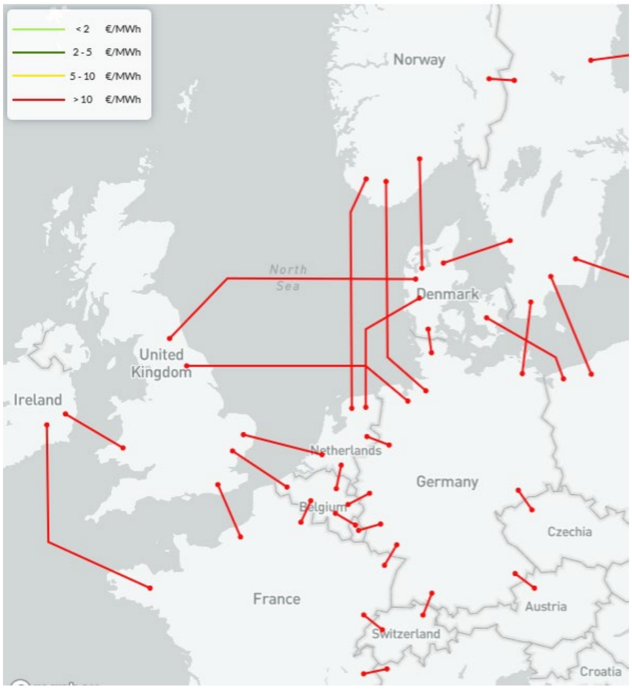


Figure 26 a – Spread of marginal costs between neighbouring bidding zones for 2040 NT scenario with 'no grid' investment after 2025

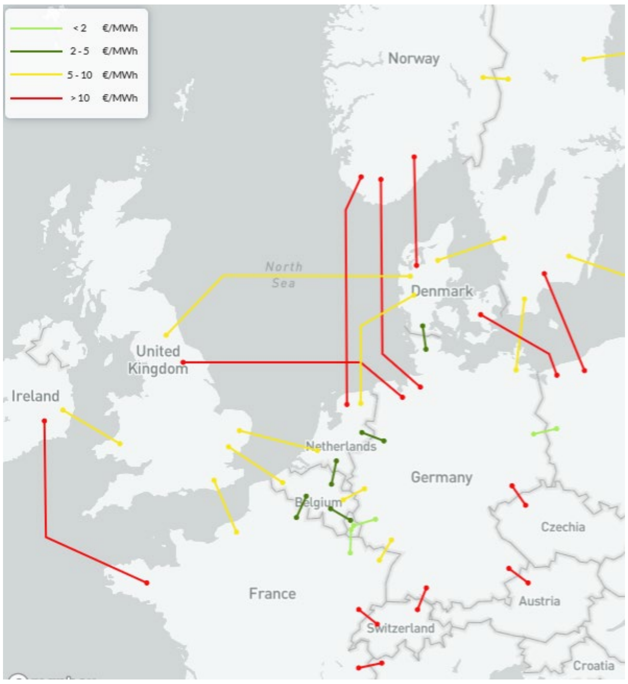


Figure 26 b – Spread of marginal costs between neighbouring bidding zones for 2040 NT scenario with 'Economic grid'

4. REGIONAL STUDIES

4.1 Northern Seas Offshore Grid Infrastructure

4.1.1 Anticipating the Future

On 3 June 2022, a new TEN-E regulation was published[8], requiring the elaboration of specific Offshore Network Development Plans (ONDPs) which give insights into the offshore potential of the European basins. The relevant sea basin for this region is the Northern Seas offshore grid, comprising the North Sea, the Irish Sea, the Celtic Sea, the English Channel and neighbouring waters.

The purpose of the plans are, according to the EC, is to increase Member State (MS) commitment related to sea-basin development, offering a high-level assessment of anticipated infrastructure costs and benefits and how they could be shared among MSs. These non-binding plans should facilitate an informed decision and avoid delay at a later stage due to a missing high-level long-term perspective. The plans should enforce collaboration among MSs and facilitate an optimal use of the sea basin space for their multiple users. The objective of the EC is to have an efficient and coordinated European approach that delivers the offshore wind energy and optimises maritime spatial planning. The ONDPs thus have a different, namely a political purpose, compared to other elements of the TYNDP, the IoSN and the CBA. The ONDPs will complement the IoSN and the CBA. However, these two products will also evolve due to recent changes of the regulation and already anticipated innovations (offshore IoSN, optimal energy system planning [OESP] across energy sectors).

The new TEN-E regulation follows on from recent policy initiatives from the EU, most notably in December 2019 the 'European Green Deal' which includes a set of policy initiatives/strategies with a direct impact on the power sector. The revised TEN-E regulation, complementing the 'Fit for 55' package, are legislative proposals to help achieve these strategies. The recent REPowerEU further complements these activities by further increasing the EU targets and by giving directions related to European energy independency.

The offshore development will unlock the RES potential of the European basins while complementing onshore transmission infrastructure and interconnections, alleviating congestions, strengthening the system and adding flexibility. The plans will be characterised by different levels of offshore RES generation and new interconnection solutions that will be required within each sea basin. The coordinated and sustainable utilisation of the marine spaces in compliance with environmental protection and spatial needs of the national economies will be a leitmotif of the various regional energy systems. For this, the new proposed TEN-E regulation has introduced priority offshore grid corridors in the different sea-basins. Reaching the level of cross-border exchanges that result from the additional interconnections will create new needs for the reinforcement of internal networks in the European national electricity grids. Therefore, national TSOs will need to analyse the situation of the internal electricity networks in the national and in the European framework, to ensure that internal network infrastructure accommodates future flows.

The development of hybrid interconnection 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.

[8] *link to the TEN-E regulation*

Table 4-3 – Priority offshore grid corridors as per the new TEN-E

Priority Offshore Grid Corridors	MSs concerned	Waters
1. NSOG	BE, DK, FR, DE, IE, LU, NL, SE	North Sea, the Irish Sea, the Celtic Sea, the English Channel and neighbouring waters
2. BEMIP offshore	DK, EE, FI, DE, LT, LV, PL, SE	Baltic Sea and neighbouring waters
3. Atlantic offshore grid	FR, IE, PT, ES	North Atlantic Ocean waters
4. South & West offshore Grid	FR, GR, IT, MT, PT, ES	the Mediterranean Sea (including Cadiz Gulf) and neighbouring waters
5. South & East offshore Grid	BG, CY, Croatia, GR, IT, RO, SL	Mediterranean Sea, Black Sea and neighbouring waters

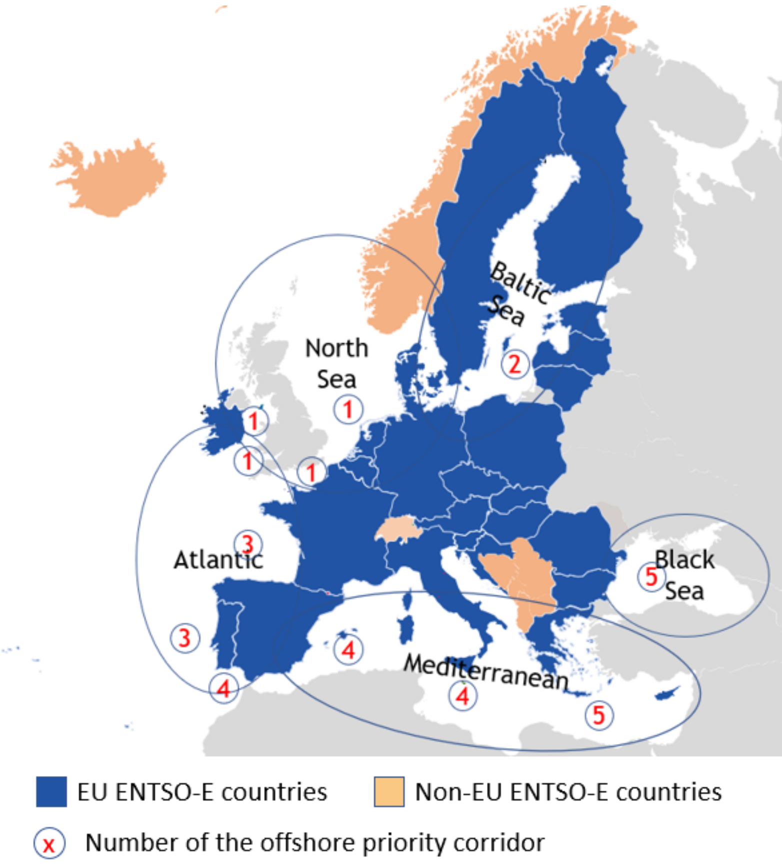


Figure 27 – Distribution of the offshore priority corridors in the different European seabasins. The Offshore Network Development plans will be composed by basin-specific reports, considering the countries which are part of the offshore corridors

The use of HVDC technology for offshore grids, onshore interconnections and internal reinforcements will transform the transmission grid into a mixed (AC/DC) configuration in some geographical areas. The increased technical capabilities of HVDC systems, such as flow control, voltage control at the converter stations and their ability to be built underground for long stretches will ensure increased transfer capacity between countries and regions, support the development of the offshore grid, and allow the possibility of increasing the internal flows within a country. Further development of technology is required to enable offshore meshed DC networks.

With the advent of offshore development plans and development of offshore hybrid projects, the system development procedures will see the parallel processes of generation optimal location and planning of the transmission infrastructure.

Although the quantification of the impact of solar generation capacity remains an object of discussion, without any doubts it has the potential to be the main energy resource in some of the European regions. Nevertheless, certain technological challenges remain in relation regarding the installation of the equipment (actual space available to be used for solar generation, efficiency of the modules, advent of offshore photovoltaic). A coordinated approach to the development of solar energy, pushing for quick improvements in the decades to come, can ensure the complete decarbonisation of the energy system in all European regions.

The potential of European basins represents a foundation stone for Europe´s energy self-sufficiency and a key necessity to facilitate EU decarbonisation goals, but also an opportunity to share the interests and the benefits among the different countries. The adequate development of offshore systems should be based on five pillars.

- Holistic planning and timeliness
- A modular and stepwise approach based on consistent planning methods
- Interoperability, unlocking a smarter, integrated and secure system operation
- Keeping energy bills and environmental footprint low through innovation
- A future-proof regulatory framework

All these pillars are needed to achieve the required investments needed to develop the on and offshore systems at the desired pace. Price signals, market integration and support mechanisms must efficiently promote security of supply, cost efficiency and the targets of the European Green Deal.

Along with onshore power plants, new offshore RES will be integrated into the existing EU electricity markets. Facilitating an efficient integration of offshore RES generation connected to two or more bidding zones, offshore hybrid projects can be connected under the current regulatory and legal framework. As already shown in the TYNDP 2020, the development of the European offshore grid infrastructure, integrating the RES potential with the interconnection capacities, will positively impact the existing marginal price differences between countries. Even though the today's prices are higher, the expansion of the offshore systems (both in terms of RES generation and interconnection levels) is still a key tool to balance prices between different bidding zones.

The current infrastructure system, if properly developed, has the capability to drive the energy transition. Significant investments will be needed to ensure a well-paced evolution towards the achievement of the climate targets. These investments will be directed both towards the existing grid, aiming at its lifetime expansion and of its technical capabilities, and towards the grid extension (128 GW as per TYNDP 2020 by 2040), including offshore grids, for a stronger and more resilient system which is able to adapt to the future energy scenarios.

An important component of the infrastructure for the energy transition will be the development of the offshore system: the integration of the European offshore RES capacities, and the development of offshore interconnection capacities will provide additional flexibility to the whole system.

4.1.2 Expected Developments in the Northern Seas

With an addition of 3.3 GW in 2021, the Northern Seas region has achieved a total instalment of 27.7 GW offshore wind capacity[9]. A specific breakdown is given in Table 5-7.

Table – Overview of grid-connected offshore wind power projects at the end of 2021

Country	Cumulative capacity (GW)	Net capacity connected in 2021 (GW)	No. of turbines connected in 2021
Germany	7.7	0	0
Denmark	2.3	0.6	72
Belgium	2.3	0	0
Netherlands	3.0	0.4	90
Ireland	0.03	0	0
Norway	0.006	0.004	1
France	0.002	0	0
Total	**15.338**	**1.004**	**163**

In accordance to its Strategy on Offshore Renewable Energy, the EC proposes to increase the installed offshore capacity in Europe to 60 GW and 300 GW in 2030 and 2050 respectively. An overview about existing national and regional long-term analysis of countries in the North Sea Energy Consortium (NSEC) is provided in the European Commission's- publication: Offshore renewable energy and grids .

ENTSO-E's scenario report assumes that part of the offshore RES will not be connected to the electrical grid, for both 'top-down' scenarios, which include a significant amount of off-grid offshore wind capacity to supply hydrogen production and derived fuels production. In 2050, the directly used and the off-grid offshore capacity in the RG NS adds up to a level of 2.5 GW in the DE scenario. The scenarios for GA and NT do not foresee such capacities in the North sea region.

For the Northern Seas countries, ENTSO-E and ENTSO-G central policy scenario 'National Trends' foresees an offshore capacity of 119 GW in 2040. This represents 7.5 % of the installed generation capacity. Table 5-8 shows the installed offshore capacities (electricity usage) for the three TYNDP 2022 scenarios for the Northern Seas region and its relation to the total European fleet in brackets:

Table 5-5 – Installed Offshore capacities (GW) in the Northern Seas countries and related to EU27 + Norway + Ukraine (%) - direct electricity usage only. Capacities for hydrogen and derived fuels production are not included

Scenario	2040 NS countries	2040 sea basin NS	2050 NS countries	2050 sea basin NS
National Trends	119 / (74%)	96.4	-	-
Distributed Energy	165 / (82%)	134.1	242 / (81%)	196.5
Global Ambition	201 /(77%)	157,2	267 / (77%)	205.8

[9] *WindEurope: 'Wind energy in Europe' – 2021 Statistics and the outlook for 2022-2026*

4.1.3 Subsea Projects in the Pipeline by 2040

The development has already started and is taking up speed. A first-of-its-kind offshore hybrid project has already entered operation in December 2020, connecting Denmark and Germany (the Krieger's Flak Combined Grid Solution (KF CGS)). Several further projects are foreseen to be developed in the coming years. Examples are listed in the recent draft TYNDP list of project candidates[10]. Many are expected to enter operation in the second half of the 2020s (see Table 4-4). Four out of six projects are part of the NSOG corridor.

Table 4-6 – List of offshore hybrid projects included in the draft TYNDP22 project portfolio (January 2022)

Project TYNDP ID	Project name	Project promoters	Status*	Commissioning year foreseen by the project promoter(s)	TYNDP20 or new project
121	Nautilus: multi-purpose interconnector Belgium - UK	Elia, National Grid	2	2030	TYNDP 2020.
260	Project 260 – Multi-purpose HVDC interconnection between Great Britain and The Netherlands	National Grid, TenneT-NL	1	2030	TYNDP 2020.
335	Project 335 - North Sea Wind Power Hub	Energinet.dk, TenneT-NL, TenneT-DE	1	2035	TYNDP 2020.
1088	Offshore Wind Park in Latvia and Estonia - ELWIND	AS Augstsprieguma tikls (AST) and AS ELERING	1	2030	new
1092	Triton Link: Offshore Hybrid HVDC Interconnector Belgium-Denmark	Energinet and Elia Transmission Belgium	1	2031	new
1106	Bornholm Energy Island (BEI)	Energinet, 50Hertz	1	2030	new

**Project status includes: 1 Under consideration; 2 Planned but not in permitting; 3 In permitting, 4 Under construction*

[10] *Link to the Draft TYNDP22 project list (January 2022)*

4.2 Energy system Integration

4.2.1 General introduction

A large amount of RES will be required to reach the European climate targets. This will increase the variability of demand and uncertainty of generation, causing the future energy system will to have higher needs to store energy. Therefore, in addition to the accelerated expansion of RES and the necessary extension of the electric grid, a timely and successful ramp-up of the hydrogen economy is a key building block for achieving the European climate targets for 2030 and 2050.

Consequently, hydrogen is being further developed at the European level, especially due to its contribution to system integration, industries that are difficult to decarbonise, long-term storage and security of supply. Its major climate policy and economic potential must be tapped in a manner that serves the energy system.

