Ten-Year Network Development Plan 2020

Regional Investment Plan
Baltic Sea

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entsoe

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1. EXECUTIVE SUMMARY

1.1 Key messages of the region

The electricity system in the Baltic Sea region is undergoing unprecedented change as the electricity generation structure is rapidly decarbonising and simultaneously becoming more variable according to weather conditions.

Construction of renewable energy in the region has been accelerated by rapid technology development and national subsidy mechanisms. In particular, the increase in wind power production has reduced the price of electricity. The energy surplus created on the market has lowered the price of electricity, and the profitability of traditional generation has also weakened significantly, which has resulted in the closure of adjustable production capacity. This development has reduced carbon dioxide emissions, but it has also increased the risk of brownouts or blackouts in parts of the region as identified in the MAF 2019 study issued by ENTSO-E in the previous year. At the same time, society's dependency on electricity is increasing. As a result, the power systems of the future might be expected to provide even greater reliability in order to safeguard the vital functioning of society.

Large quantities of new renewable energy generation are still being planned across the region, and these must be integrated successfully, while also maintaining security of supply and facilitating an efficient and secure European energy market. The integration of renewables will further replace production from thermal power plants and the grid needs to facilitate flows to cover the deficit at load centres, due to the closure of power plants and the growing flows between synchronous areas. In order to solve the challenges regarding load balancing and power generation - in all parts of the region - further grid development is favourable and necessary. As the future generation-mix is expected to be much more weather-dependent, this increases the need to strengthen the grid.

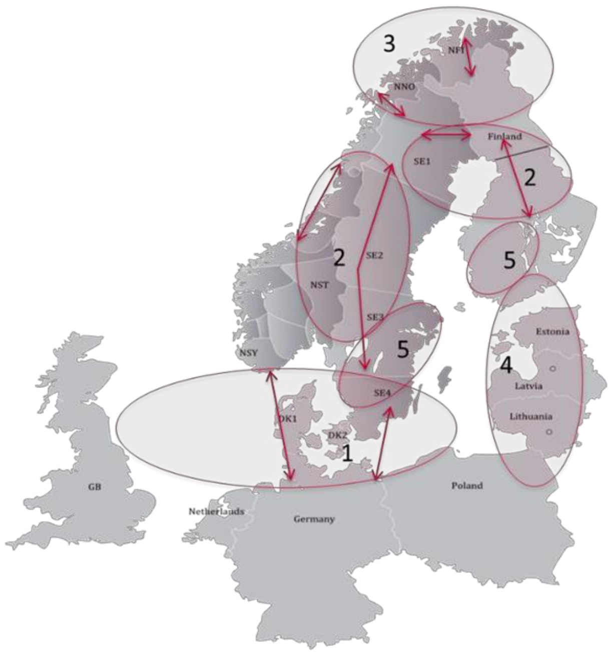


Figure 1-2 - Key drivers of the Baltic Sea region

The main driver for the energy system in the region is the green energy transition, along with climate and decarbonisation goals. From a grid development perspective, the drivers within the Baltic Sea region are as follows:

Driver 1: Need for flexibility - Further integration between synchronous areas

The transformation of the European power system leads to a less flexible generation-mix. The Nordic system continues to be a flexible system, due to its hydro-dominated generation-mix. In addition, the Nordic system is likely to increase the annual energy surplus, even though some nuclear power plants are decommissioned. Both the flexibility-need and the expected price-differences between the systems, seem to be a driver for further integration between different synchronous systems. In continental low wind-situations energy might be exported from the Nordic system, while in continental high wind-situations power might be imported and stored in the hydro-dominated Nordic system.

Driver 2: Integration of renewables - Increased North-South flows

Based on the political goals of reduced CO2 emissions, and based on the cost development of wind and solar generation units, further integration of renewables is expected within the Nordic countries. In Germany large amounts of solar has already been established and is expected to further increase. In Germany, Denmark and Sweden large amounts of onshore wind is already integrated. Next to come appears to be offshore wind, which offers huge potential to the Baltic Sea region. New interconnectors to the continent/Baltic States, in combination with substantial amounts of new renewable generation capacity, is increasing the need to strengthen transmission capacities in the North-South direction in Germany, Sweden, Norway, Finland and Denmark. In addition, nuclear and/or thermal plants are expected to be decommissioned in southern Germany, Sweden, Denmark and Finland, which further increases capacity-need in the North-South direction.

Driver 3: Electrification/New consumption - Reinforcements of the grid

According to EU climate goals, the European energy system is expected to become much more efficient. This means more efficient use of energy both within industry, transport and households, as well as solutions lowering energy consumption. As a result, the total energy demand for Europe is expected to decrease. At the same time, electrification of all kinds of consumption will play a major role in this transformation to a much more efficient and decarbonised system. In addition, new type of consumption like data-storage will increase electricity-consumption. Over the coming decades, energy-consumption is expected to decrease, while electricity-consumption is expected to increase. This increased electricity-consumption and electrification will therefore mean huge reinforcements of the grid might be necessary.

Driver 4: Baltic integration - Improved security of supply for the Baltic system

For historical reasons, the Baltic States are currently operated in synchronous mode with the Russian and Belarussian electricity systems (the IPS/UPS system). In recent years, great progress has been made in integrating the Baltic countries with European energy markets, with the commissioning of the NordBalt and LitPol links. The Baltic countries are now connected to Finland, Sweden and Poland via HVDC connections.

The three Baltic TSOs are now preparing to de-synchronise from IPS/UPS, and instead synchronise with the Continental European Network (CEN) through current interconnection between Lithuania and Poland. In addition, a new subsea HVDC (Harmony Link) is planned between Lithuania and Poland with the aim of improving the level of security of supply. Synchronising the Baltic countries with the CEN will ensure energy security by connection to a grid that is operated using joint European rules.

Driver 5: Nuclear and thermal decommissioning - Challenges for security of supply

All nuclear power plants in Germany, a substantial proportion of the thermal/nuclear power plants in Sweden, and a substantial proportion of the thermal power plants in Germany, Denmark and Finland are expected to be decommissioned by 2030. Furthermore, the decommissioning of thermal power plants, particularly in Poland, is needed to achieve the EU's climate targets. Decommissioning of both nuclear and thermal power plants would lead to an increased system-risk, challenging security of supply. Nuclear and thermal power have many important features in today's system, and a phase-out will require new generation capacity, grid development, and further development of system services.

Driver 6: Smart sector integration and flexible loads - Optimising decarbonisation

Sector integration, demand response and flexible loads are core instruments for cutting emissions in a cost-effective way. Smart Sector Integration (SSI) seeks the optimal solution for the whole energy system, supporting a fast and cost-optimised path to zero emissions by 2050. Electricity would be used either directly, in other sectors such as transportation and heating in buildings and industry, or to produce green hydrogen. Hydrogen may in turn be used directly in transportation, heating, and even power generation - for example, during hours of scarcity - or to produce methane, fuels, ammonia or more. The benefits of SSI arise from the variable character and the falling costs of wind and solar power. In addition to cutting emissions in a more cost-effective way, SSI also provides flexibility between different energy systems. This again increases security of supply levels in the power system. Flexible loads and demand response will help optimise the dimensioning and operation of the power system. Flexibility markets may be used in the future to solve bottlenecks in the system.

1.2 Future capacity needs

The drivers described above are the basis for further grid development. The grid development needs in the short term can be studied by analysing the current measurements, trends and generation plans, as well as consumption changes. Grid infrastructure is a long-term investment with a lifetime of tens of years; building a new line, for example, can take a decade or more, particularly when factoring in all the necessary planning and permitting. Therefore, it is important to be able to consider the benefits of new infrastructure in the long term. It is not meaningful to try to forecast the future as 'one truth', because small changes, for example in policies or fuel prices, can have a major impact on the resulting view of the future.