To become even more independent of energy imports, hydrogen is to be increasingly used. Most recently, the EC rightly emphasised this central role once again in its 'REPowerEU' package of 18 May 2022, for the faster reduction of the EU's dependence on imports of fossil energy sources: by 2030, 10 million tons of renewable hydrogen are to be produced in the EU and a further 10 million tons imported into the EU. This significantly increases the targets of the European Hydrogen Strategy. This target is ambitious, but at the same time it is an important and correct signal for the decarbonisation of energy supply and European industry provided the generation mix is sufficiently green, as well as for securing Europe's energy supply security. However, it is also clear that the target can only be achieved if the energy industry is put in a position to drive forward the ramp-up of a European hydrogen economy at the required pace. To this end, on 20 May 2022, as part of the 'REPowerEU' package, the EC will present a draft delegated act on electricity procurement criteria for renewable hydrogen to implement Article 27(3) of the Renewable Energy Directive (RED II). In doing so, the temporal and spatial coupling of renewable generation and consumption by the electrolyser for the production of green hydrogen is stipulated on a European level for the biofuel sector and guiding for other origin definitions.

For more information, we refer you to the ENTSO-E Roadmap for a multi-sectorial Planning Support.

The next section shows, per country, how smart sector integration is foreseen.

4.2.2 Belgium

The climate targets set out by the European Commission push all sectors to decrease their carbon emissions. Smart sector integration or energy system integration (as defined by the EC) is a way to decarbonise the European energy system by focusing on four main concepts:

1. Evolve towards a circular energy system with energy efficiency at its core;
2. Electrification of transport, heating, and industrial processes where possible;
3. Evolve towards renewable and carbon-free fuels for processes for which electrification is not feasible or efficient;
4. Evolve towards a multi-directional system in which consumers play an active role in generation and consumption.

In its study 'Roadmap to net zero'[11], Elia Group investigates two main approaches to decarbonise the European energy system with different degrees of sector coupling.

- An electricity driven pathway in which Europe's final electricity demand in 2050 is assumed to increase by 70% compared with today's demand as a result of strong electrification.
- A molecule driven pathway in which Europe's final electricity demand in 2050 is assumed to increase by 30% due to a higher share of 'green molecules' in the final energy consumption.

Both pathways assume an increased degree of sector coupling compared to today. In the electricity driven pathway, the sector coupling mainly occurs through electrification (electric vehicles [EVs] heat pumps, …). The molecule driven pathway relies on a higher amount of power to X applications.

In both pathways, Belgium's direct electricity demand increases by about 35% (115 TWh_el) to +100% (175TWh_el) compared to today for the molecule driven and electricity driven pathways respectively. In general, Belgium reaches a slightly lower electrification rate than the EU average which is mainly explained by the high importance of harder to electrify industrial sectors, such as the chemical industry in the ports.

The study shows that Belgium lacks domestic RES potential to decarbonise its total energy demand by 2050. Due to the conversion losses in the production of green molecules, it would be more energy efficient to use the scarce domestic RES potential for electrified end appliances. The economic viability of power to gas now and in the future remains an open question and will be influenced by policymakers (e.g. subsidising green hydrogen and/or increasing the CO2 price). By 2026, a minimum target of 150 MW of electrolyser capacity has been set by government, supported with technology innovation funds. Furthermore, the Belgian ambition to become an important hub for import of renewable molecules has also been set.

Elia has already noticed the electrification trend as it received the request of several clients to increase their power rating. Elia is proactively striving to create a strong and reliable grid with new substations 380 kV, from which clients could be supplied directly, enabling significant electrification levels. Several requests for power to X applications have been received as well, ranging from a few ten to a few hundred of MWs.

Sector coupling also enables more flexibility between different energy vectors. End use and industrial flexibility can provide significant amounts of short-term storage and demand-shifting potential for the system in the future. Widespread digitalisation is the key to making this happen. To further exploit & study systemic flexibility,

the Elia Group also published a paper[12] on a consumer-centric market design. The digitalisation is allowing the massive deployment of electrified and connected appliances that can be remotely steered and monitored (such as EVs and heat pumps). Consumer expectations are changing: increasingly, they are searching for tailor-made solutions and more traceability. The energy-as-a-service market is set to gradually replace the energy-as-a-commodity market. These developments have created the potential for flexible and manageable electricity consumption to become the norm. Unleashing this potential will lead to greater operational security and more efficient markets, while supporting decarbonisation and increased comfort for consumers. It is the Elia Group's vision to evolve towards a consumer-centric market design which will place consumers at its heart, giving them the full freedom to choose services from different providers at the appliance level. Its goal is to unlock active demand participation and flexibility while fostering innovative business models behind the meter. In other words, the consumer-centric market design will not only allow competition 'in front of the meter' but also competition 'behind the meter'. It is its ambition to implement a consumer-centric market design as soon as 2023 or 2024, providing all stakeholders work hand-in-hand to make it happen.

[11] *https://www.elia.be/-/media/project/elia/shared/documents/elia-group/publications/studies-and-reports/20211203_roadmap-to-net-zero_en.pdf*
[12] *CCMD (eliagroup.eu), 2021*

4.2.3 Denmark

Today, more than 60% of the Danish total annual electric energy demand is covered by RES, with about 47% being provided by variable RES (wind and solar PV) and the main part of the rest by biomass. Aiming for a 100% RES-share of electricity by the year 2030 and a 70% reduction of GHG emissions compared to a 1990 reference, the country enters the next phase towards a future, when not only the electricity sector but all energy sectors must be fossil-free, which is the Danish political target by 2050.

In Denmark, the coupling of the electricity and heat sectors has already been realised for several decades. A widespread district heating system including CHPs with large heat storage tanks facilitates a certain degree of decoupled production of heat and/or power, providing flexibility to the high VRES system. Some electric boilers acting on market terms convert cheap surplus electricity into heat. The electricity and gas sectors are implicitly coupled via the Danish TSO Energinet, who is responsible for both systems, thus capturing synergies through their joint planning.

In the TYNDP20 edition, a study made by Energinet[13] is described, which has shown that by the advanced use of sector-integration combined with a strong international grid, the Danish energy targets are feasible. Some of the advantages of multi-sector planning have been demonstrated, developing a cost-efficient and securely functioning decarbonised future.

This study was followed in May 2020 by a joint analysis from Energinet and Dansk Energi (business organisation for Danish energy companies) 'Game changers for PtX and PtX infrastructure'[14], which identified several game changers that may provide marked leaps.

Denmark has significant RES that can support a large Danish PtX production but also international competition, national and European climate ambitions may have great impact on national developments. In case a regional or continental hydrogen network would arise, hydrogen can be imported and exported via international pipes. The location of electrolysis systems regarding the electricity network's capacity are of great importance for a cost-effective PtX development.

As Denmark is planning for at least two energy Islands[15] with 2 GW or 3 GW offshore wind capacity respectively, to be built around 2030, part of the produced electricity might be converted to hydrogen. The study from May 2020 concluded that this might happen close to where the offshore wind is landed and should be combined with other energy infrastructure, especially by limiting electricity grid development where renewable energy production is grid dimensioning. The study estimated that it is likely that hydrogen infrastructure will be used for efficient distribution, flexibility from underground hydrogen storage and exports.

In summer 2021, a new analysis[16] provided a status of game changers identified the year before. Currently, further studies are ongoing to establish where conversion from electricity to hydrogen would be most appropriate.

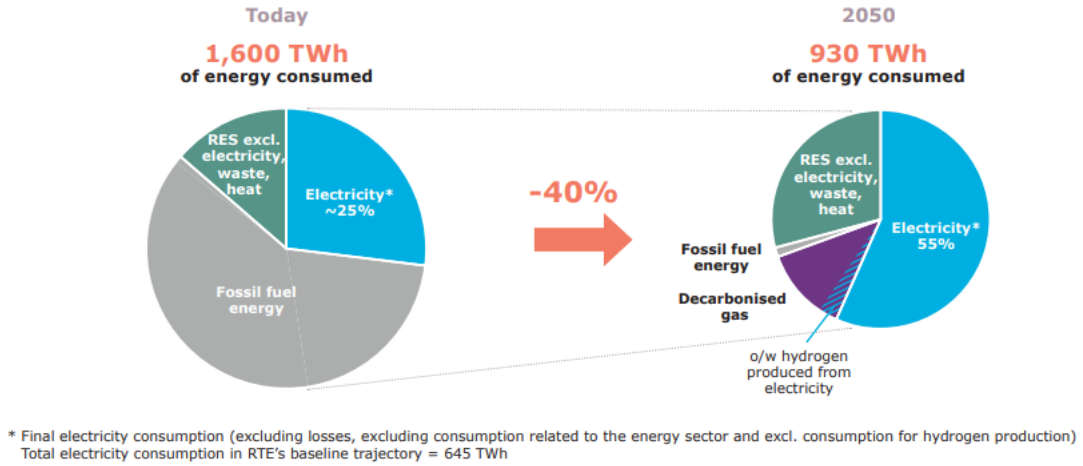
To ease network integration, both for new generation and for new demand, Energinet, together with Green Power Denmark, provides capacity maps (link). This is a map of Denmark with more than 1,000 nodes in the electricity grid, which designates locations where the electricity network has plenty of room for more electricity production or consumption. The purpose is to guide network users to places where they can expect fastest connection, thus the green transition can fastest materialise.

[13] Energinet; 'System perspective 2035',
[14] *Gamechangers for PtX og PtX-infrastruktur, Energinet & Danske Energi (Maj 2020):https://energinet.dk/ptxinfrastruktur*
[15] *https://en.energinet.dk/Infrastructure-Projects/Energy-Islands*
[16] *https://energinet.dk/Om-nyheder/Nyheder/2021/04/15/NY-ANALYSE-PTX-BAROMETRE-STATUS-FOR-PTX-ANNO-2021 (in Danish)*

4.2.4 France

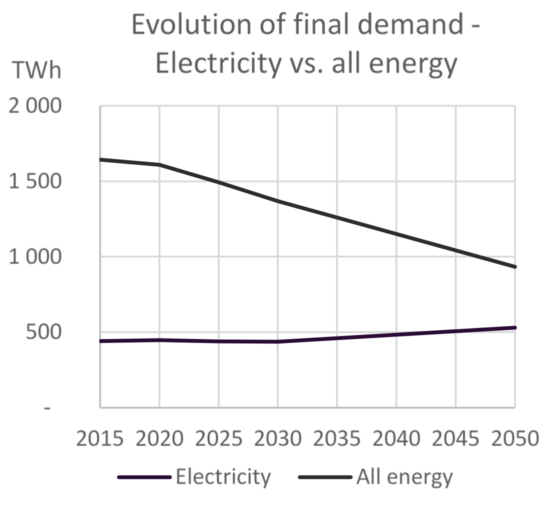
Policy framework

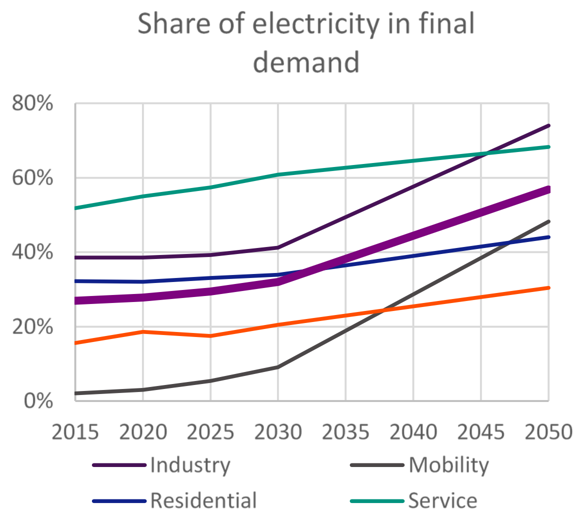
France's energy climate plan targets carbon neutrality by 2050. The National Low Carbon Strategy (SNBC) defines a pathway combining the strong energy efficiency and massive electrification of all sectors. The electrification level is expected to increase from the current 25% to around 55% in 2050.



Source : data from RTE Study 'Energy Pathways 2050'

The generation mix will be diversified with a massive development of RES and a reduction of the share of nuclear generation. In 2035, their shares in the power production should reach 50%.





Source : data from SNBC/AMS scenario

The Multi-Annual Energy Plan (PPE) defines intermediate targets up to 2028.

The ambition to develop a new hydrogen economy is emblematic of the energy transition. In France, the state has initiated a dynamic through:

- The publication of a hydrogen roadmap launching 18 actions to foster low carbon hydrogen development. As part of these actions, gas and electricity system operators have published studies analysing hydrogen impact on their respective infrastructure;
- The definition of a 40 TWh target for low carbon hydrogen in 2050 (SNBC);
- The setting of intermediate binding targets for low carbon hydrogen in the industrial sector: 10% of the demand in 2023 and between 20% and 40% in 2028.

RTE deliverables related to sector integration

Reaching carbon neutrality will require the optimal use of energy resources, energy carriers and flexibility solutions. Sector integration technologies (such as electrolysers) are explicitly considered as part of the solution. Their role will be twofold: activating the fields of optimisation at the interface between sectors and taking the benefit of cheap wind and solar to further electrify the economy directly or through the decarbonation of other energy carriers.

RTE, the French TSO, is involved in the preparation of this future energy system by providing technical, economic and environmental analyses of pathways to a carbon neutral energy system, and testing technical solutions. On the 2035 time horizon, the Generation Adequacy Report published showed that the anticipated 50% share of dispatchable power generation (nuclear and a small share of CCGT) should prevent major RES integration challenges. Security of supply can be ensured.

By building bridges, sector integration widens the scope of these system analysis. Enhanced knowledge of new technologies and the ability to model the overall energy system are prerequisites of any meaningful assessments under a resilience or efficiency perspective.

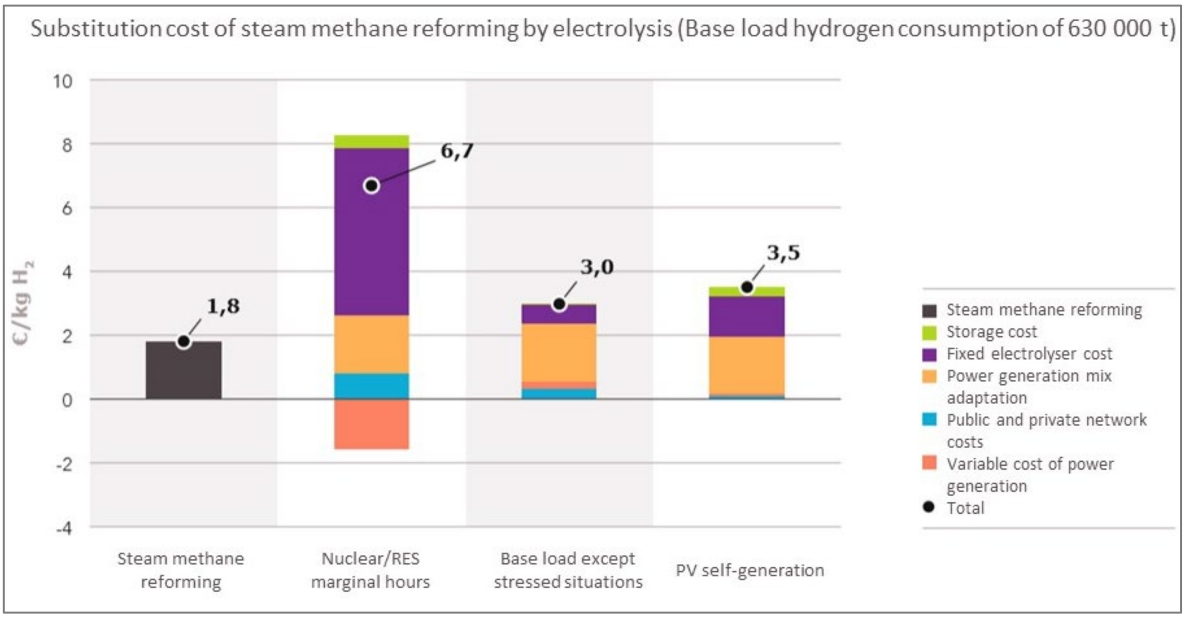
For this purpose, RTE continues to develop its knowledge in cooperation with players of various sectors (gas, mobility, heating and building sectors).

- Hydrogen

The RTE report focuses on the ability of the French electricity system to produce low carbon hydrogen.