In addition to the main drivers described above, in the list below are given the key messages explaining the future capacity needs and positive effects of transmission grid expansion up to 2050:

- The green energy transition along with climate goals and decarbonisation will lead to fundamental change in generation and energy demand, which triggers changed power flows across the region. The dominant power flow direction will go from North to South.

- Rapid expansion of both onshore and offshore renewables in the region and decommissioning of nuclear generation in Germany up to the end of 2022, and potentially in Sweden by 2040, triggers related offshore and onshore infrastructure needs.

- Flexibility is challenged; however, Sector Integration and demand response will be a part of the solution in combination with hydro resources. (Electrification and load increase is expected to keep in line with industrial and transport development.)

- The above requires new interconnectors, some of which are already in preparation, or under construction (NO-DE, SE-FI etc), and will also help IEM, SoS and RES integration. Continued strong collaboration between actors in the region is needed, and those actors are responsible for the timely implementation of interconnectors.

- Baltic countries will be synchronised with Continental Europe by 2025, but security of supply will need to be further enhanced. The med-term system adequacy issue (SoS) in the Baltic States, is primarily related to flexibility needs after desynchronisation from IP/UPS and synchronisation with the CEN.

All the scenarios being studied in the Identification of System Needs (IoSN) include a large increase in renewable generation and a decrease in CO2 emissions; but without additional grid development the price spread between market areas in the region would increase rapidly and some of the climate benefits would not be realised. The benefits of increased capacities in the scenarios are clearly visible in Chapter 4 where the market results of IoSN have been described. Increasing capacities at the borders would have a significant impact on both the electrical system and on society. In summary, the main benefits of satisfying the identified capacity needs, if the scenarios end up realising the summarised results, are shown below:

- Up to €50 per MWh reduction in marginal costs
- From 46-80TWh less curtailed energy
- A 10MT reduction in CO2 emissions

2. INTRODUCTION

2.1 Regional Investment Plans as a foundation for the TYNDP 2020

ENTSO-E's Ten-Year Network Development Plan (TYNDP) is the most comprehensive planning reference for the pan-European electricity transmission network. Released every even year, it presents and assesses all relevant pan-European projects at a specific time horizon, as defined by a set of various scenarios to describe the future development and transition of the electricity market. The TYNDP serves as a basis to derive the EU list of European Projects of Common Interest (PCI).

An essential part of the TYNDP 2020 package, the six Regional Investment Plans address challenges and system needs at the regional level, for each of ENTSO-E's six system development regions (Figure 2-1).

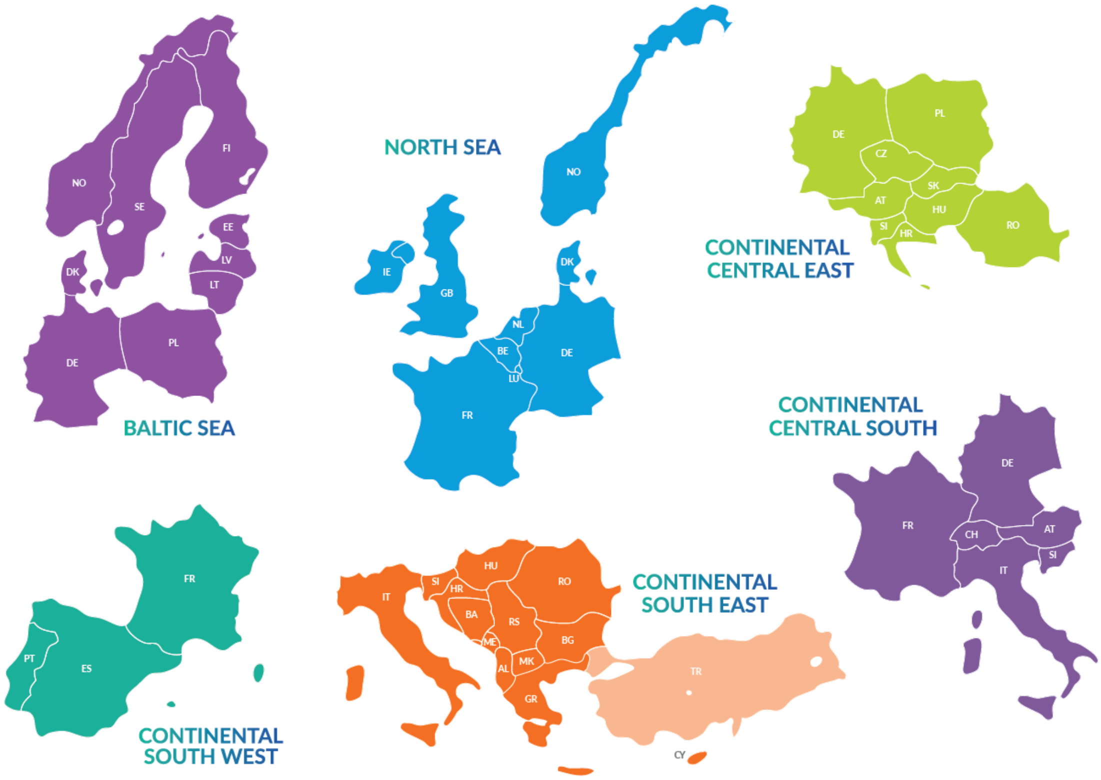


Figure 2-1 - ENTSO-E's six system development regions

The regional investment plans are part of the TYNDP 2020 package, which also include, among others, the 'Completing the map - Power system needs in 2030 and 2040' report and the Scenarios report, describing the scenarios serving as a basis for the IoSN 2040 and regional investment plans.