Up to 2035, the main value of low carbon hydrogen produced by electrolysis will be to foster the decarbonation of industry.

The analysis highlights that the costs and the CO_2 emissions related to hydrogen production will strongly depend on electrolysis running patterns: RES or nuclear marginal hours, base load or even in a self-consumption mode with PV.



Source: RTE study on low carbon hydrogen

Electrolysers can provide storage/flexibility services to the electricity system. Nevertheless, the French electricity system does not show such need until 2035. Beyond 2035, the role of hydrogen as energy storage has to be assessed, depending on the future energy mix.

Electrolysers are also able to provide ancillary services, but the related economic value compared to other flexibility sources is not sufficient to be the sole basis of a business model.

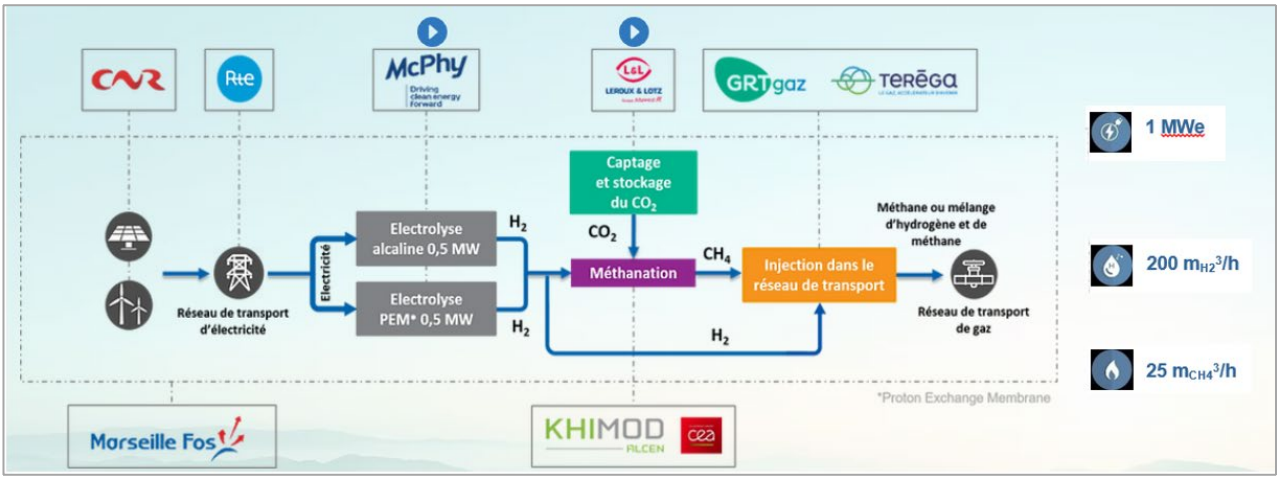
- Mobility

In 2019, RTE has released, in cooperation with AVERE-France (French association for the development of e-mobility and part of the AVERE European network), a study analysing the system impact of a wide range of electricity mobility scenarios up to 2035. The report covers different dimensions such as the number of vehicles, charging solutions, autonomous cars, auto-consumption and battery manufacturing.

It shows that electric mobility has a strong potential to reduce CO2 emissions and can deliver flexibility to the electricity system through smart charging approaches even without the need of Vehicle-to-Grid technologies.

<u>Power-to-Gas pilot – Jupiter 1000</u>

The same as hydrogen, Power-to-Gas (P2G) is an emblematic technology of sector integration. It is the most well-known representative of wider range of Power-to-X technologies. To better understand the possible role of this technology, RTE has joined the consortium of the Jupiter 1000 project led by GRTgaz.



Source: Jupiter 1000 website

The project consists of a pair of 0.5 MW electrolysers (one alkaline and one PEM) combined with a catalytic methanation stage, producing synthetic methane from hydrogen with CO_2 captured from an industrial process. The facility can inject both pure hydrogen up to a 6% (vol.) dilution and synthetic methane in the gas transmission network.

The pilot will provide intelligence on the technical behaviour of P2G (especially the flexibility of the different electrolysis technologies) and the different use cases (e.g. network injection, industrial feedstock, mobility…).

4.2.5 Germany

TenneT

Also for Germany, sector integration will become an increasingly important topic over the next few years. The scenarios for the NEP 2023 include, for 2045, up to 37 Mio. E-Cars, 16 Mio. Heatpumps, 14 GW Power-to-Heat and 80 GW P2G. This accompanying additional load will have a big influence on the necessary grid extensions.

The location and use of the P2G devices has a major impact on the necessary expansion of the power grid. To find a solution that is optimal for the system, coordinated planning between the electricity grid and the H_2 network is necessary. A first step therefore is the 'Quo vadis, Elektrolyse?' study of Gasunie Germany, Thyssengas and TenneT Germany. In the study, substations in the TenneT control area in Germany were examined to see how advantageous they are as a location for P2G. This was done using a multi-criteria approach that considers both aspects of the electricity grid and the gas grid as well as basic location factors for P2G.

The criteria and their weight are shown in the following tables:

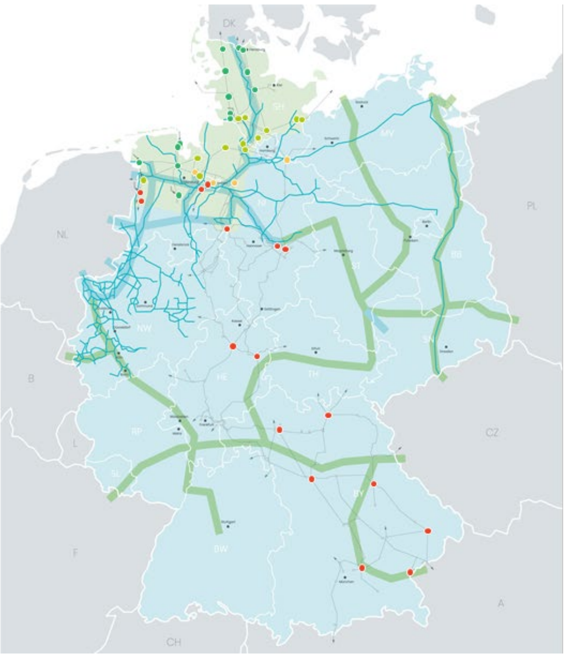
Electricity (50%)	Socio-Economic-Welfare	25%	Reduction in redispatch costs
	Change of CO_2 Emissions of the Overall System	25%	Impact of the electrolyser on the CO_2-emissions of the electric power generation

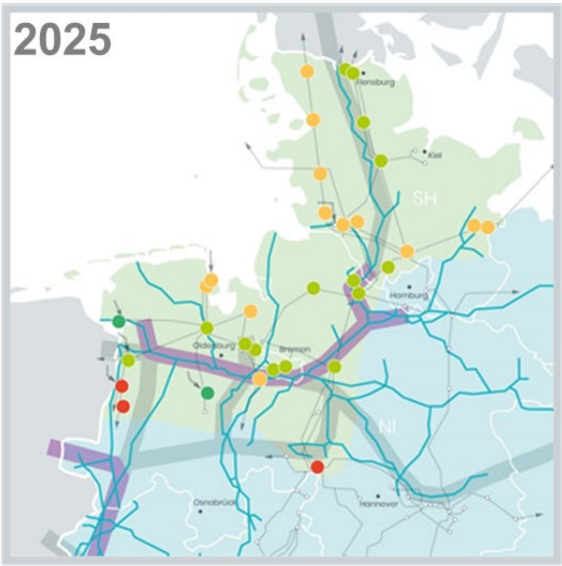
Gas (40%)	Feed-In Potential	20%	Existence of H_2-Grid / potential coupling to CH_4-Network
	Connection Costs	15%	Costs of connection to H_2-Grid / feasibility of the connection
	H_2-Grid-supportiveness	4%	Feasibility of the supply of large demand centres, distance to potential EHB
	Storage Connection	1%	Possibility of transport to cavern storage facilities

Environment (10%)	Hydrogen Consumption	2%	Potential H_2-Customers in the reachable environment
	Secondary Products	3%	Utilisation Potential for Heat, Oxygen, Methanisation
	Water Availability	5%	Existence of (Drinking-) Water Sources

The calculations show that substations in Schleswig-Holstein and near the coast in Lower Saxony are best suited.

In the following map, the results for 2025 are shown. In the left picture is only the E-criteria; the right one shows the overall results for the areas with most potential (dark green are the best, red the worst analysed locations).





Takeaways from the study:

- To achieve an optimum for the overall energy system, the right choice of location for PtG is essential.
- To prevent P2G devices from being built on a large scale at unfavourable locations, it is necessary to set up a Germany-wide hydrogen network as quickly as possible. This H_2 network should be part of a pan-European network.

The complete study can be found here: https://www.tennet.eu/fileadmin/user_upload/Company/Innovation/Hydrogen/Quo-Vadis-Elektrolyse_DIN-A4_quer_V8_download.pdf

Amprion

By 2045, Germany aims to become greenhouse gas neutral. The objective of climate neutrality entails the deployment of RES across energy sectors, i.e., electricity, heating, transport, industry, and gas. Importantly, there is not only one approach towards achieving a climate neutral energy system, but there are rather various possible pathways for infrastructure development towards a decarbonised system. The German TSO Amprion GmbH captures the wide spectrum of different approaches in its project 'Systemvision 2050'. In this project, Amprion invited different stakeholders from policy, industry, NGOs and civil society to present their 'vision' of a fully decarbonized energy system in 2050. In doing so, Amprion asked the stakeholders, the so-called 'Systemvision partners' (project partners), for their input for a set of key parameters across energy sectors for the year 2050, such as residential heating demand, installed capacity of wind and solar PV, storage, electrolysis and number of EVs. These key parameter sets were translated into consistent scenarios. Amprion's toolset of energy models generated results for the energy system across all sectors. This enabled 'Systemvision partners' to develop a deep understanding of the interactions between sectors of the energy system. The geographical focus of the modelling results was Germany; however, interdependencies with the energy sectors in surrounding European countries as well as imports and exports were included in the analysis. Due to the consistent application of the same methodology for all 'Systemvision partners', the results are highly comparable and thereby help to objectify assumptions and interdependencies of possible pathways towards a German decarbonised energy system. Sankey diagrams were used as a tool for visualising the inflows and outflows across different energy sectors.

Based on the modelling results, the 'Systemvision partners' wrote their own contributions to the project as blog articles, explaining their main assumptions, key findings and conclusions. In addition to referring to the quantified outcomes, project partners were also free to describe the qualitative factors they considered important for achieving a climate neutral energy system. The blog articles are published on this website: https://systemvision2050.de/

For Amprion, the invaluable insights gained were two-fold: first, the project allowed the implications for infrastructure needs to be evaluated in a cooperative manner, together with various kinds of stakeholders. Second, the project gave the opportunity to improve the energy system modelling approach and tools based on the requirements of stakeholders. Transparency and an open discussion among a wide range of stakeholders are essential for finding sustainable pathways towards decarbonisation.

4.2.6 Ireland and Northern Ireland

Sector integration in Ireland and Northern Ireland will become more evident in the future through the increasing integration of energy end-use and supply-side sectors with one another. This includes the electrification of end-use sectors such as heating and transport as well as the further integration of the electricity and gas sectors. EirGrid and SONI capture this sector integration in their respective scenario planning processes.

EirGrid and SONI use scenario planning to manage the uncertainty present in the medium and longer-term planning timeframes. In March 2021, the *Shaping Our Electricity Future* consultation was launched, which made use of the Tomorrow's Energy Scenarios (TES) and Tomorrow's Energy Scenarios Northern Ireland (TESNI) datasets to help identify the scale of network development required to achieve the renewable ambition for 2030.

Ireland's demand is expected to grow significantly in the period to 2030, primarily driven by the connections of Large Energy Users (LEU), increased EVs, and the electrification of heat and transport. LEUs are not anticipated to develop at a similar scale in Northern Ireland, although a modest amount of such demand may occur by 2030.

In both Ireland and Northern Ireland, the transition away from fossil fuels in the heating and transport sectors will see some of those demands being met from electricity.

Demand assumptions are largely consistent with the high demand scenario contained in the Generation Capacity Statement 2021–2030[13]. The spatial distribution of this additional demand is an important consideration in ensuring that the growth needs for specific regions are identified. This includes reinforcement needs for Dublin and the Mid-East, which is forecast to see disproportionate demand growth compared to other regions in Ireland. The spatial distribution of demand is illustrated in Figure 28.

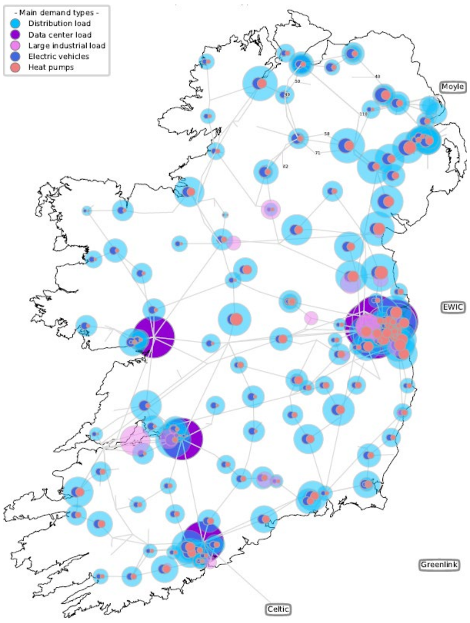


Figure 28 – Demand spatial distribution for IE and NI, 2030.

A subset of demand assumptions is shown in Table 4-5.

Table 4-7 – Summary of demand assumptions

Total Electricity Requirement (TER)	TWh	46.5	10.1
TER peak demand	GW	7.01	1.85
Number of electric vehicles	1000s	936	273
Number of heat pumps	1000s	600	67
Large Energy User demand	MW	1550	15

Although the focus of Shaping Our Electricity Future is on the issues to be addressed to deliver on policy objectives out to 2030, it is acknowledged that recent developments in EU legislation and policy will require Energy system or sector integration to become standard – delivering coordinated planning and operation of the energy system 'as a whole' across multiple energy carriers, infrastructures, and consumption sectors. This will require electricity TSOs to work more closely with gas TSOs and wider sectors of the energy chain than today (e.g. hydrogen production).

The EU has estimated that electricity demand is projected to increase significantly on a pathway towards climate neutrality, with the share of electricity in final energy consumption growing from 23% today to around 30% in 2030, and towards 50% by 2050. In comparison, that share has only increased by 5 percentage points over the last thirty years. This will result in the large-scale electrification of heat and transport, but much wider sector coupling will also be required. Sector coupling involves the increased integration of energy end-use and supply sectors with one another. This can improve the efficiency and flexibility of the energy system as well as its reliability and adequacy. In addition, sector coupling can reduce the costs of decarbonisation, and will require electricity, heat and transport sectors to work collaboratively to solve challenges interchangeably with other sectors. To foster the full potential of sector coupling, it will be important that existing techno-economic, policy and regulatory barriers are removed. In this world with high levels of renewables and low marginal prices, the market perspective will be crucial to ensuring that sector coupling is efficient and affordable, and points to the need for a fundamental rethink of the overarching electricity market. It is unlikely in this world that a retail tariff structure of unit price and standing charge would remain; there will have to be an evolution of market investment incentives and market design based on energy efficient sector coupling to ensure sufficient low carbon energy generation to meet all sector requirements. It would appear that markets that better reflect the utility of the consumer rather than specific commodities such as electricity, hydrogen and gas appear to have the best chance of efficiently coupling.

With this in mind, the proposal to place increasing value on maintaining the resilience of the power system seems to fit into this future perspective and can be built upon. From a consumer perspective, a supply of clean low carbon energy is desired but so too is an energy system that works as expected whenever it is required. That resilience is important to the consumer.

It is also important to consider that business models for energy supply may change dramatically as consumers integrate both generation and smart demand into homes and businesses, with incentives to supply services such as demand response or incidence response for those with the capability and desire to provide such. These evolving business models will impact how wholesale markets evolve and we as TSOs need to stay cognisant of such forthcoming change.

Similar to other jurisdictions, in Ireland and Northern Ireland, sector coupling between power and gas is currently evident in the form of gas fired electricity generation ('gas to power'). This type of sector coupling will continue to be important in the transition to a low carbon energy future.

In the future, sector coupling in the form of 'power to gas' will also likely play a role. Power to gas is the process of using electricity to produce hydrogen via electrolysis, or, in a consecutive step, using hydrogen together with carbon dioxide to produce methane via methanation.

In TES 2019 Ireland, power to gas is seen as an enabler of sector-coupling and experiences growth in scenarios with high demand for renewable gas. As seen from the electricity system, power to gas is a load increase. Such a form of flexibility becomes beneficial during times when variable renewable energy curtailment would otherwise occur, thereby increasing realised renewable energy capacity factors.

Figure 29 below shows the capacities for pumped hydro energy storage (PHES), battery energy storage (BES), demand side management (DSM) and power to gas for different study years and three different scenarios, Centralised Energy ('CE'), Delayed Transition ('DT') and Coordinated Action ('CA'). The increase in power to gas capacity, and thus the positive impact of power to gas on curtailment levels, is particularly observed in the period between 2030 and 2040.

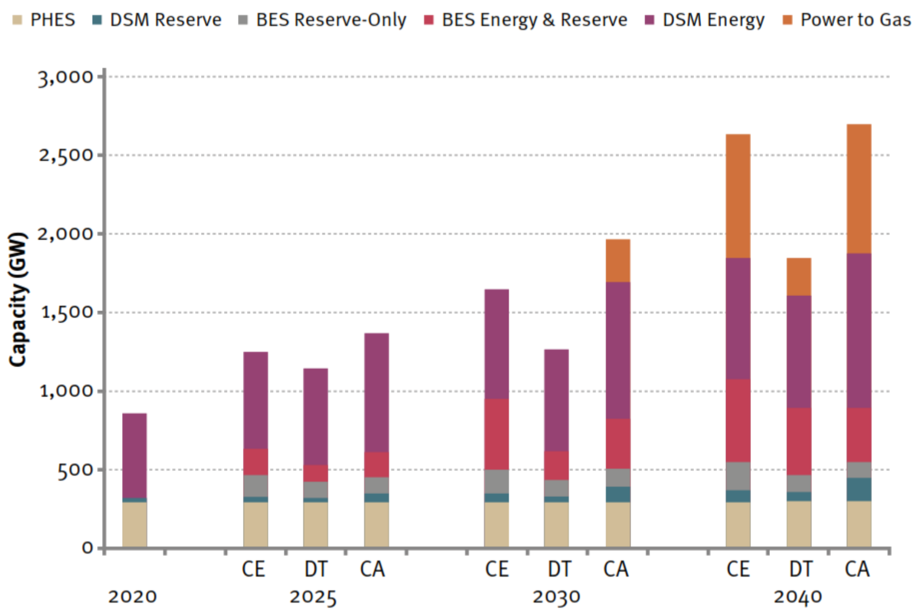


Figure 29 – Storage, DSM and power to gas installed capacity

In TES 2019 Northern Ireland, similar to TES Ireland, power to gas is seen as an enabler of sector-coupling and experiences growth in scenarios with high demand for renewable gas.

In the longer term, seasonal storage will play an important role in electricity systems with high levels of weather-dependent generation. Power to gas developments may allow for the seasonal storage of gas produced from renewable electricity.

The share of methane (CH_4) and hydrogen (H_2) sourced from power to gas is given in Figure 30. The scenario Addressing Climate Change has the highest share of power to gas due to a higher consumer demand for renewable gas in heating and transport.

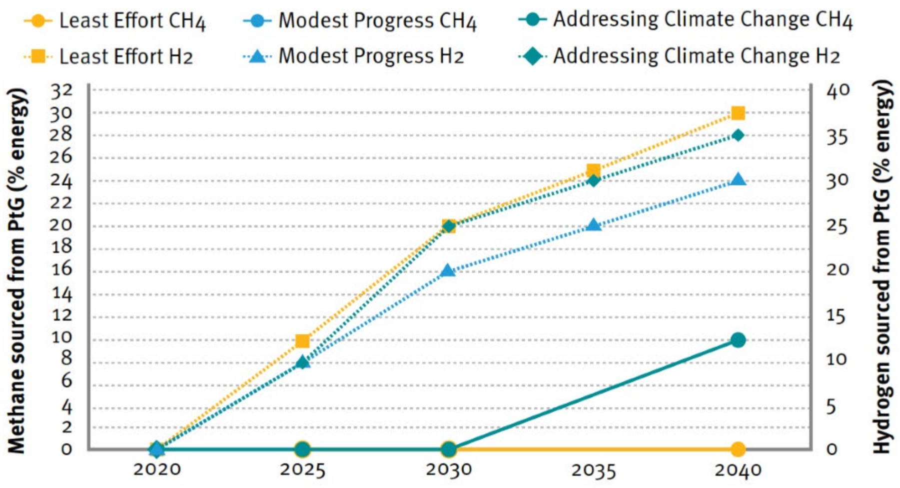


Figure 30 – Proportion of methane and hydrogen supplied by power to gas

4.2.7 Luxembourg

The energy transition in Luxembourg is in full swing, and the electricity sector is playing a particularly important role in decarbonising the Luxembourgish energy system. Electricity generation from RES is continuously growing, energy end uses such as heat and mobility are being electrified, and new services are on the rise due to enhanced digital technologies and business opportunities.

While Creos as an electricity and gas TSO actively contributes to the energy transition by developing and operating the grid infrastructure, it also faces a number of challenges. A particular challenge on the transmission system level is that even though the fast-growing renewable energy generation will have to be integrated into the power grid to reduce the overall amount of imported electricity, power consumption is equally increasing. Specifically, for times of peak demand, the system must be ready to balance supply and demand, often with the help of imports from our neighbouring countries.

The decarbonisation potential reduction currently assessed by the industry sector may significantly impact the electricity grid. In parallel with direct electrification and efficiency measures, hydrogen will make an important contribution to the decarbonisation efforts of the industry sector, particularly for hard-to-abate emissions in industrial processes (such as steel or glass production). Hydrogen produced locally by electrolysis could increase the peak demand of the Luxemburgish grid.

'Smart Grid' and 'Smart Sector Integration' solutions are needed to better utilise the existing and future infrastructure. Electrical storage solutions such as smaller, decentralised battery storages or bigger seasonal 'Power to X' storage might emerge in the future to accumulate a surplus of generated electricity and to provide it when there is a consumption need. Electrical storage methods could indeed help reduce import peak demands and better balance demand and generation, although in a limited manner, and might be of importance then. Nevertheless, these measures will not be sufficient to accommodate the future power demands of the country by themselves but will need to be complemented by a stronger grid infrastructure. The future economic and demographic development and the desired decarbonisation will lead to an increasing importance of electricity in the mix of energy end uses. It is recommended to promote and support all technical or economic means, such as smart-charging solutions for EVs, load-shifting or peak shaving measures, which could help to optimise the utilization of the entire electrical infrastructure.

4.2.8 The Netherlands

The integral infrastructure exploration study[17] made together by all electricity and gas TSOs and DSOs in the Netherlands offers a perspective on four possible energy systems of the future. The study was started as a follow-up of the Dutch energy agreement of 2019. It looks at 2050 and examines all sectors and all main energy carriers. It shows that in each of the scenarios flexibility and sector coupling plays an important role. It shows both the need for large amounts of short-term (e.g. batteries), long-term gas storage and conversion technologies (e.g. power-to-gas, power-to-heat) and flexible power generation (e.g. hydrogen power plants) in 2050.

With the new government in place since beginning 2022, new targets have been set for speeding up the energy transition. Next to a faster development of renewables, of especially offshore wind, targets have also been set which speed up the sector integration. The energy transition gets an extra push due to the current geopolitical and energy crisis.

The ambition for electrolyser has been raised from the 2019 target of 3–4 GW to 8 GW in 2030. The produced hydrogen is foreseen to be used mainly in the industry. In the build environment, another impactful target has been set on having hybrid heat pumps to be the standard from 2026 instead of the natural gas-fired boilers.

In the second version of the integral infrastructure exploration study, which will be available end 2023, will show an energy system analysis for the years 2030, 2040 and 2050. Furthermore, it will consider the new targets set by the conferment and will consider the newest input from sectors such as the industry and updated numbers from the local regions.

4.2.9 Norway

Norway has been a frontrunner regarding stimulating electrical transport. Regarding PtX-development this Norwegian success story is first and foremost due to a substantial package of incentives developed to promote zero-emission vehicles into the market. The incentives have been gradually introduced by different governments and broad coalitions of parties since the early 1990s to speed up the transition. The EV incentives include, among others, exemption from 25% VAT, no annual road tax, access to bus lanes and free municipal parking.

The Norwegian Parliament has decided on a national goal that all new cars sold by 2025 should be zero-emission (electric or hydrogen). By February 2022, there were more than 470,000 registered battery electric cars (BEVs) in Norway. BEVs held a 64 % market share in 2021. The speed of the transition is closely related to policy instruments and a wide range of incentives. The current Government has decided to keep the incentives for zero-emission cars until the end of 2022. After 2022, the incentives will be revised and adjusted parallel with the market development.

[17] *Link: https://www.tennet.eu/nl/bedrijf/publicaties/ii3050/ (in Dutch)*

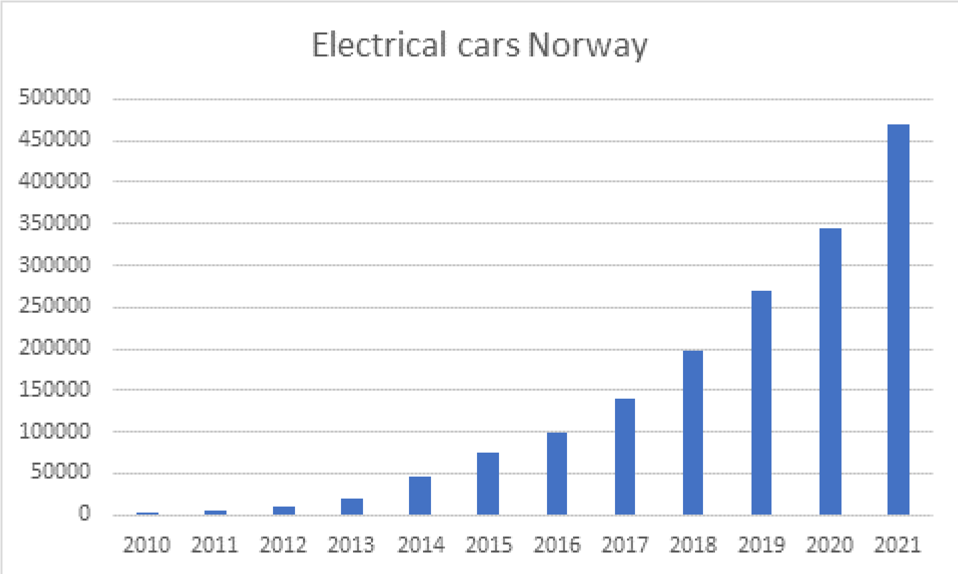


Figure 31 – Development of electrical cars in Norway

4.3 Challenges of operation with high variable RES

The integration of a large volume of renewable generation proposed for the Northern Seas Region presents several operational challenges requiring innovative solutions. Several studies are ongoing and are discussed in this section.

The island of Ireland comprises two jurisdictions, Ireland and Northern Ireland, which are operated as one electricity market, the Single Electricity Market (SEM). The SEM is a small system and is not synchronously connected to either Great Britain or Continental Europe. It has a high penetration of renewable generation, c.40% RES-E in 2020, the vast majority of which is non-synchronous renewable generation. The large increase in penetration of non-synchronous renewable generation has led to several challenges. The following issues when operating a grid with a high penetration of renewable generation have been detected:

- a higher Rate of Change of Frequency (RoCoF) on the system;
- a reduced transient stability of the system;
- voltage dips arising from slow post fault recovery of wind farms leading to frequency dips; and
- a need for credible, reliable performance from thermal generation.

As a small island with a high penetration of renewable generation, the issues experienced and identified in IE and NI are expected to become relevant to other countries in the region as their generation portfolios develop.

4.3.1 System Operations Programme

To simplify matters, a metric was derived to consider all operation constraints. This metric is referred to as the System Non-Synchronous Penetration (SNSP). The total amount of non-synchronous generation (renewable generation and HVDC interconnection imports) is considered against the total synchronous generation operating instantaneously. To meet 2020 renewable electricity generation targets, there was a requirement for at least 75% SNSP. This was deemed required to allow curtailment to be kept sufficiently low for renewable generation to remain investable. This was identified as part of the DS3 (Delivering a Secure Sustainable Power System) programme which was set up by the Irish and Northern Irish TSOs to manage the challenges of operating a system with a high penetration of renewable generation.

In April 2022, EirGrid and SONI permanently raised the operational SNSP limit to 75% following a successful trial period where the electricity grid ran between 70% and 75% variable renewable energy for a total of 232 hours during the trial period. This is a culmination of the 11-year DS3 programme of work. To deliver on government renewable energy policies for 2030, it will be necessary to accommodate unprecedented penetrations of variable non-synchronous RES such as offshore wind, onshore wind, and solar, while keeping curtailment levels to a minimum. This will require a significant evolution of the operation of the power system and for EirGrid and SONI to deal with unique challenges that will not be faced in larger power systems for years to come. Four of the key operational metrics that will need to evolve by 2030 are as follows:

- SNSP;
- Inertia Floor;
- Operational RoCoF; and
- Minimum Number of Large Synchronous Units.

By 2030, the objective is to operate at SNSP levels up to 95%, to have a reduced Inertia Floor (reduction from the current floor of 23,000 MWs), to have implemented a secure RoCoF limit of 1Hz/s (an operational trial is currently underway) and to have a significantly reduced Minimum Number of Large Synchronous Units requirement (the current requirement is to keep 8 large conventional synchronous units synchronised across the island). The purpose of evolving these, and other, operational metrics is to facilitate a reduction in the minimum level of conventional synchronous generation (in MW terms) required on the system. By reducing the minimum required level of conventional synchronous generation, increased levels of non-synchronous RES can be facilitated.

To achieve the 2030 renewable generation policy ambitions, a programme of work has been developed to enable the enhancement of system operations capability out to 2030. The System Operations programme will build upon the programme of activity that was carried out as part of EirGrid and SONI's 'Delivering a Secure Sustainable Electricity System (DS3)' Programme previously established in 2011. Looking forward to 2030, there are four key pillars underpinning the System Operations Programme (see Figure 32), with each pillar comprising several work streams:

Standards and Services: This pillar aims to ensure that we have the right operational standards (e.g. Grid Code) as well as appropriate commercial frameworks in place to support necessary investment in the capability required to mitigate technical challenges on the power system. This will build on the existing system services arrangements, introducing new services as appropriate.

Operational Policies and Tools: The aim of this pillar is to continue to evolve our operational practices, developing the necessary operational polices and developing and implementing new control centre tools to enable our engineers to safely and securely operate a resilient power system as complexity and uncertainty increases.

Technology Enablement: This pillar focuses on breaking down barriers to entry and enabling the integration of new technologies at scale. The existing FlexTech Initiative[14] will be central to achieving these objectives, in addition to other enabling initiatives developed throughout the duration of the System Operations Programme.

TSO–DSO: Finally, with so many of the future generation and system service providers expected to be connected to the distribution system as the portfolio decentralises and diversifies, we will need to partner with the DSOs to ensure that the needs of both distribution and transmission systems, and ultimately the needs of consumers, are met.

The following are key milestones to meeting the challenges of operating the electricity system in a secure manner while achieving our 2030 RES-E ambitions:

- 2021: 75% SNSP
- 2022: Grid Code modifications approved
- 2023: Go-Live of new DS3 System Services Arrangements
- 2025: 85% SNSP
- 2030: 95% SNSP

Figure 32 – System Operations programme – key pillars

The ultimate measure of achievement for the programme will be the ability of EirGrid and SONI to operate the power system of Ireland and Northern Ireland in a manner that enables the renewable ambitions in both jurisdictions of ca. 80% of electricity demand being met by RES by 2030.

The System Operations Programme is currently under development to enable the enhancement of power system operational capability out to 2030. This is captured in EirGrid and SONI's Shaping our Electricity Future technical roadmap report[18]. The report sets out:

- key operational metrics/constraints which currently have the largest impact on RES curtailment levels;
- the main technical challenges that are likely to be seen in 2030 informed by a range of different analyses, as well as the implications of not sufficiently addressing those challenges; and
- some potential mitigations that are under consideration to deal with the technical challenges. A high-level description of the evolution of operational policy to 2030 and some of the expected operational changes required is also provided.