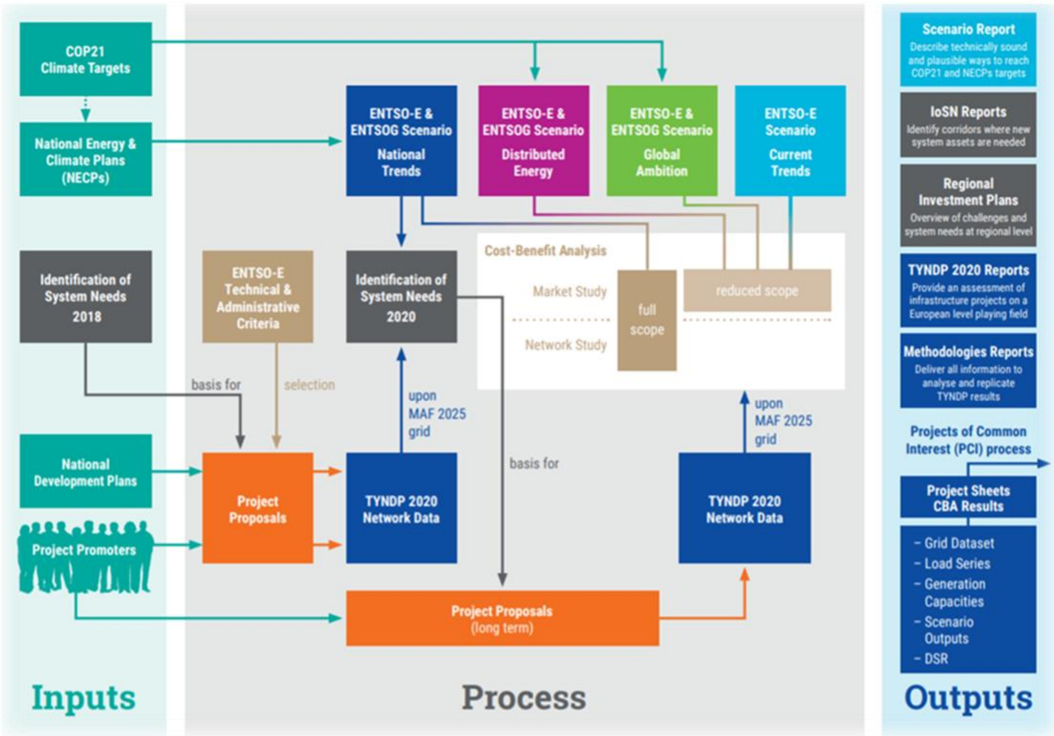


Figure 2-2 - Overview of TYNDP 2020 process and outputs

2.2 Legal requirements

Regulation (EU) 2019/943 Article 34 (recast of Regulation (EC) 714/2009) states that TSOs shall establish regional cooperation within ENTSO-E and shall publish regional investment plans every two years. TSOs may take investment decisions based on regional investment plans. Article 48 further states that ENTSO-E shall publish a non-binding community-wide Ten-Year Network Development Plan, which shall be built on national investment plans, take into account regional investment plans and the reasonable needs of all system users and shall identify investment gaps.

In addition, the TYNDP package complies with Regulation (EU) 347/2013, which defines new European governance and organisational structures that shall promote transmission grid development.

2.3 Scope and structure of the Regional Investment Plans

The Regional Investment Plans are based on pan-European market study results, combined with European and/or regional network studies. They present the current situation of the region as well as the expected future regional challenges, considering a 2040 time-horizon. To illustrate circumstances that are especially relevant to each region, available regional sensitivities and other available studies are included in the Plans. The operational functioning of the regional system and associated future challenges may also be addressed.

As one of the solutions to future challenges, the TYNDP project has performed market and network studies for the long-term 2040 time horizon National Trend scenario, to identify investment needs that is, cross-border capacity increases and related necessary reinforcements of the internal grid that can help to mitigate these challenges.

In addition, the Regional Investment Plans list the regional projects from the TYNDP 2020 project collection. In 2020, each of these projects has been assessed and presented in the TYNDP 2020 package.

The approach followed by the regional investment plans is summarised in Figure 2-3.

Figure 2-3 - Mitigating future challenges - TYNDP methodology

The current document comprises five chapters with detailed information at the regional level:

- Chapter 1 presents the key messages about the region
- Chapter 2 sets out in detail the general and legal basis of the TYNDP and regional investment plans and provides a short summary of the general methodology used by all ENTSO-E regions
- Chapter 3 covers a general description of the present situation of the region. The future challenges of the region are also presented when describing the evolution of generation and demand profiles in the 2040 horizon, while considering a grid as expected by the 2025 horizon. This chapter also includes links to the respective national development plans (NDPs) of the countries of the region
- Chapter 4 includes an overview of the regional needs in terms of capacity increases and the main results from the market perspective
- Chapter 5 is dedicated to additional analyses conducted inside the regional group or by external parties outside the core TYNDP process
- The Appendix includes the list of links to the National Development Plans, projects proposed by promoters in the region at the Pan-European level, as well as important regional projects that are not part of the European TYNDP process. In the Appendix the abbreviations and terminology used in the whole report is included as well as additional content and detailed results.

The actual Regional Investment Plan does not include the CBA-based assessment of projects. These analyses are developed in a second step and presented in the TYNDP 2020 package.

2.4 General methodology

The Regional Investment Plans build on the results of studies, called 'Identification of System Needs' (IoSN), which are conducted by a European team of market and network experts originating from the six regional groups of ENTSO-E's System Development Committee. The results of these studies have been discussed and, in some cases, extended with additional regional studies by the regional groups to cover all relevant aspects in the regions.

The aim of the Identification of System Needs is to identify investment needs in the long-term time horizon (2040) - triggered by market integration, RES integration, security of supply and interconnection targets - in a coordinated pan-European manner that also builds on the expertise of the grid planners of all the TSOs.

A more detailed description of this methodology is available in the TYNDP 2020 'Completing the map - Power system needs in 2030 and 2040' report.

2.5 Introduction to the region

The Baltic Sea Regional Group, under the scope of the ENTSO-E System Development Committee, is among the six regional groups that have been set up to cover short-and long-term transmission grid planning and system development tasks. The countries belonging to the Baltic Sea Regional Group are shown below.

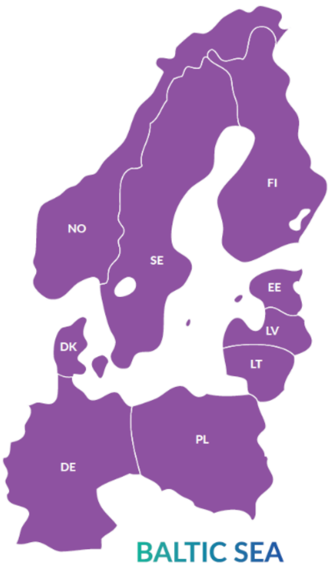


Figure 2-4 - ENTSO-E System Development Committee Baltic Sea region

The Regional Group Baltic Sea comprises nine countries, listed in Table 2-1 along with their representative TSO.

Country	Company/TSO
Denmark	ENERGINET
Estonia	ELERING
Finland	FINGRID
Germany	50HERTZ GmbH
Latvia	AS AUGSTSPRIEGUMA TIKLS
Lithuania	LITGRID AB
Norway	STATNETT
Poland	PSE S.A.
Sweden	SVENSKA KRAFTNÄT

Table 2-1 - ENTSO-E Regional Group Baltic Sea membership

2.6 Evolution since RegIP 2017

The EU has agreed a comprehensive update of its energy policy framework to facilitate the transition away from fossil fuels towards carbon-neutral energy. It also aims to deliver commitments for reducing greenhouse gas emissions, that create growth and jobs in a modern economy while increasing our quality of life as citizens. Buildings are responsible for approximately 40% of energy consumption and 36% of CO2 emissions in the EU. Therefore, by improving energy performance in buildings, the EU can more readily achieve its energy and climate goals. The EU has set an ambitious, binding target of 32% for renewable energy sources in the EU's energy mix by 2030. Energy efficiency is also a key objective in the package, as energy savings are the easiest way of saving money for consumers and for reducing greenhouse gas emissions. The EU has set binding targets of reducing its energy consumption through improvements in energy efficiency by 2030 by at least 32.5%, relative to a 'business as usual' scenario.

According to political agreement by the Council and the European Parliament in 2018 and early 2019, EU countries have up to two years to transpose the new directives into national law. The *Clean Energy for all Europeans* package consists of eight legislative acts that aim to set the right balance between making decisions at EU, national and local levels. The package marks a significant step towards the implementation of the Energy Union strategy and explains the numerous benefits the new EU rules will provide. The changes will bring considerable consumer, environmental and economic benefits and provides an important contribution to the EU's long-term strategy of achieving carbon neutrality by 2050.

The *Clean energy for all Europeans* package includes a robust governance system for the Energy Union, through which each Member State is required to draft integrated and sustainable 10-year national energy and climate plans (NECPSs) up to 2030 and with a view towards 2050. As required under the rules, the

European Commission published an analysis of each draft plan with recommendations to be taken into account during 2019.