In addition to the work already completed on potential solutions, the TSOs recently published a series of more detailed studies to identify and further confirm potential solutions to the challenges identified[19].

4.3.2 EU-Sysflex

EU-SysFlex was a project to test a high level of integration of RES in the pan-European electricity system. The aim of the project was to identify issues and solutions associated with integrating large-scale renewable energy and create a plan to provide practical assistance to power system operators across Europe.

Eu-Sysflex consists of a unique consortium of 34 members comprising transmission and distribution system operators, aggregators, technology providers, research and academic institutions as well as consultancies. They are located in 15 countries across Europe.

Tasks in the EU-SysFlex project include:

- identifying the needs, and associated solutions, of the future power system with a high share of renewables;
- creating a plan to provide practical assistance to power system operators across Europe;
- recommending enhancements to market design and regulation to enable new business solutions;
- conducting seven industrial-scale demonstrations testing new flexibility and system services, and data management and exchange; and
- identifying a long-term roadmap to facilitate the large-scale integration of renewable energy across Europe.

Project Deliverable 2.4 'Technical Shortfalls for Pan European Power System with High Levels of Renewable Generation' was published in April 2020. This describes the detailed technical power system studies performed and the scarcities identified for three synchronous power systems (the Ireland and Northern Ireland system, the Nordic system and the synchronised Continental European system). The technical scarcities studied were divided into several categories: frequency stability; voltage stability; rotor angle stability; network congestion and system restoration. Mitigation measures for the technical scarcities identified will be evaluated in future project deliverables, thus enabling the formulation of a roadmap to facilitate power system decarbonisation. The EU-SysFlex project commenced in November 2017 and concluded in early 2022.

[18] https://www.eirgridgroup.com/site-files/library/EirGrid/Shaping_Our_Electricity_Future_Roadmap.pdf
[19] https://www.eirgridgroup.com/site-files/library/EirGrid/Technical-Assessment-of-2030-Study-Outcomes.pdf

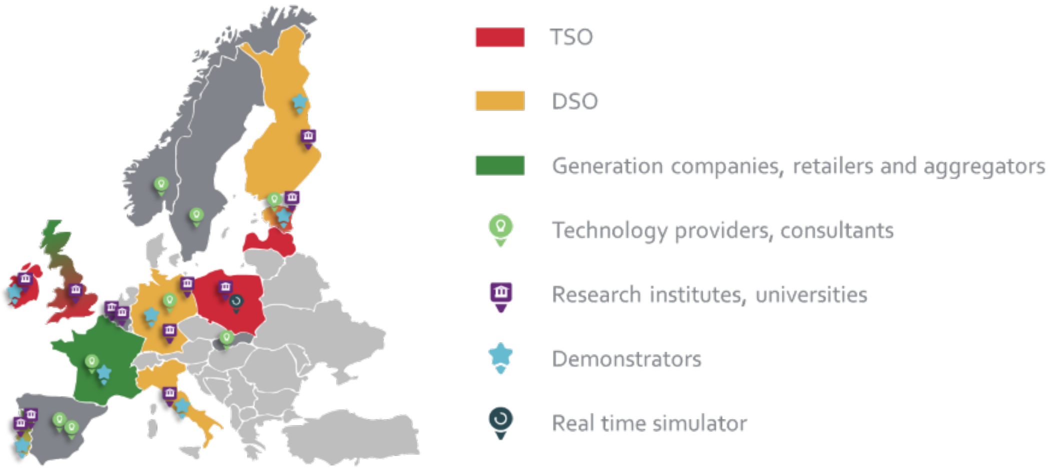


Figure 33 – EU Sysflex consortium

Based on the analysis of ambitious EU renewable scenarios, the project identified the technical scarcities on the future power system, market and regulatory enhancements required to incentivise investment in System Services and, through seven demonstration projects and trials, explored the capability of a suite of technologies and solutions to deliver much needed flexibility. The project has designed a system operation flexibility roadmap for Europe to facilitate the large-scale integration of renewable technology and flexible capability.

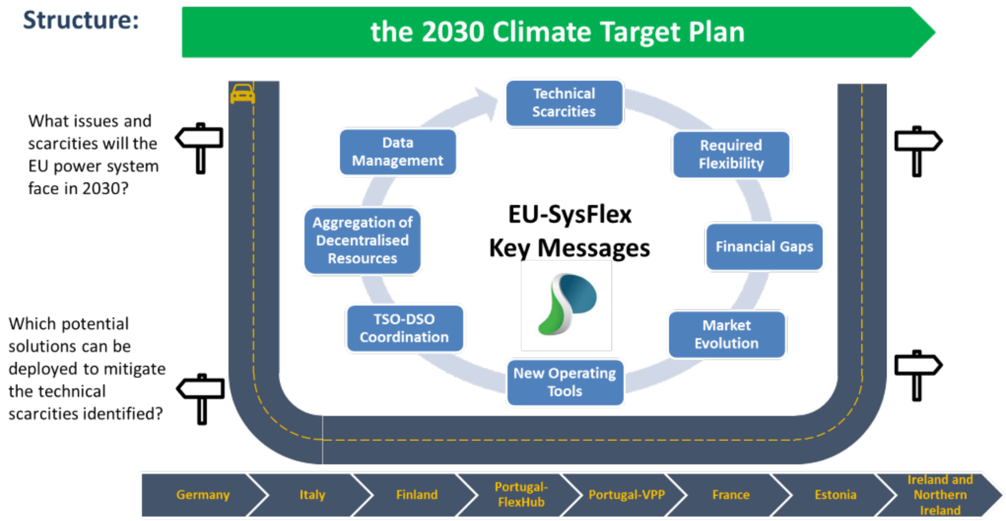


Figure 34 – EU Sysflex flexibility roadmap

The European power system flexibility roadmap incorporates the findings and results of the EU-SysFlex project. It is built upon the scalability and replicability analysis (SRA) of solutions from the analysis and investigations on technical scarcities, system services, market design, system operator procedures, and data management, as well as the results from seven demonstration projects and qualification trials. The flexibility roadmap addresses the key questions that must be addressed to ensure the European power system is capable of managing the changing dynamics and complexities on the power system as we transition towards 2030 renewable targets and beyond to net zero:

- What issues and scarcities will the EU power system face in 2030?
- Which potential solutions can be deployed to mitigate the technical scarcities identified?
- How do we support an appropriate mix of technologies to provide the necessary technical solutions and system services?
- How do we enable the utilisation of technical solutions and system services?

The heart of this roadmap is the key messages and recommendations extracted and refined by EU-SysFlex investigations and trials, organised into eight sections: technical scarcities, required flexibility, financial gaps, market evolution, new operating tools, TSO–DSO coordination, aggregation of distributed resources, and data management. The key messages are as follows:

- As we transition to a European power system with a high share of variable renewables, significant technical scarcities in flexibility appear.
- Existing energy market structures will not guarantee the required flexibility and volume of system services to address the identified technical scarcities and support investment in low carbon generation.
- Enhanced services will be required from a wide range of technologies to mitigate the identified technical scarcities and ensure the required system flexibility.
- New flexibility products and market evolution are required to ensure the provision of sufficient system services capability to mitigate the identified technical scarcities.
- New operator decision support tools with enhanced forecasting, state estimation and optimisation capabilities are required for the future power system to activate new flexibilities.
- Aggregation of decentralised resources enables access to a wider range of flexibility options, including the participation of residential customers and a range of distribution-connected assets.
- Efficient coordination between TSOs and DSOs is critical given the significant share of future resources connecting to the distribution network.
- A customer-centric approach including standardised access to data and data-driven services is crucial to guarantee stakeholder and information system interoperability for effective data exchanges at the European level.

Increasing the flexibility of the pan-European system requires a comprehensive and all-encompassing vision that extends across a broad portfolio of new approaches, solutions and technologies. EU-SysFlex provides this by demonstrating different business use cases in seven field tests at all system levels and across Europe: Portugal, Germany, Italy, Finland, France, Poland and Estonia, as well as a qualification trial process in Ireland and Northern Ireland.

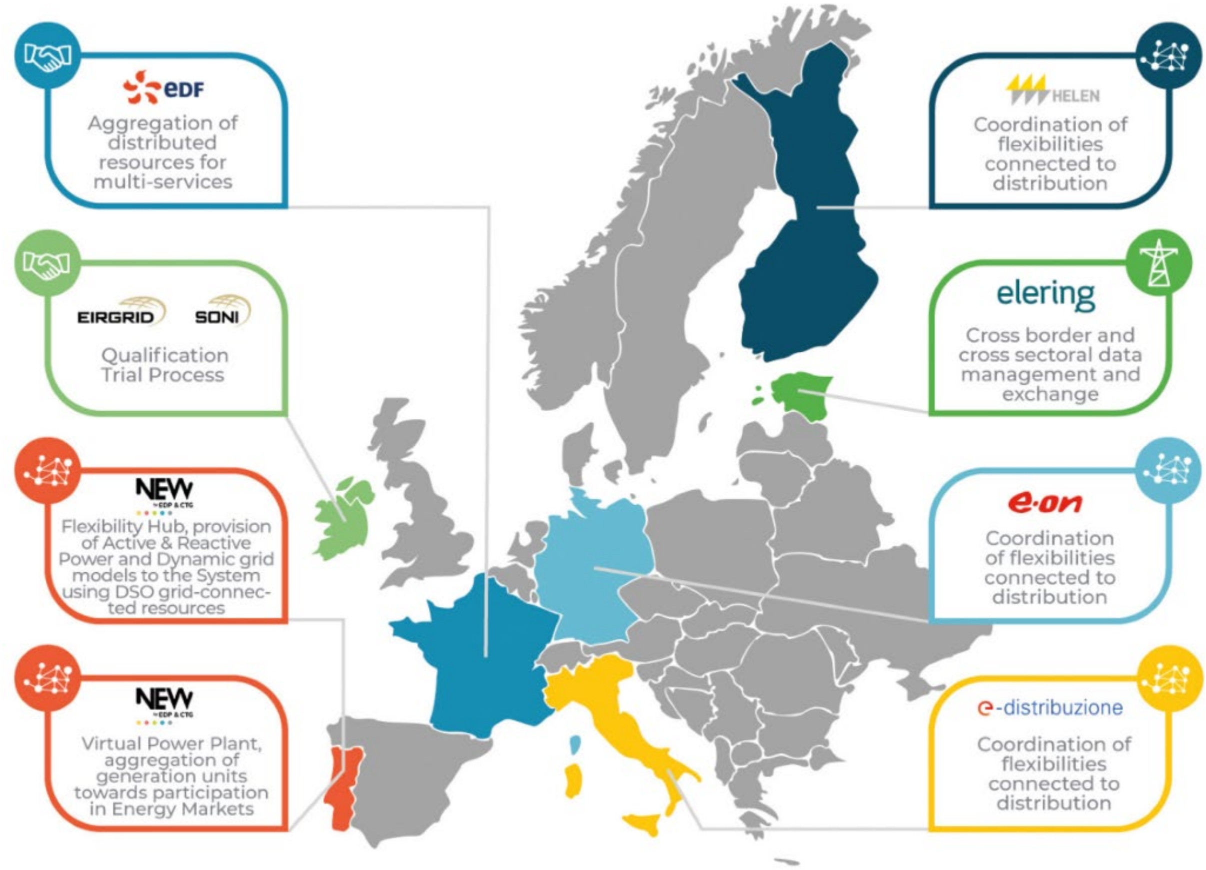


Figure 35 – EU Sysflex demonstrations and trials

The demonstrations and trials provide evidence of how the timely provision of required system services will be achieved using new approaches to coordinate the resources, actors and new technology mixes that will be present in the future European system. This involves testing new concepts, tools and a wide range of flexibilities, including centralised pump storage plants, batteries, wind and PV, heat loads and EVs. The interaction between the system layers and actors, and the replicability of concepts and approaches is also addressed.

More information on the EU-SysFlex project and concluding publications can be found on the project website.

Controllable Devices, non-wire solution and curative measures

The proportion of RES is increasing much more quickly than the necessary grid expansion required to transport it. Consequently, this is creating temporary bottlenecks in transmission. To solve the related congestions nowadays, conventional power plants are used for preventive redispatch. Alternative solutions have to be implemented as the availability of conventional power plants will decrease or even phase out, and the costs for redispatch will increase significantly. To help TSOs solve these congestions, two courses of action may offer solutions. Firstly, the available grid may be more balanced by the use of controllable devices such as HVDC or PSTs to bypass these congested areas. Secondly, technical solutions for the higher utilisation of the existing grid may be implemented. Therefore, TSOs already implement Dynamic Line Rating (DLR) and furthermore have developed concepts for a system wide usage of curative congestion management. Considering such technologies, three solutions proposed by TSOs and approved by national regulators are presented in this chapter:

1. As the generation and demand connected to the network changes, network power flows change and circuits can become unevenly loaded (e.g. some circuits reach their maximum capacity while others are well below their limits). Installing power flow controllers allows TSOs to provide the Electricity System Operator with the tools to quickly reduce the congestion that limits renewable generation, with minimal impact on communities and the environment: PSTs have already been in operation for a long time. Additional PSTs and other power flow controllers such as Thyristor Controlled Series Capacitors (TCSCs) will be installed in the grid in the coming years.

2. In the region, some TSOs received agreement from their respective National Regulatory Authorities (NRAs) to experiment with a dual storage solution to alleviate congestion. The substations where these devices will be installed have been selected to achieve an optimal impact on these congestions.

   Example from RTE :

   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 is then lost.

   In its role as an innovator and major player in the energy transition, RTE is responding to this problem with the RINGO electricity storage experiment, approved by the CRE (Commission de Régulation de l'Energie).

   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 over 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 then remotely and automatically controls all the batteries connected to its network simultaneously, 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 the efficient use of the renewable electricity produced in France.

The experimentation phase will begin with three different sites : Bellac (10MW), Ventavol (10MW) and Vingeanne (12MW). The experimental framework provides for strict neutrality on the functioning of the electricity market. Thus, the three sites are synchronised: when one or two sites are under load, the other(s) must discharge by an equivalent volume to avoid any impact on the national supply–demand balance.

Works are well advanced on the different sites for a commissioning date and a start of experimentation foreseen to be commissioned during June 2022.

3. The new planed and implemented controllable devices, e.g. the Gridbooster, offer significantly faster reaction times on grid events which would lead to congestions. Considering these faster reaction times and free thermal short time capacities within the assets and lines, curative congestion management may unleash the unused potential of the grid. With respect to a coordinated system operation process, the curative usage of the above-mentioned devices may enable the higher utilisation of the grid. Within the German research project InnoSys 2030, the potential of these approaches were highlighted, concepts for curative measures were developed and a roadmap for implementation was published. A first Gridbooster pilot system in Germany (Audorf/Süd and Ottenhofen) should begin operation in 2023. These are used to test the innovative concept for the higher utilisation of the transmission grid.

5. FUTURE CHALLENGES IN THE REGION

5.1 New transmission-projects decrease the gap between today's system and the future needs

The European power system has, in the last decade, began a huge transformation. The main driver for this transformation is the strategy of replacing more conventional power generation (thermal and partly nuclear decommissioning) with more renewables (wind and solar), which leads to more weather-dependent and less flexible power-generation. This triggers a pressing need for more flexible solutions, whereby a part of the solution will be increased interconnector-capacities between countries and between synchronous systems.

Figure 36 – Interconnector-capacity in the North Sea-region of the winter 2010/11.

The interconnector-capacity in the North Sea-region 10 years ago was, as indicated in Figure 36, much lower than today. The figure of TYNDP 2010 shows the interconnector-capacity of winter 2010/11 and was, as shown, much lower than todays' capacity. At the same time, the previous TYNDPs indicate the future needs to be much higher than today.

Two of the most important tasks for the TYNDP is to:

- Identify future transmission-needs (2030/40/50), with a special focus on the climate goals
- Qualify transmission-projects for the PCI-list

Both the above tasks have been carried out as natural parts of the TYNDP-process. In TYNDP 2016, ENTSO-E started the so-called 'Investigation of Future System Needs-Analyses'. The idea was to show the future system needs for the transmission system with a specific focus on climate-goals, security of supply and socioeconomic benefits. These analyses have been carried out every second year and are based on the latest updated assumptions and scenarios. Hence, the results are varying, but the trend is very visible. The future transmission-need is increasing, due to the changes foreseen for the future energy system.

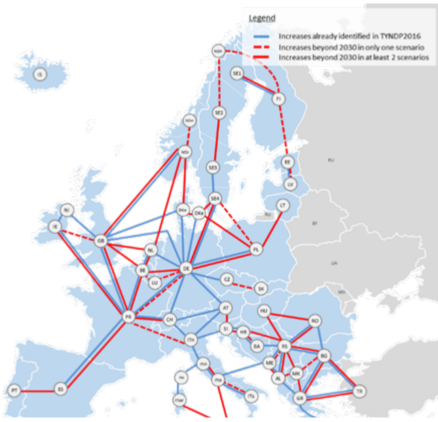


Figure 37 – Investigation of system needs (TYNDP 2018).

To close the gap towards the future need, indicated in the 'System-needs-analyses', investment-decisions for several transmission-projects have been taken in the last decade. Chapter 2.2.2 lists cross-border transmission-projects in the North Sea-region being commissioned since 2010. These projects will all help to close the indicated gap. In addition, several projects are either under construction or in the permitting-phase. These projects are shown in the project-list of TYNDP 2022 and will all contribute to increasing capacity both between countries and between different synchronous areas.

5.2 Fundamental change of the generation and demand portfolio

The Northern Seas power plant fleet has evolved over many decades. To limit climate change, an evolution to technologies with low or zero emissions is necessary. Established and emerging technologies are available for the future such as renewable energies, H2-ready gas fired power plants and nuclear power plants. The EU's 'taxonomy regulation' defines which economic activities are considered sustainable. The implementation act of the taxonomy for sustainable activities will follow in 2022. It is expected that this implementation act will have an influence on the generation mix in the region.

Variable renewables (wind and solar) play a key role in the energy transition. The scenario DE assumes that in 2050, 80% of the installed capacity in the NS region consists of these two energy carriers. It is expected to have an installed capacity of 773 GW and 590.5 GW solar and wind, respectively. The installed offshore wind power totals 241.5 GW in the region. For the GA scenario, the share of wind and solar is also 80%. Solar capacity amounts to 479.2 GW, whereas wind capacity is expected to be 539.6 GW (267.4 GW offshore). For all scenarios it can be seen that the potential of hydro power in the region is very limited and will reach its maximum expansion in 2040. Biofuels are not expected to play a significant role.

The capacity share of nuclear will be reduced by 0.9% (DE) to 3% (GA) by 2050. Germany, France, Great Britain, and the Netherlands have announced coal phase-outs in the future. In Belgium, the coal phase-out has already been completed. Consequently, there are no more coal power plants foreseen after 2040.

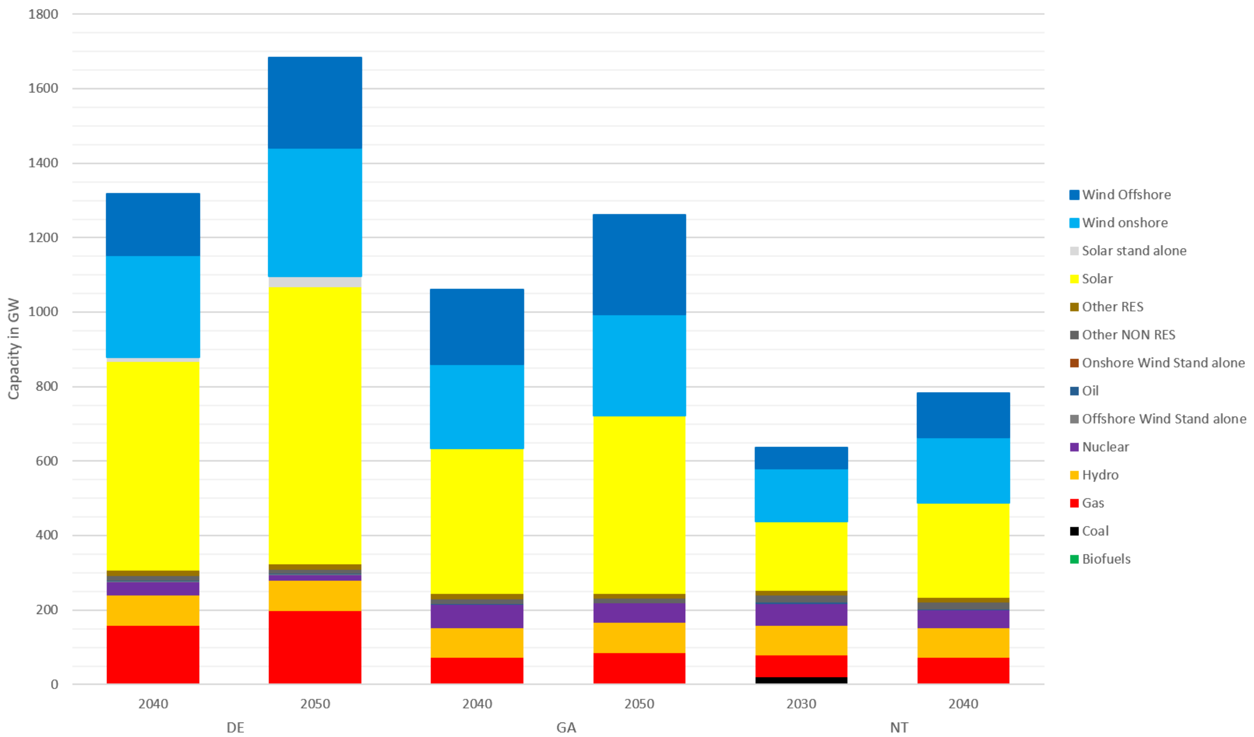


Figure 38 – Generation capacity

Thermal capacities are overall reduced, not only due to national phase-out policies, but the fact that some generation units will no longer be economically viable due to reduced running hours or will reach the end of their lifetime. This will have a considerable impact on the structure of power prices, which are increasingly influenced by variable RES.

To counter the current energy crisis the European Commission proposes the ‘REPowerEU’ plan. Therein it is aimed to reduce the usage of fossil gas by 155 billion cubic metres (BCM) in 2030. Among others this shall be realised by measures of energy efficiency and an increase of the average deployment rate for renewable energies. Some countries of the North Sea region have already decided to further accelerate the integration of RES capacities. This will further increase crowing rate and overall capacity of RES in the region. For the member states the result might be an additional demand of interconnection and internal network reinforcements.

5.3 Need to integrate huge amounts of offshore RES

With an addition of 3.3 GW in 2021, the Northern Seas region has achieved a total instalment of 27.7 GW offshore wind capacity[20]. Depending on the ENTSO-E scenario, an amount of 119… 201 GW is expected to be installed by 2040 and an amount of 242… 267 GW by 2050 in the Northern Seas countries. It is not only in the TYNDP scenario that the Northern Seas region has the largest share in 2050. In its 'EU Strategy to harness the potential of offshore renewable energy for a climate neutral future', the EC highlights that the North Sea region has highest potential for offshore wind energy. On the other hand, this confronts the corresponding TSOs with the greatest challenges of its integration into the grid. This refers to the necessary offshore grids, interconnection of different market zones, internal network reinforcements and stability issues caused by the high penetration of converter interfaced generation units. The EU supports the TSOs in this task. One example is the TEN-E regulation, in which a North Seas offshore grid (NSOG) is defined as one of nine priority corridors in the field of energy infrastructure.

The resource potential for offshore in the Northern Seas region as well as its capacity factors in several areas are very high. The cost of offshore wind has declined substantially in the last decade, making it an attractive contributor to the European Green Deal.

Today, curtailment remains one of the most significant challenges for offshore integration into the Northern Seas systems especially in Ireland, which is poorly interconnected to other electrical systems, or in countries such as Germany, where the roll out of infrastructure is holding back the development of wind generating units. In addition, a wide number of conventional generators are under must-run obligations to provide the necessary flexibility to the system, thus leading to a stagnant supply side. These units are needed for reserve mechanisms reactive power and voltage control mechanisms. However, this means that a portion of RES-energy would need to be curtailed. However, according to the CEP, since 1 January 2020, RES (esp. wind) have an obligation to be balanced and to provide balancing services as well; this will change the overall picture. In addition, RES like wind energy is able to provide system services, but this needs to be triggered by respective market products calling for their contribution, which are not in place in all countries.

Onshore grids were developed step by step over almost a century. The offshore transmission infrastructure and related onshore connections and reinforcements need to be built in only a few decades. It is clear that to achieve this unprecedented on- and offshore expansion, a holistic planning approach, combining the fields of grid and spatial market integration, engineering, construction and financing, is a must. ENTSO-E has identified multiple basic pillars for a successful offshore development: supporting offshore wind integration in electricity systems over time, space and sectors, promoting system security, cost efficiency and the ambitions of the European Green Deal. For a complete insight, please refer to ENTSO-E's Position Paper on Offshore Development (link).

[20] *WindEurope: 'Wind energy in Europe' – 2021 Statistics and the outlook for 2022-2026*

5.4 Need to satisfy increasing electricity demand and security of supply

Following the European trend, final electricity demand is rising in all Northern Seas countries. Depending on the scenario, the electricity demand in the RGNS-member states increases to 2,906 TWh in 2040 and 3,486 TWh in 2050 (scenario DE) or 2,838 TWh in 2040 and 3,587 TWh in 2050 (scenario GA). The NT scenario shows an electricity demand of 1,567 TWh in 2030 and 1,718 TWh in 2040. The results are displayed in figure 39.

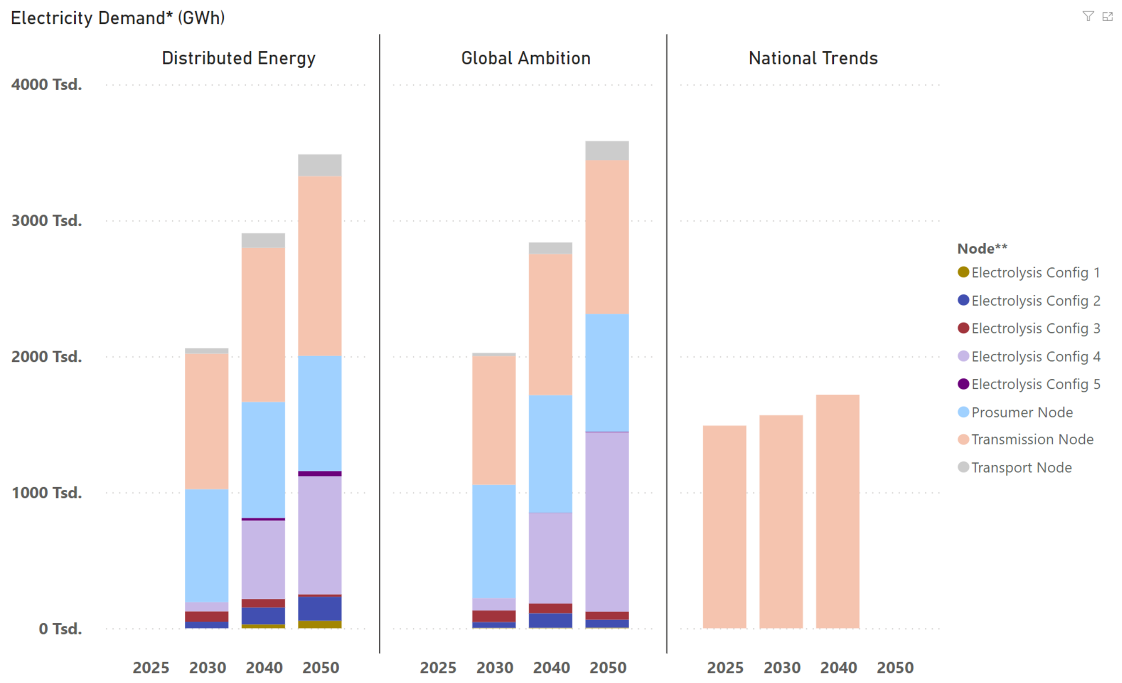


Figure 39 Electricity demand

In the future data centres are expected to represent a considerable share of the electricity demand. The uncertainty of their location is a challenge for the TSOs.

In order to the overall efficiency of the energy system, the direct use of electricity should be prioritised whenever possible.

<u>Security of supply</u>

As in the last Regional Investment Plan 2020, in general unserved energy demand remains a limited concern in the Northern Seas region, especially when compared relatively to the country's annual demands. The key reason is the fact that scenarios are constructed to be in line with adequacy standards. To reach such adequacy standards however, new flexible thermal generation is assumed in the scenarios. This new thermal generation is not necessarily economically viable in an energy-only market, hence, at least partially it might have to rely on existing or new capacity remuneration mechanisms. Thanks to the sharing of resources, interconnectors ensure security of supply in a more cost-effective manner compared to a nationally isolated approach, which would require greater installed generation capacity at an individual country level.

5.5 Change in the Flow across the Region - Grid congestions

Reaching the level of cross-border exchanges that result from the needs identified in the IoSN Needs 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. Therefore, 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.

5.6 High price differences between market areas

In general, as written in the Interconnection Target Expert Group's report, validated by the EC, MSs should aim at yearly average price differentials as low as possible (with 2€/MWh being the threshold that requires further reinforcement investigations). This ensures peak demand will be met through national capacity as well as from interconnections and ensures maximum RES integration by having sufficient interconnection capacity for import and export. To attain the set forth-interconnection targets, investigating and investing in more interconnection between market areas remains a necessity, so that in the end an efficient internal energy market can be obtained which guarantees competitive electric wholesale prices, subject to a positive societal CBA.

5.7 Ensuring flexibility in the energy system

TSOs are responsible for ensuring and maintaining the instantaneous system balance between generation and demand both on a national level as on their respective synchronous area level. With the significant increased shares of variable renewable generation, such tasks become more challenging and largely depend on the available means (e.g. both availability and amount of controllable generation – from all technologies) to control the system balancing needs (variability of the residual load ramps between and within subsequent hours). When considering both the average case as well as the higher percentiles of the future market scenarios, all countries experience large ramps when considering their residual peak loads. In general, expected residual load ramps are increasing and require an increase in flexibility (control means) across the region, which could be provided by various sources, including additional interconnections (which can provide access to control means outside of national control areas), storage and more fast-acting peaking units and demand response.

Hydrogen is considered to play a significant role as a future energy carrier. For the northern seas region scenario, DE expects an installed electrolysis capacity of 105,342.57 MW and 152,752.94 MW in 2040 and 2050 accordingly. The yearly demand of Hydrogen amounts to 503.48 GWh (2040) and 750.31 GWh (2050). The scenario GA foresees a slower roll out (85,809.85 MW and 628.62 GWh in 2040) but a higher final demand (168,365.85 MW and 1013.76 GWh in 2050).

6. APPENDICES

Appendix 1.

Projects relevant for the region (TYNDP projects, PMI/PMI projects, other relevant projects)

1.1 TYNDP projects in the region
1.2 PCI/PMI/... projects in the region
1.3 Additional/other projects relevant for the region

A1: Pan-European Projects

The TYNDP22 draft project portfolio has been published on the ENTSO-E Website in January 2022: 220121_TYNDP2022_draft_project_portfolio.xlsx (live.com)

A2: Regional Projects

In this chapter, the NS projects of 'regional' and 'national' significance are listed. These are needed as substantial and inherent support to the Pan-European projects which will be published on central level inclusion into the future transmission systems. These are critical links to facilitate regional and Pan-European flows and reach the European Climate targets. All these projects include an appropriate description and the main driver, and why they are designed to be realised in the future scenarios, together with the expected commissioning dates and evolution drivers in case they were introduced in the past RegIPs.

There are no criteria for the regional significance projects inclusion in this list. They are included purely based on the project promoter's decision if the project is relevant to be included.

In the table below, projects of regional and national significance in NS region are listed.