A further part of the package seeks to establish a modern design for the EU electricity market, adapted to the new realities of the market - more flexible, more market oriented and better placed to integrate a greater share of renewable. In addition to the legal acts in the *Clean energy for all Europeans* package, the Commission has started a number of non-legislative initiatives aimed at facilitating the clean energy transition and ensuring that it is fair transition.

The link to the publication of the full Clean Energy for all Europeans package can be viewed here.

3. REGIONAL CONTEXT

The following chapter describes the present Baltic Sea regional situation regarding the transmission grid, power generation, consumption and power flow exchanges, as well as the most-significant grid constraints among Baltic Sea region countries.

3.1 Present situation

3.1.1 The transmission grid in the Baltic Sea region

The Baltic Sea region comprises Sweden, Norway, Finland, Denmark, Estonia, Latvia, Lithuania, Poland and Germany. Within this region, there are three separate synchronous systems: the Nordic system, the Continental system, and the Baltic States power system, which is currently synchronous with the IPS/UPS system (Russia and Belarus). The synchronous areas are illustrated in Figure 3-1. Note that Denmark is divided between two synchronous areas: Denmark-East, which is a part of the Nordic system, and Denmark-West, which is the part of the Continental system.

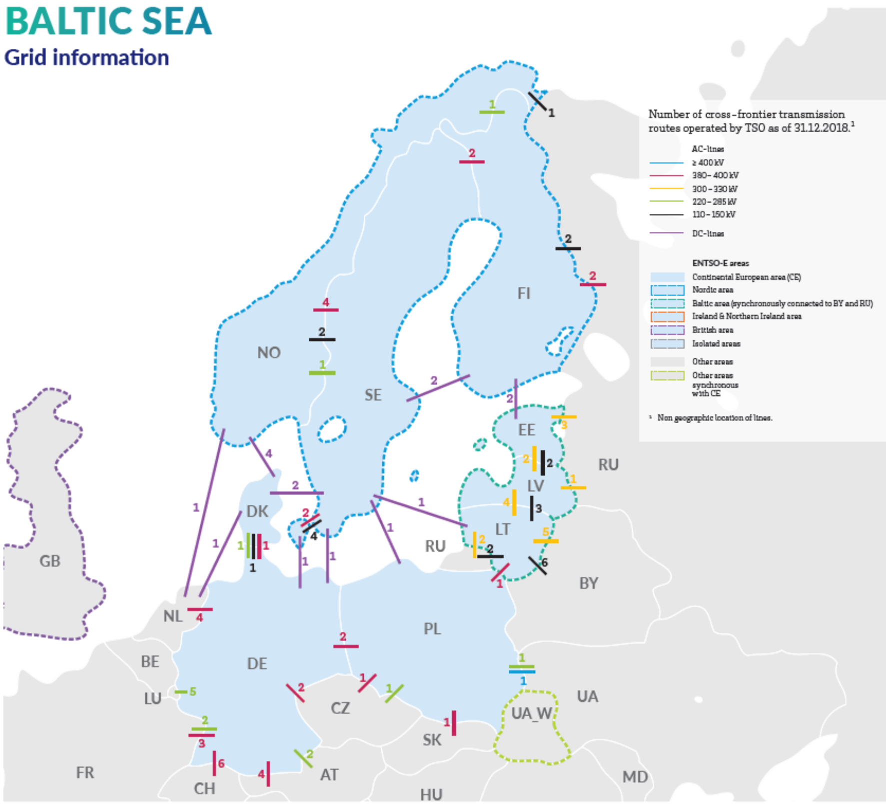


Figure 3-1 - Synchronous areas and existing interconnections in the Baltic Sea region

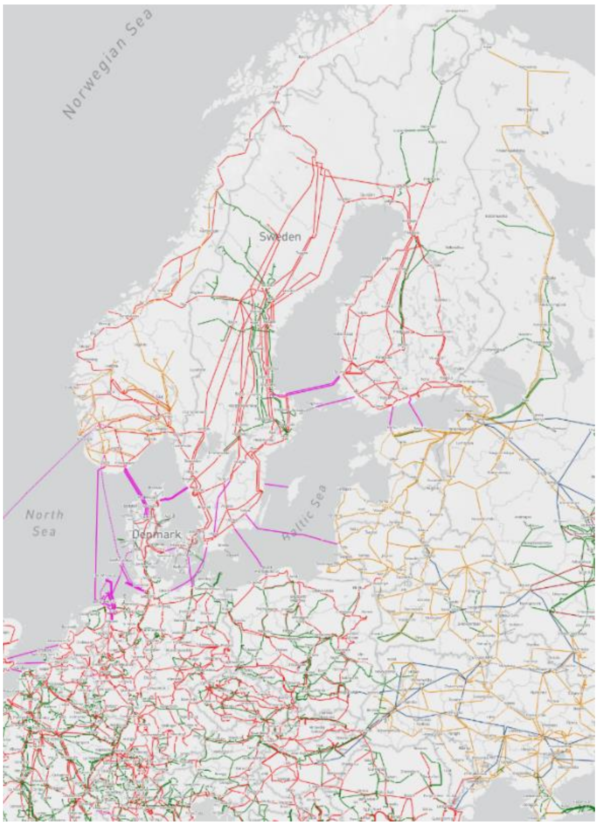
The Baltic States are currently in the same synchronous area with the Russian IPS/UPS power system and have several AC connections to both Russia and Belarus. However, Latvia and Estonia have no market exchange with Russia. Interconnection capacities between the Baltic States are strongly dependent on the operations of non-ENTSO-E countries; therefore, there is political motivation in the Baltic States to desynchronise from the IPS/UPS system and synchronise with the European system. The synchronisation project started on 28 June 2018 when the then European Commission President Jean-Claude Juncker together with the Heads of State or Government of Lithuania, Latvia, Estonia and Poland agreed on the Political Roadmap on the synchronisation of the Baltic States' electricity networks, with the Continental European Network via Poland, by the target date of 2025. In line with that Political Roadmap, the BEMIP High Level Group (senior-official level) on the synchronisation project, on 14 September 2018, agreed on the technical and economic feasibility of the synchronisation option. It consists in the existing double-circuit Alternating Current line between Poland and Lithuania (LitPol Link), complemented by the construction of an offshore High Voltage Direct Current link together with other optimisation measures, including synchronous condensers.

Transmission capacity plays a key role in addressing future power system challenges. Adequate transmission capacity allows for the cost-effective utilisation of power, ensures access to adequate generation capacity, enables the smooth exchange of system services, and is key to a well-integrated market. A cost-effective transition towards a green power system depends largely on the strength of the transmission networks.

Many new HVDC interconnectors since 2010.

Seven new interconnectors have been commissioned since 2010, which has increased total capacity by approximately 4450 MW. These new interconnectors are Skagerrak 4 (Norway-Denmark), Fenno-Skan 2 (Sweden-Finland), Estlink 2 (Estonia-Finland), Nordbalt (Sweden-Lithuania), LitPol link (Lithuania-Poland), Cobra (Denmark-The Netherlands) and the Kriegers Flak CGS (Denmark-Germany) project. Four new HVDC connections are planned to be commissioned in the region during the next five years. Preparatory works for construction of the Harmony link - HVDC link between Poland and Lithuania started in 2019 as a result of the Baltic synchronisation project.

The Interconnected HVAC network in the Baltic Sea region is illustrated in Figure 3-2 and is also found at https://www.entsoe.eu/map/. The Nordic and continental systems utilise 400kV AC as the main transmission voltage level and 220/130/110kV AC as sub-transmission voltage levels. In the Baltic States power system, the main transmission voltage level is 330kV. The map in Figure 3-3 shows the diverse level of Net Transfer Capacities (NTC) in the Baltic Sea region. The NTC is the maximum total exchange capacity in the market between two adjacent price areas.