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
France	Sud Aveyron			2023	New substation on the 400-kV Gaudière-Rueyres line for local RES integration.	RES integration	Yes
France	Dambron –Chaingy	Dambron	Chaingy	>2030	New line 400kV	Maintenance, RES integration and market integration	
France	Eguzon-Marmagne 400kV	Eguzon	Marmagne	>2030	Reconstruction in double circuit	Maintenance, RES integration and market integration	Yes
France	Long-term perspective 'Façade Atlantique'			>2030	Upgrade of the north-south 400kV corridor between Nouvelle Aquitaine and the Loire valley, under study	RES integration and market integration	Yes
France	Long-term perspective 'Rhône – Bourgogne'			>2030	Upgrade of the north-south 400kV corridors between Lorraine and Alsace and Franche-Comté, between Champagne-Ardenne and Bourgogne and in the Rhone valley Upgrade of the 400kV east-west corridors between Languedoc and the Rhone valley and in the West of Provence Under study.	RES integration and market integration	Yes
France	Long-term perspective 'Normandie – bassin parisien'			>2030	Upgrade of the north-south 400kV corridor between Normandy and Paris basin, under study	RES integration	Yes
France	Long-term perspective 'Massif central – Centre'			>2030	Upgrade of the north-south 400-kV corridors in the Massif central-Centre, under study	RES integration and market integration	Yes
Germany	P38-M27a+M27b+M27c	Pulgar (DE)	Vieselbach (DE)		Construction of new 380 kV double-circuit OHL in existing corridor Pulgar - Vieselbach (104 km).	RES integration / Security of supply	yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
					Detailed information given in Germany's Grid Development.		
Germany	P84-M367	Hamburg/Nord (DE)	Hamburg/Ost (DE)		Reinforcement of existing 380 kV OHL Hamburg/Nord - Hamburg/Ost. Detailed information given in Germany's Grid Development.	RES integration	yes
Germany	P84-M368mod	Hamburg/Ost (DE)	Ämter Büchen/Breitenfelde/Schwarzenbek-Land (DE)		New 380 kV OHL in existing corridor Krümmel - Hamburg/Ost. Detailed information given in Germany's Grid Development.	RES integration	yes
Germany	P22-M80	Elsfleht/West (DE)	Ganderkesee (DE)		New 380 kV OHL in existing corridor for RES integration between Elsfleth/West, Niedervieland and Ganderkesee	RES integration	yes
Germany	P23-M20	Dollern (DE)	Alfstedt (DE)		New 380-kV-OHL in existing corridor in Northern Lower Saxony for RES integration	RES integration	yes
Germany	P23-M20	Alfstedt (DE)	Elsfleth/West (DE)		New 380-kV-line Alfstedt - Elsfleth/West in existing corridor for RES integration	RES integration	Yes
Germany	P20-M69	Emden (DE)	Halbemond (DE)		New 380-kV-line Emden - Halbemond for RES integration. Contruction of new substation Halbemond	RES integration	Yes
Germany	P22-M92	Conneforde (DE)	Unterweser (DE)		New 380-kV-OHL in existing corridor for RES integration in Lower Saxony	RES integration	yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P124-M209a	Wolmirstedt (DE)	Klostermansfeld (DE)		New 380 kV OHL in existing corridor for RES integration between Wolmirstedt - Klostermansfeld	RES integration	Yes
Germany	P124-M209b	Klostermannsfeld (DE)	Schraplau/Obhausen – Lauchstädt (DE)		New 380 kV OHL in existing corridor between Klostermannsfeld - Schraplau/Obhausen - Lauchstädt. Detailed information given in Germany's Grid Development.	RES integration	yes
Germany	P47a-M64	Point Kriftel (DE)	Farbwerke Höchst-Süd (DE)		The 220 kV substation Farbwerke Höchst-Süd will be upgraded to 380 kV and integrated into the existing grid.	RES integration / Security of supply	yes
Germany	P407	Several			Vertical Measures in the Amprion zone	RES integration / Security of supply	yes
Germany	P26-M76	Büttel (DE)	Wilster/West (DE)		New 380-kV-line in extisting corridor in Schleswig - Holstein for integration of RES especially wind on- and offshore	RES integration	yes
Germany	P26-M432	Brunsbüttel (DE)	Büttel (DE)		New 380-kV-line Brunsbüttel - Büttel in existing corridor for RES integration	RES integration	Yes
Germany	P26-M89	Wilster/West (DE)	Stade/West (DE)		New 380-kV-line Wilster/West - Stade/West in existing corridor for RES integration	RES integration	Yes
Germany		junction Mehrum (DE)	Mehrum (DE)		New 380-kV-line junction Mehrum (line Wahle - Grohnde) - Mehrum including a 380/220-kV-transformer in Mehrum	RES integration	yes
Germany	P118-M207	Borken (DE)	Mecklar (DE)		New 380-kV-line Borken - Mecklar in existing corridor for RES integration	RES integration	yes
Germany	P133-M253	Borken (DE)	Gießen (DE)		New 380-kV-line Borken - Gießen in existing corridor for RES integration	RES integration	yes
Germany	P151-M353	Borken (DE)	Twistetal (DE)		New 380-kV-line Borken - Twistetal in existing corridor for RES integration	RES integration	yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P159-M62	Bürstadt (DE)	BASF (DE)		New line and extension of existing line to 400 kV double circuit OHL Bürstadt - BASF including extension of existing substations.	RES integration / Security of supply	yes
Germany	50HzT-003	Neuenhagen (DE)	Vierraden (DE)		Project of new 380 kV double-circuit OHL Neuenhagen - Vierraden - Bertikow with 125 km length as prerequisite for the planned upgrading of the existing 220 kV double-circuit interconnection Krajnik (PL) – Vierraden (DE Hertz Transmission). Detailed information given in Germany's Grid Development.	RES integration / Security of supply	yes
Germany	50HzT-007	Neuenhagen (DE)	Wustermark (DE)		Construction of new 380 kV double-circuit OHL between the substations Wustermark and Neuenhagen with 75 km length. Support of RES and conventional generation integration, maintaining of security of supply and support of market development. Detailed information given in Germany's Grid Development.	RES integration / Security of supply	yes
Germany	50HzT-P36	Pasewalk (DE)	Bertikow (DE)		Construction of new 380 kV double-circuit OHLs in North-Eastern part of 50HzT control area and decommissioning of existing old 220 kV double-circuit OHLs, incl. 380 kV OHL Bertikow - Pasewalk (30 km). Support of RES and conventional generation integration in North Germany, maintaining of security of supply and support of market development. Detailed information given in Germany's Grid Development.	RES integration / Security of supply	yes
Germany	P39-M29a+M29b	Röhrsdorf (DE)	Remptendorf (DE)		Construction of new double-circuit 380 kV OHL in existing corridor Röhrsdorf - Weida - Remptendorf (103 km)	Security of supply	yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P37-M25a+b	Vieselbach (DE)	Mecklar (DE)		New double circuit OHL 380 kV line in existing OHL corridor. Detailed information given in Germany's Grid Development Plan.	RES integration	yes
Germany	P211-M434	Gießen/Nord (DE)	Karben (DE)		new 380-kV-line Gießen/Nord - Karben in existing corridor for RES integration	RES integration	yes
Germany	P150-M352a+M352b	Schraplau/Obhausen (DE)	Wolkramshausen (DE)		New 380 kV OHL in existing corridor between Schraplau/Obhausen and Wolkramshausen. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P180-M406	Marzahn (DE)	Teufelsbruch (DE)		AC grid reinforcement between Marzahn and Teufelsbruch (380 kV cable in Berlin). Detailed information given in Germany's Grid Development Plan.	Security of supply	Yes
Germany	P215-M454, M579, M586	Güstrow (DE)	search area communities Sanitz/Dettmannsdorf (DE)		New 380 kV OHL in existing corridor between Güstrow - Bentwisch - search area communities Sanitz/Gnewitz/Dettmannsdorf/town Marlow and M586+M579: cable connection in Papendorf. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P215-M692, M597, M521TR1	Bentwisch, Papendorf, search area Communities Sanitz/Dettmannsdorf (DE)			This investment includes a new 380/220 kV transformer in Bentwisch and a new 380/220 kV transformer in Papendorf and a new 380/220 kV transformer in search area communities Sanitz/Dettmannsdorf. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P216-M455 und M523	Güstrow (DE)	Pasewalk (DE)		New 380 kV OHL in existing corridor between Güstrow – Siedenbrünzow – Iven/Krusenfelde/Krien/Spantekow /Werder/ Bartow – Pasewalk/Nord – Pasewalk . Detailed information given in Germany's Grid Development Plan.	RES integration	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P150-M463	Wolkramshausen (DE)	Vieselbach (DE)		New 380 kV OHL in existing corridor between Wolkramshausen - Ebeleben - Vieselbach. Detailed information given in Germany's Grid Development Plan.	Security of supply	Yes
Germany	P310-M485	Bürstadt (DE)	Kühmoos (DE)		An addtional 380 kV OHL will be installed on existing power poles.	RES integration / Security of supply	Yes
Germany	TTG-P33-M24a	Wahle (DE)	Border Saxony/Anhalt - Lower Saxony (DE)		New 380 kV OHL in existing corridor between Wahle - Hattorf - Helmstedt/Ost - Border Saxony/Anhalt - Lower Saxony. Detailed information given in Germany's Grid Development Plan.	RES integration	yes
Germany	50HzT-P33-M24a2	Wolmirstedt (DE)	Border Saxony/Anhalt - Lower Saxony (DE)		New 380 kV OHL in existing corridor between Wolmirstedt - Border Saxony/Anhalt - Lower Saxony. Detailed information given in Germany's Grid Development Plan.	RES integration	yes
Germany	P33-M24b	Wolmirstedt (DE)	Gleidingen/Hallendorf (DE)		New 380 kV OHL in existing corridor between Wolmirstedt - Helmstedt - Gleidingen/Hallendorf. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P222-M461	Oberbachern (DE)	Ottenhofen (DE)		Upgrade of the existing 380 kV line. Detailed information given in Germany's Grid Development.	RES integration / Security of supply	Yes
Germany	P72-M49, M50	Kreis Segeberg (DE)	Siems (DE)		New 380-kV-line Kreis Segeberg - Siems in existing corridor for RES integration	RES integration	Yes
Germany	P72-M351	Lübeck (DE)	Göhl (DE)		New 380-kV-line Lübeck - Göhl for RES integration. Contruction of new substation in Göhl	RES integration	Yes
Germany	P53-M54, M350	Raitersaich (DE)	Altheim (DE)		New 380-kV-line Raitersaich - Altheim in existing corridor for RES integration	RES integration	Yes
Germany	M46	Redwitz (DE)	Schwandorf (DE)		New 380-kV-line Redwitz - Schwandorf in existing corridor for RES integration	RES integration	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	50HzT-P34-M22a+M22b+M22c	Güstrow (DE)	Wolmirstedt (DE)		New 380 kV OHL in existing corridor between Güstrow - Parchim/Süd - Perleberg - Stendal/West - Wolmirstedt. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P113-M212, M202a, M203	Krümmel (DE)	Wahle (DE)		Including Ad-hoc-Maßnahme Serienkompensation Stadorf-Wahle	RES integration	Yes
Germany	P135-M255	Bechterdissen	Ovenstädt		Reinforcement of existing 380-kV-line between Bechterdissen and Ovenstädt	RES integration	Yes
Germany	P161-M91	Großkrotzenburg (DE)	Urberach (DE)		Reinforcement of existing 380-kV-line between Großkrotzenburg and Urberach	RES integration	Yes
Germany	P175	Wilhelmshaven 2 (DE)	Fedderwarden (DE)		New 380-kV-line Wilhelmshaven 2 - Fedderwarden for RES integration	RES integration	Yes
Germany	P200	point Blatzheim (DE)	Oberzier (DE)		Reinforcement of existing 380-kV-line between point Blatzheim and Oberzier	Res integration	Yes
Germany	P228	Landesbergen (DE)	Mehrum/Nord (DE)		New 380-kV-line Kreis Segeberg - Siems in existing corridor for RES integration	RES integration	Yes
Germany	P314				Phase-shifting transformers in the Saarland	Res integration	Yes
Germany	P315	Hanekenfähr (DE)	Gronau (DE)		Reinforcement of existing/ new 380-kV-line between Hanekenfähr and Gronau	Res integration	Yes
Germany	P327				Ad-hoc phase-shifting transformers in the Ruhr region	Res integration	Yes
Germany	P345-M556	Hamburg/Ost (DE)			4 phase-shifting transformers in substation Hamburg/Ost	RES integration	Yes
Germany	P346	Hanekenfähr (DE)			Ad-hoc-phase-shifting transformers in Hanekenfähr	Res integration	Yes
Germany	P347	Oberzier (DE)			Ad-hoc-phase-shifting transformers in Oberzier	Res integration	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P348	Krempermarsch (former: Wilster/West) (DE)			New phase-shifting transformers in Wilster/West	RES integration	Yes
Germany	P349	Würgau			New phase-shifting transformers in in Würgau	RES integration	Yes
Germany	P353	Twistetal			New phase-shifting transformers in Twistetal	RES integration	Yes
Germany	P357-M566	Güstrow (DE)			4 phase-shifting transformers in substation Güstrow	RES integration	Yes
Germany	P358-M567	Lauchstädt + Weida (DE)			This investment includes two new 380/220 kV transformers in Lauchstädt and a new 380/220 kV transformer in Weida	RES integration	Yes
Germany	P359-M571+M582b	Stendal/West (DE)	Wolmirstedt (DE)		New 380 kV OHL in existing corridor between Stendal/West - Wolmirstedt. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany	P360-M464+M464b+M595a-q+M605a-c+M685a-g+M686+M695a-c+M752	substations in Mitte, Malchow, search area Osterburg, search area Schraplau/Obhausen, search area Schwanbeck, Zeitz, search area Delitzsch, Streumen, Altenfeld, search area			Installation of reactive power compensation (eg. MSCDN, STATCOM,...) in 50Hertz control area (substations in Mitte, Malchow, search area Osterburg, search area Schraplau/Obhausen, search area Schwanbeck, Zeitz, search area Delitzsch, Streumen, Altenfeld, search area Ebenheim, Weida, Wolkramshausen, Altdöbern, Bertikow, Preilack, Thyrow, Berlin/South-East, Hamburg/Northeast, Bentwisch, Güstrow, Pasewalk, Parchim/South, Jessen/North, Pulgar, Altöbern, Pulitz/South, Altentreptow/South and Betzsee/North)	RES integration / Security of supply	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
		Ebenheim, Weida, Wolkramshausen, Altdöbern, Bertikow, Preilack, Thyrow, Berlin/South-East, Hamburg/Northeast, Bentwisch, Güstrow, Pasewalk, Parchim/South, Jessen/North, Pulgar, Altöbern, Pulitz/South, Altentreptow/South and Betzsee/North (DE)					
Germany	P365-M383	Audorf/Süd	Ottenhofen (DE)		100 MW grid booster in substations Audorf/Süd and Ottenhofen	RES integration	Yes
Germany	P400	Grid of TenneT (DE)			Construction of several reactive power compensation units in grid of TenneT (DE)	RES integration	Yes
Germany	P403-M603	Hattingen (DE)	Linde (DE)		reinforcement of existing OHL between Hattingen and Linde	Res integration	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P410-M624	Enniger			Phase-shifting transformers in Enniger	Res integration	Yes
Germany	P412				Several reactive power compensation systems in the area of the Amprion GmbH	Res integration	Yes
Germany	P450-M678+M786	Güstrow (DE)	Stendal/West (DE)		Reinforcement of existing 380 kV OHL (M678: Putlitz/Süd – Putlitz – Perleberg – Stendal/West; M786: Güstrow – Siedenbrünzow – Putlitz/Süd)	RES integration	Yes
Germany	P451-M681	Graustein (DE)	Bärwalde (DE)		Reinforcement of existing 380 kV OHL Graustein - Bärwalde	RES integration	Yes
Germany	P450-M683	Ragow (DE)	Streumen (DE)		Reinforcement of existing 380 kV OHL Ragow - Streumen	RES integration	Yes
Germany	P460-M687				Grid reinforcements in the region Büscherhof	Res integration	Yes
Germany	P462-M689				Grid reinforcements in the region Aachen	Res integration	Yes
Germany	P463-M690				Grid reinforcements in western Rhein region	Res integration	Yes
Germany	P119-M90, M535	Conneforde (DE)	Samtgemeinde Sottrum (DE)		New 380-kV-line Conneforde - Sottrum in existing corridor for RES integration	RES integration	Yes
Germany	P43	Mecklar (DE)	Bergrheinfeld/West (DE)		New 380-kV-line Mecklar - Bergrheinfeld/West for RES integration	Res integration	Yes
Germany	P24	Dollern (DE)	Landesbergen (DE)		New 380-kV-line Dollern - Landesbergen in existing corridor for RES integration	Res integration	Yes
Germany	P21	Conneforde (DE)	Cloppenburg (DE)		New 380-kV-line Conneforde - Landkreis Cloppenburg in existing corridor for RES integration	Res integration	Yes
Germany	P21	Cloppenburg (DE)	Merzen (DE)		New 380-kV-line Landkreis Cloppenburg - Merzen for RES integration	Res integration	Yes
Germany	TTG-006	Wahle (DE)	Mecklar (DE)		New 380-kV-line Wahle - Mecklar for RES integration	RES integration	No