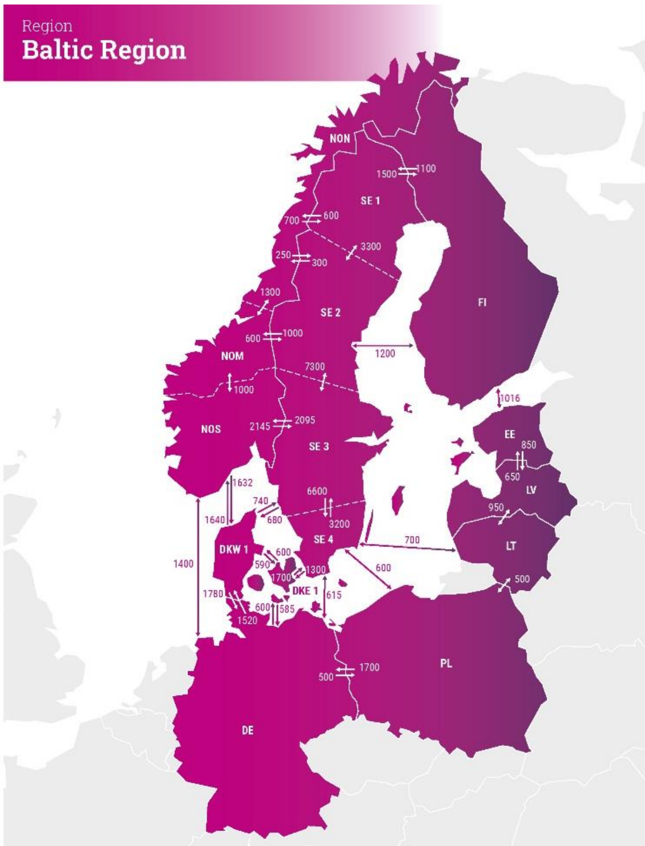


Figure 3-2 - Interconnected network of the Baltic Sea region	Figure 3-3 - NTCs in the Baltic Sea region

3.1.2 Power generation, consumption and exchange in the Baltic Sea region

The total annual power consumption in the Baltic Sea region is approximately 1100TWh, of which half is consumed in Germany. The peak load is much higher in winter than in summer due to colder weather and the high share of electric heating in the Nordic and Baltic countries. From 2010 up to 2018, peak load has only shown moderate growth in the region, while renewable generation capacity has greatly increased, as shown in Figure 3-4. Thermal fossil fuel-fired generating capacity has decreased in the Nordic countries, while it has slightly increased in continental Europe. German nuclear phase-out is also clearly visible in the figure.

The Continental and Nordic markets currently have sufficient thermal production capacity to cover demand during periods of low production from variable renewable sources or during dry years with low hydro production. Currently, all countries except Finland, Sweden and Lithuania have enough reliably available capacity to cover peak load without having to import from neighbouring countries. However, the trend in Denmark is also towards dependency on imports in peak load situations.

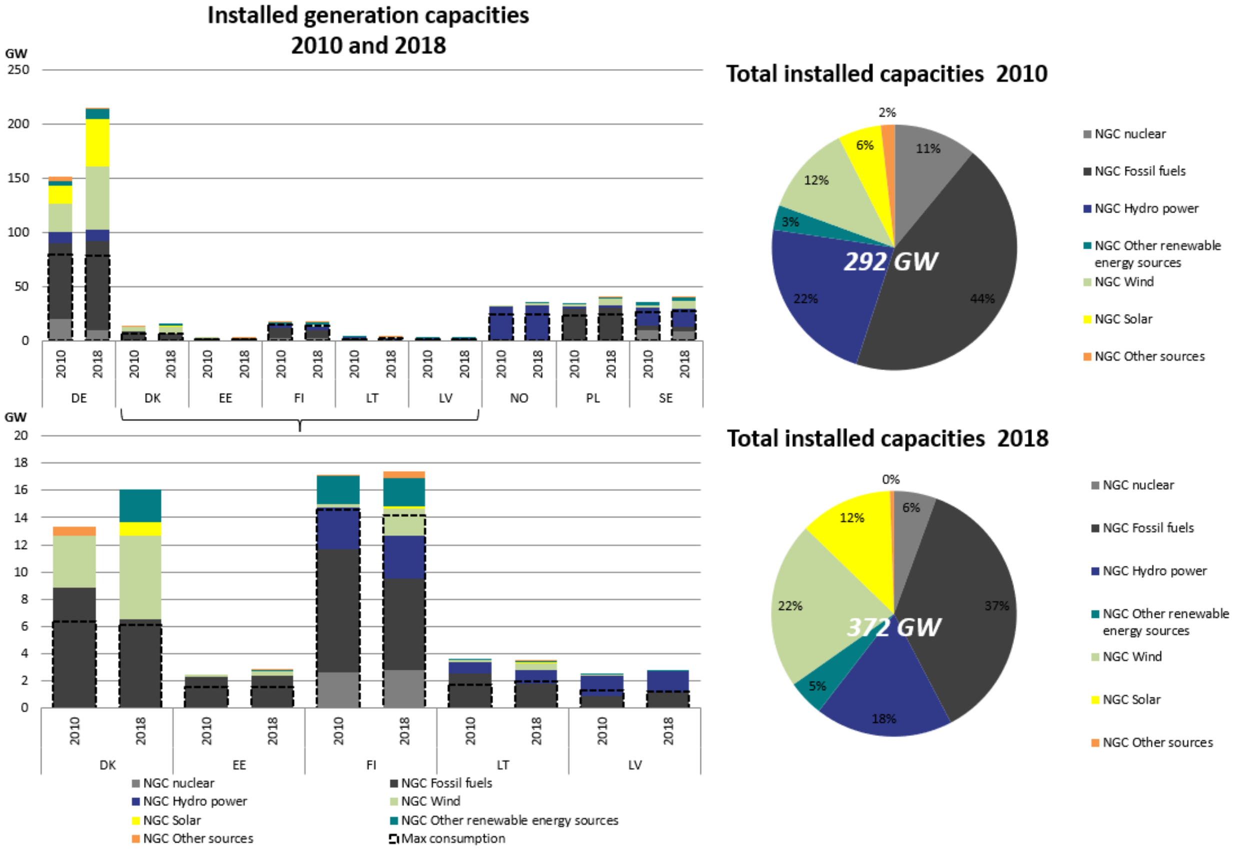


Figure 3-4 - Installed generation capacities by fuel type and maximum consumption in the Baltic Sea region in 2010 and 2018

The Nordic power system is dominated by hydropower, followed by nuclear, wind and combined heat and power (CHP). Most of the hydropower plants are located in Norway and northern Sweden and the nuclear power plants are located in southern Sweden and Finland. During a year with normal inflow, hydropower represents approximately 50% of annual electricity generation in the Nordic countries, but variations between wet and dry years are significant. For Norway, the variations can be almost 60 - 70TWh between a dry and wet year. Consumption in the Nordic countries is characterised by a high amount of electrical heating and energy intensive industries. The power balance in the region is positive in a normal year but varies significantly between wet/warm and dry/cold years. Sweden and Norway have an energy surplus, whereas Finland has an energy deficit and is dependent on imports. The development of generation and demand in the Baltic Sea region is shown in Figure 3-5.