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	AMP/TTG 007	Dörpen/West (DE)	Niederrhein (DE)		New 380-kV-line Dörpen/West - Niederrhein for RES integration	RES integration	No
Germany	AMP/TTG 009	Ganderkesee (DE)	Wehrendorf (DE)		New 380-kV-line Ganderkesee - Wehrendorf for RES integration	RES integration	No
Germany	TTG-P25	Husum/Nord (DE)	Klixbühl/Süd (DE)		Westcoastline Heide/West - Klixbühl for RES integration	RES integration	No
Germany	DC 20	Klein Rogahn/Stralendorf/Warsow/Holthusen/Schossin(DE)	Isar (DC)		New HVDC-cable Klein Rogahn/Stralendorf/Warsow/Holthusen/Schossin – Isar for RES integration	RES integration	no
Germany	DC 31	Hemmingstedt/Lieth/Lohe-Rickelshof/ Wöhrden (DE)	Klein Rogahn/Stralendorf/ Warsow/ Holthusen/Schossin (DE)		New HVDC-cable Hemmingstedt/Lieth/Lohe-Rickelshof/ Wöhrden (DE) - Klein Rogahn/Stralendorf/ Warsow/ Holthusen/Schossin for RES integration	RES integration	no
Germany	P212	Landesbergen (DE)	Borken (DE)		new 380-kV-line Landesbergen-Borken in existing corridor for RES integration	RES integration	no
Germany	P227	Lübeck/West (DE)	Krümmel (DE)		New 380-kV-line Lübeck/West - Krümmel for RES integraton	RES integration	no
Germany	P500	Sombron	Urberach (DE)		New 380-kV-line Somborn-Aschaffenburg-Urberach for RES integration	RES integration	no
Germany	TNG-P47-M31, M32, M33, M34, M31TR1	Weinheim (DE)	Daxlanden (DE)		Upgrade of existing 380 kV lines in the area from Weinheim to Daxlanden. In addition the new phase-shifting transformer in Weinheim to the distribution grid is necessary.	Res integration	Yes
Germany	AMP-P47- M60	Urberach (DE)	Weinheim (DE)		Upgrade of existing 380 kV lines in the region Frankfurt-Karlsruhe	Res integration	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	TNG-P48-M38a, M39	Grafenrheinfeld (DE)	Großgartach (DE)		Additional 380 kV circuit between Point Rittershausen and Kupferzell inkl. the enhancement of substation in Kupferzell. Reinforcements in existing corridor between Kupferzell and Großgartach.	RES integration	Yes
Germany	TNG-P49	Daxlanden (DE)	Eichstetten (DE)		Upgrade of existing 220 kV lines from Daxlanden via Bühl, Kuppenheim and Weier to Eichstetten to 380 kV. The enhancement of corresponding substations will be carried out.	Res integration	Yes
Germany	TNG-P50-M366SA1	Pulverdingen(DE)			Extension of substation Pulverdingen	Res integration	Yes
Germany	TNG-P70	Birkenfeld (DE)	Ötisheim (DE)		A new 380 kV OHL Birkenfeld-Ötisheim (Mast 115A) inkl. new 380 kV GIS-substation in Birkenfeld	Security of supply	Yes
Germany	TNG-P90	Grid of TransnetBW			Construction of several reactive power compensation systems in the area of the TransnetBW GmbH	Res integration	Yes
Germany	TNG-P350-M561	Pulverdingen(DE)			New phase-shifting transformer in Pulverdingen	Res integration	Yes
Germany	P51-M37	Großgartach (DE)	Endersbach (DE)		Grid reinforcements in existing corridor between Großgartach and Endersbach. Enhancement of the substations Endersbach and Großgartach is requiered.	Security of supply	Yes
Germany	P302-M511	Höpfingen (DE)	Hüffenhardt (DE)		Additional 380 kV line between Höpfingen and Huffenhardt inkl. grid reinforcements in the corresponding substations.	Res integration	Yes
Germany	P206-M417	Herbertingen/ Area of Constance/Beuren (DE)	Gurtweil/Tiengen (DE)		Increase of transmission capacity in the Hochrhine region by replacement of existing 220 kV infrastrukture.	Security of supply	Yes

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P428-M700	Kühmoos			Upgrade of 380 kV substation Kühmoos in Southern Germany	Res integration	Yes
Germany	P430-M646	Kupferzell			250 MW grid booster in substation Kupferzell	Res integration	Yes
Germany	P421-M702	Trossingen			Connection of existing 380kV line Engstlatt-Gurtweil-Villingen to the substation in Trossingen. Enhancement of substation Trossingen and other connected lines is required.	Security of supply	No
Germany	P223-M462a	Güstrow (DE)	Krümmel (DE)		New 380 kV OHL in existing corridor between Güstrow – Wessin – Görries – Gemeinden Klein Rogahn/Stralendorf/Warsow/Holthusen/Schossin – Gemeinden Talkau/Elmenhorst/Kankelau/Fuhlenhagen – Krümmel. Detailed information given in Germany's Grid Development.	RES integration	No
Germany	P252-M534a	Marzahn (DE)	Wuhlheide (DE)		New 380 kV OHL in existing corridor between Marzahn – Wuhlheide. Detailed information given in Germany's Grid Development.	Security of supply	No
Germany	P528-M750	Lauchstädt (DE)	Pulgar (DE)		New 380 kV OHL in existing corridor between Lauchstädt – Leuna/Merseburg/Weißenfels – Pulgar. Detailed information given in Germany's Grid Development Plan.	Security of supply	No
Germany	P402	Westerkappeln (DE)	Gersteinwerk (DE)		380-kV HL OHL in new corridor between Westerkappeln and Gersteinwerk	RES integration	No
Germany	P408	Eiberg (DE)	Emscherbruch (DE)		380-kV HL OHL in existing corridor from Eiberg to Emscherbruch	RES integration	No

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Germany	P464	Saarland (DE)	Sarwellingen (DE)		New 380/110kV transformers.	Security of supply	No
Germany	P501	Gersteinwerk (DE)	Mengede (DE)		380-kV HL OHL in existing corridor from Gersteinwerk to Mengede	RES integration	No
Germany	P502	Walsum (DE)	Beeck (DE)		380-kV HL OHL in existing corridor from Walsum to Beeck	RES integration	No
Germany	P504	Sechtem (DE)	Weißenthurm (DE)		New 380-kV-line reinforecement from Sechtem to Weißenthurm	RES integration	No
Germany	P531-M531a/M531b	Thyrow (DE)	Reuter (DE)		New 380 kV OHL in existing corridor between Thyrow – search area Großbeeren/Blankenfelde-Mahlow – Berlin/Südost/search area Stadtbezirk Steglitz-Zehlendorf – search area Stadtbezirke Mitte/Friedrichshain-Kreuzberg M531b: Malchow – search area Stadtbezirke Mitte/Reinickendorf – Reuter. Detailed information given in Germany's Grid Development Plan.	Security of supply	No
Belgium	Modular Offshore Grid II	Coast (BE)	Offshore (BE)	2028	The development of an offshore modular grid to enable the connection of an additional 2 GW of offshore wind power	Res integration	TYNDP18
Belgium	Ventilus	Avelgem (BE)	Coast (BE)	2028	The development of a new axis 380 kV between the coastal region and the inner country in order to integrate an additional 2 GW of offshore wind power and the possibility to connect a new interconnector.	Res integration Security of Supply Market integration	TYNDP18
Belgium	Boucle du Hainaut	Courcelles (BE)	Avelgem(BE)	2028	The development of a new axis 380 kV between Avelgem and Courcelles to integrate an additional 2 GW of offshore wind power and the possibility of a new interconnector.	Res integration Security of Supply Market integration	TYNDP18

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2020?
		From	To				
Belgium	Internal Belgian Backbone Center-East: HTLS upgrade Massenhoven-VanEyck-Gramme-Courcelles-Bruegel-Mercator	Massenhoven (BE) VanEyck (BE) Gramme (BE) Courcelle (BE) Breugel (BE) Mercator (BE)	VanEyck (BE) Gramme (BE) Courcelles (BE) Breugel (BE) Mercator (BE) Massenhoven (BE)	2024 2029 2033 2035 2025 2030	The upgrade of the existing 380 kV backbone of the Belgian grid to High Temperature Low Sag conductors to unlock potential additional cross border capacity.	Security of Supply Market integration	TYNDP18

Appendix 2. Links to national development plans

Table A3-9 provides a link to the development plan of all countries in the Northern Seas region, where available.

Table A3-8 – ENTSO-E Regional Group Northern Seas countries national development plans

Country	Company/TSO
Belgium	https://www.elia.be/nl/infrastructuur-en-projecten/investeringsplannen/federaal-ontwikkelingsplan-2020-2030
France	https://www.rte-france.com/sites/default/files/sddr2019_synthese_gb_ok.pdf
The Netherlands	https://www.tennet.eu/nl/bedrijf/publicaties/investeringsplannen/
Germany	https://www.netzentwicklungsplan.de/de
Ireland	https://www.eirgridgroup.com/site-files/library/EirGrid/Transmission-Development-Plan-2020-2029.pdf
Northern Ireland	https://www.soni.ltd.uk/media/documents/SONI-Transmission-Development-Plan-Northern-Ireland-2020-2029.pdf
Denmark	Energinets Langsigtede Udviklingsplan 2022 | Energinet
Norway	National Grid Development Plan Norway | Statnett
Luxembourg	https://www.creos-net.lu/fileadmin/dokumente/NEWS/pdf/2020-2022/20201029_Scenario_Report_2040.pdf

Appendix 3. Glossary

Acronym	Term	Definition
ACER	Agency for the Cooperation of Energy Regulators	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.
BEMIP Electricity	Baltic Energy Market Interconnection Plan in electricity	One of the four priority corridors for electricity identified by the TEN-E Regulation. Interconnections between Member States in the Baltic region and the strengthening of internal grid infrastructure, to end the energy isolation of the Baltic States and to foster market integration; this includes working towards the integration of renewable energy in the region.
	Bottom-Up	This approach of the scenario building process collects supply and demand data from Gas and Electricity TSOs.
	Carbon budget	This is the amount of carbon dioxide the world can emit while still having a likely chance of limiting average global temperature rise to 1.5 °C above pre-industrial levels, an internationally agreed-upon target.
CCS	Carbon Capture and Storage	Process of sequestrating CO2 and storing it in such a manner that it will not enter the atmosphere.
CCU	Carbon Capture and Usage	The captured CO2, instead of being stored in geological formations, is used to create other products, such as plastic.
CHP	Combined Heat and Power	Combined heat and power generation.
	Congestion revenue / rent	The revenue derived by interconnector owners from the sale of the interconnector capacity through auctions. In general, the value of the congestion rent is equal to the price differential between the two connected markets, multiplied by the capacity of the interconnector.
	Congestion	Means 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.
COP21		21st Conference of the Parties to the United Nations Framework Convention on Climate Change, organised in 2015, where participating states reached the Paris Agreement.
CBA	Cost-benefit analysis	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 minimise congestion of transmission or otherwise manage the system or achieve the optimum mix of resources.
DSR	Demand side response	Consumers have an active role in softening peaks in energy demand by changing their energy consumption according to the energy price and availability.
EH2050	e-Highway2050	Study funded by the European Commission aimed at building a modular development plan for the European transmission network

		from 2020 to 2050, led by a consortium including ENTSO-E and 15 TSOs from 2012 to 2015 (to e-Highway2050 website).
	Electricity corridors	Four priority corridors for electricity identify by the TEN-E Regulation: North Seas offshore grid (NSOG); North-south electricity interconnections in western Europe (NSI West Electricity); North-south electricity interconnections in central eastern and south eastern Europe (NSI East Electricity); Baltic Energy Market Interconnection Plan in electricity (BEMIP Electricity).
ENS	Energy not served	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.
GTC	Grid transfer capacity	Represents the aggregated capacity of the physical infrastructure connecting nodes in reality; it is not only set by the transmission capacities of cross-border lines but also by the ratings of so-called 'critical' domestic components. The GTC value is thus generally not equal to the sum of the capacities of the physical lines that are represented by this branch; it is represented by a typical value across the year.
IEM	Internal Energy Market	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.
	Investment (in the TYNDP)	Individual equipment or facility, such as a transmission line, a cable or a substation.
MAF	Mid-term adequacy forecast	ENTSO-E's yearly pan-European monitoring assessment of power system resource adequacy spanning a timeframe from one to ten years ahead.
NTC	Net transfer capacity	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.
	N-1 criterion	The rule according to which elements remaining in operation within a TSO's responsibility area after a contingency from the contingency list must be capable of accommodating the new operational situation without violating operational security limits.
NECP	National Energy and Climate Plan	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.
NSOG	North Seas offshore grid	One of the four priority corridors for electricity identified by the TEN-E Regulation. Integrated offshore electricity grid development and related interconnectors in the North Sea, Irish Sea, English Channel, Baltic Sea and neighbouring waters to transport electricity from renewable offshore energy sources to centres of consumption and storage and to increase cross-border electricity exchange.

NSI East Electricity	North-south electricity interconnections in central eastern and south eastern Europe	One of the four priority corridors for electricity identified by the TEN-E Regulation. Interconnections and internal lines in north-south and east-west directions to complete the EU internal energy market and integrate renewable energy sources.
NSI West Electricity	North-south electricity interconnections in western Europe	One of the four priority corridors for electricity identified by the TEN-E Regulation. Interconnections between EU countries in this region and with the Mediterranean area including the Iberian peninsula, in particular to integrate electricity from RES and reinforce internal grid infrastructures to promote market integration in the region.
P2G	Power to gas	Technology that uses electricity to produce hydrogen (Power to Hydrogen – P2H2) by splitting water into oxygen and hydrogen (electrolysis). The hydrogen produced can then be combined with CO2 to obtain synthetic methane (Power to Methane – P2CH4).
	Project (in the TYNDP)	Either a single investment or a set of investments, clustered together to form a project, in order to achieve a common goal.
PCI	Project of common interest	A project which meets the general and at least one of the specific criteria defined in Art. 4 of the TEN-E Regulation and which has been granted the label of PCI project according to the provisions of the TEN-E Regulation.
PINT	Put IN one at the Time	Methodology that considers each new network investment/project (line, substation, PST or other transmission network device) on the given network structure one by one and evaluates the load flows over the lines with and without the examined network reinforcement.
	Reference grid	The existing network plus all mature TYNDP developments, allowing the application of the TOOT approach.
	Reference capacity	Cross-border capacity of the reference grid used for applying the TOOT/PINT methodology in the assessment according to the CBA.
	Scenario	A set of assumptions for modelling purposes related to a specific future situation in which certain conditions regarding electricity and gas demand and supply, infrastructures, fuel prices and global context occur.
TOOT	Take Out One at the Time	Methodology that consists of excluding investment items (line, substation, PST or other transmission network device) or complete projects from the forecasted network structure on a one-by-one basis and to evaluate the load flows over the lines with and without the examined network reinforcement.
TYNDP	Ten-Year Network Development Plan	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.
	Top-Down	The 'Top-Down Carbon Budget' scenario building process is an approach that uses the 'bottom-up' model information gathered from the gas and electricity TSOs. The methodologies are developed in line with the Carbon Budget approach.
TEN-E	Trans-European Networks for Energy	Policy focused on linking the energy infrastructure of EU countries. It identifies nine priority corridors (including 4 for electricity) and three priority thematic areas.

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