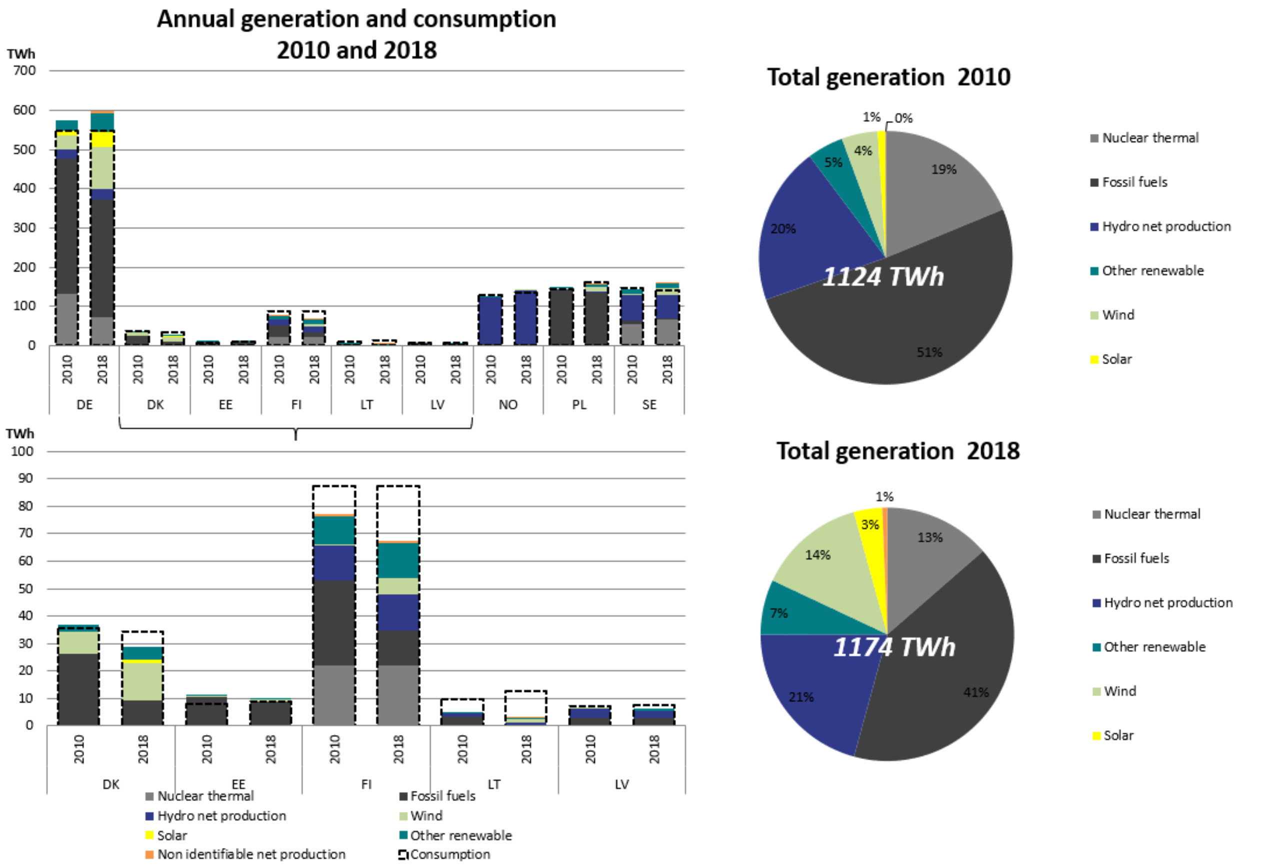


Figure 3-5 - Annual generation by fuel type and annual consumption in the Baltic Sea region in 2010 and 2018

Power production in the continental part of the Baltic Sea region and the Baltic States area is dominated by thermal power, except in the Danish power system, which is dominated by wind and other renewable energy sources (RES) and accounts for more than 60% of consumption. Consumption in the area is less temperature-dependent than that of the Nordic countries. Denmark, Poland, Estonia and Latvia have a neutral annual power balance during an average year, whereas Germany has a yearly surplus. Lithuania, on the other hand, is currently operating with a large energy deficit. The massive increase in RES generation in Germany has replaced nuclear production, but has only slightly decreased fossil fuel-based generation while significantly increasing exports.

Cross-border flows in 2018 are shown in Figure 3-6 and the development in cross-border exchanges from 2010-18 is presented in Figure 3-7. The largest exchanges are from Norway, Sweden and Germany to neighbouring countries, while the largest increases in power flow during 2010-18 are from Sweden to Finland and from Germany to the Netherlands. In the Nordic countries, the flow pattern varies a lot from year to year as a result of variations in hydrological inflow (both 2010 and 2018 were dry years, but 2010 was drier). In wet years, exports from Sweden and Norway are typically much larger than during dry years. In addition, Finnish imports from Russia have decreased as a result of a new market design in Russia, which significantly increases the price of exports during peak hours. In practice, this has limited Finnish imports to nights and weekends.

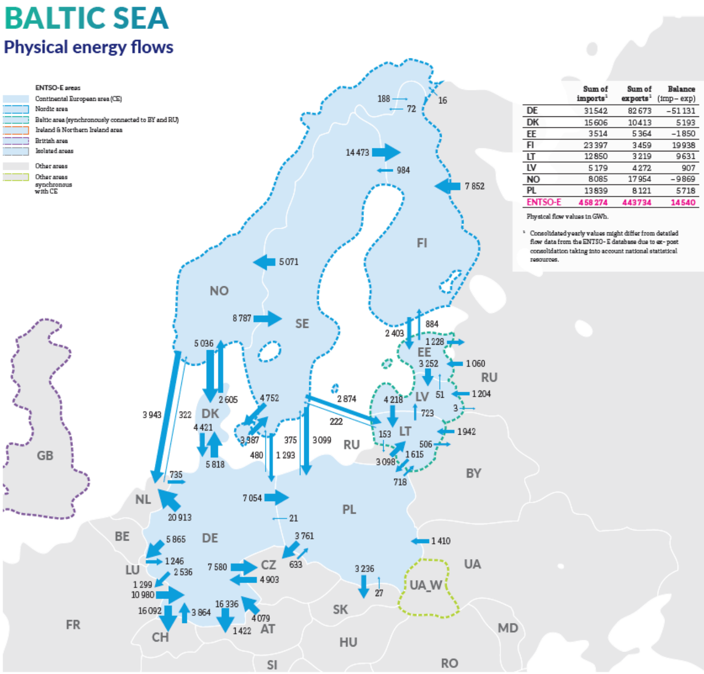


Figure 3-6 - Cross-border physical energy flows (GWh) in the Baltic Sea region in 2018

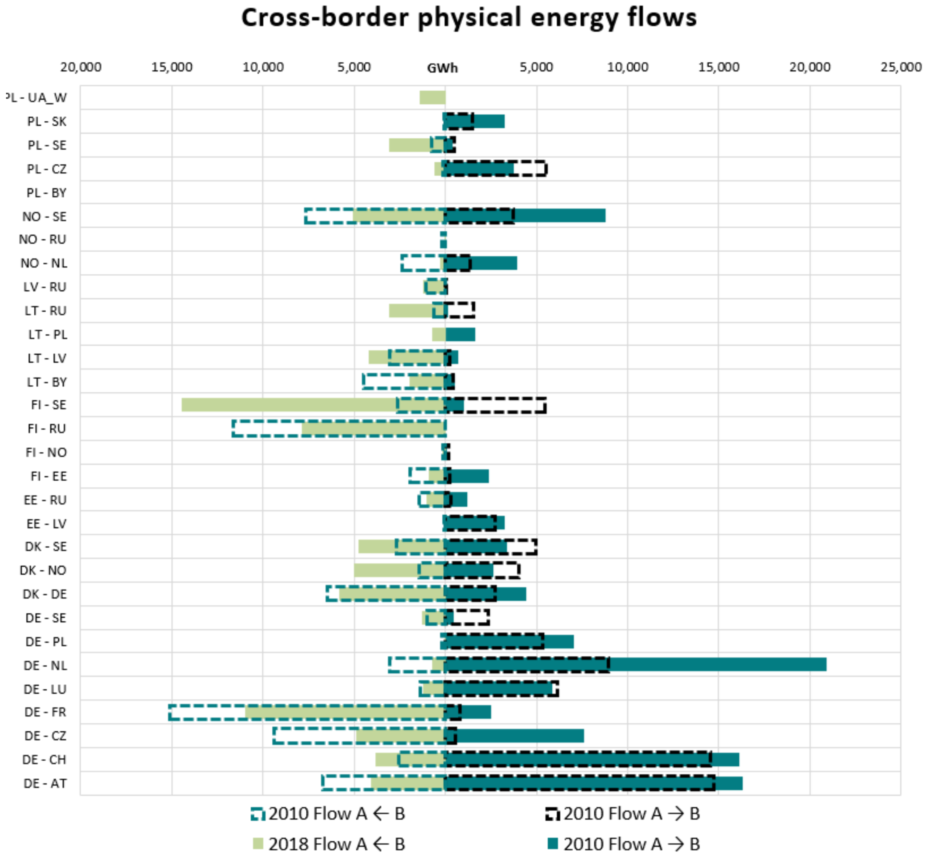


Figure 3-7 - Cross-border physical energy flows (GWh) in the Baltic Sea region in 2010 and 2018

3.1. Grid constraints in the Baltic Sea region

Figure 3-8 illustrates the price differences between market areas in the Baltic Sea region during 2019 and 2020. The Figure shows two cases when the price difference is €2/MWh and €5/MWh. The average amount of bottleneck hours between price areas is dependent on the weather conditions during the period under observation. Looking at 2019-20, this was a normal year throughout the whole Nordic region, which indicates the normal average flow of electricity from the northern hydro reservoir areas to the south. A normal year means that the annual amount of precipitation is somewhere between dry and wet years, with no very high-water inflow on hydro generation being observed. During the wet years the increased power flow results in the increased amount of bottleneck hours, for example, between northern Norway and Sweden.

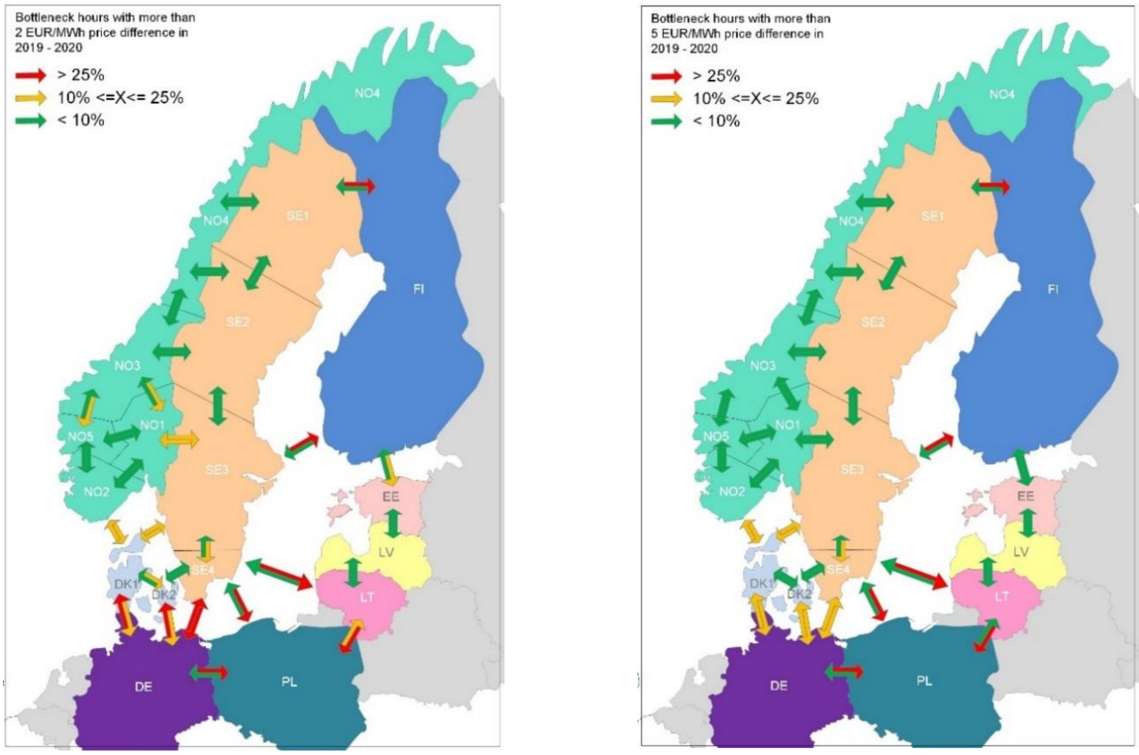


Figure 3-8 - Percentage of hours with different market prices per market area border and direction

Some of the typical situations that can occur due to grid constraints today, which are also visible in Figure 3-8, are:

- bottlenecks between Sweden and Finland, in the direction towards Finland;
- bottleneck on the Lithuania-Poland cross-border, resulting in higher prices for Poland and a weak connection between the Baltic States and Continental Europe;
- bottlenecks around Poland and Germany, that can't reduce the price in Continental European countries;
- limitations on transmission capacities between Germany and Denmark, Germany and Sweden and Germany and Poland; and
- internal bottlenecks in Norway and Sweden, which can lead to lower prices or even hydropower spillage in cases of high reservoir levels and high inflows, such as during a wet year in Norway.

3.2 Description of the scenarios

The scenarios in which the studies in this report have been performed are presented in this chapter. First, the expected changes in the generation portfolio of the region are explained, followed by a description of the pan-European TYNDP scenarios as well as the regional scenarios. The regional scenarios are created and used in the studies to highlight the regional specifics.

The TYNDP 2020 Scenario edition published in June 2020 represents the first step in quantifying the long-term challenges of the energy transition on European electricity and gas infrastructure.

The joint work of ENTSO-E and ENTSOG, stakeholders and over 80 TSOs covering more than 35 countries, provided a basis to allow assessment for the European Commission's Projects of Common Interest (PCI) list for energy, as ENTSO-E and ENTSOG progress to develop their respective TYNDPs.

We strongly recommend the reader familiarises themselves with the content included in the Scenario Report and visualisation platform, as these will provide full transparency on the development and outcomes of the scenarios mentioned in this report.

Scenario Storylines

The joint scenario building process presents three storylines for TYNDP 2020:

- **National Trends (NT),** the central policy scenario, based on Member States National Energy and Climate Plans (NECPs) as well as on EU climate targets. NT is further compliant with the EU's 2030 Climate and Energy Framework (32% renewables, 32.5% energy efficiency) and the European Commission's 2050 Long-Term Strategy with an agreed climate target of 80-95% CO2 reduction compared to 1990 levels.

- **Global Ambition (GA),** a full energy scenario in line with the 1.5ºC target of the Paris Agreement, envisions a future characterised by economic development in centralised generation. Hence, significant cost reductions in emerging technologies such as offshore wind and Power-to-X are led by economies of scale.

- **Distributed Energy (DE**), a full energy scenario also compliant with the 1.5ºC target of the Paris Agreement, presents a decentralised approach to the energy transition. In this scenario, prosumers actively participate in a society driven by small scale decentralised solutions and circular approaches. Both Distributed Energy and Global Ambition reach carbon neutrality by 2050.

Figure 3-9 - Key parameters for the scenario storylines

Bottom-Up: This approach of the scenario building process collects supply and demand data from gas and electricity TSOs.

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 a Carbon Budget approach.

Full energy scenario: A full energy scenario employs a holistic view of the European energy system, thus capturing all fuel and sectors as well as a full picture of primary energy demand.

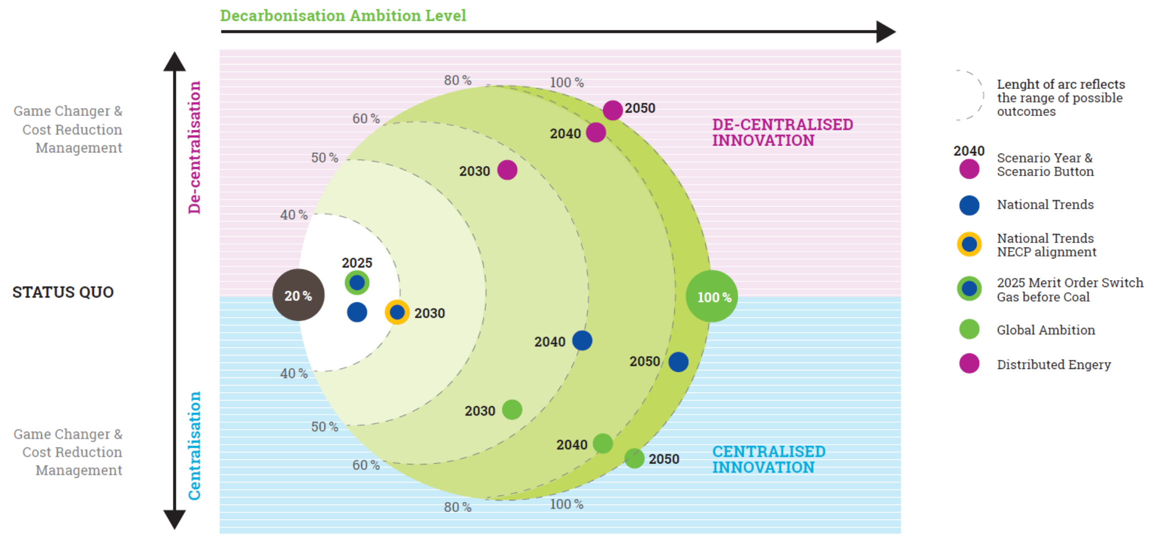


Figure 3-10 - Key drivers of scenario storylines

3.2.1 Selective description of electricity results

To comply with the 1.5°C target of the Paris Agreement, carbon neutrality must be achieved by 2040 in the electricity sector and by 2050 in all sectors

Distributed Energy and Global Ambition (also referred to as 'COP 21 Scenarios') are meant to assess sensible pathways to reach the target set by the Paris Agreement during COP 21: 1.5°C or at least well below 2°C by the end of the century. For the purpose of the TYNDP scenarios, this target has been translated by ENTSO-E and ENTSOG into a carbon budget to stay below +1.5°C at the end of the century with a 66.7% probability.

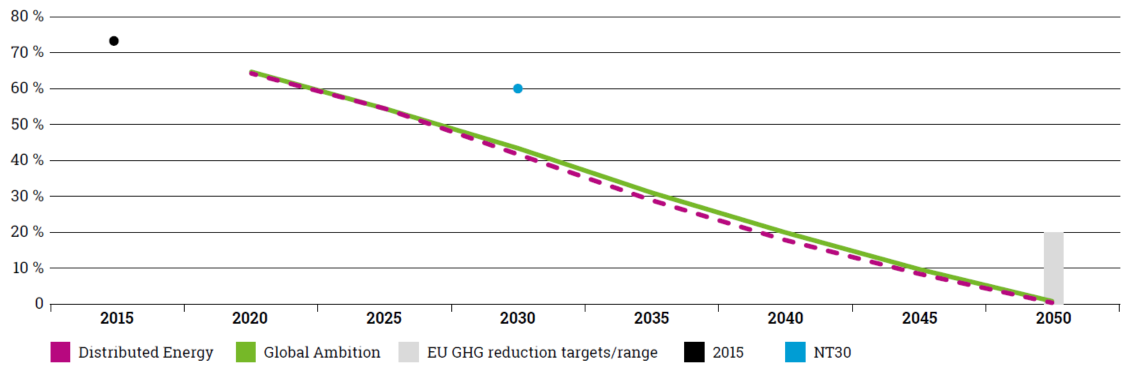


Figure 3-11 - GHG Emissions in ENTSOs' Scenarios

To optimise conversions, the direct use of electricity is an important option resulting in progressive electrification throughout all scenarios

The scenarios show that higher direct electrification of final use demand across all sectors results in an increase in the need for electricity generation.

Distributed Energy is the scenario storyline with the highest annual electricity demand hitting around 4300TWh by 2040. The results for scenarios show there is the potential for year on year growth in the EU28 for direct electricity demand. Figure 3-12 provides annual EU28 electricity demand volumes and the associated growth rate for the specified periods.

The growth rates for the storylines show that by 2040, National Trends is centrally positioned in terms of growth between the two more-ambitious top-down scenarios Distributed Energy and Global Ambition. The main reason for the switch in growth rates is due to the fact that Global Ambition has the strongest levels of energy efficiency, whereas for Distributed Energy strong electricity demand growth is linked to high electrification from strong uptake of electric vehicles and heat pumps, dominating electrical energy efficiency gains.

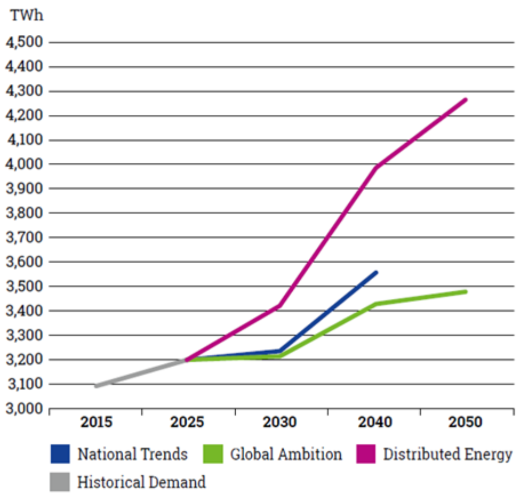


Figure 3-12 – Direct Electricity Demand per Scenario (EU28)

In the COP 21 Scenarios, the electricity mix becomes carbon neutral by 2040

In the EU28, electricity from renewable sources meets up to 64% of power demand in 2030 and 83% in 2040. Variable renewables - wind and solar - play a key role in this transition, as their share in the electricity mix grows to over 40% by 2030 and over 60% by 2040.

The remaining renewable capacity consists of biofuels and hydro. All figures stated above exclude power dedicated for P2X use, which is assumed to be entirely from curtailed RES, and newly build renewables that are not grid-connected, and therefore not considered in this representation.

To move towards a low carbon energy system, significant investment in gas and electricity renewable technologies is required

Distributed Energy is the scenario with the highest investment in generation capacity, driven mainly by the highest level of electrical demand. Distributed Energy mainly focuses on the development of Solar PV. This technology has the lowest load factor, as a result Solar PV installed capacity will be higher compared to offshore or onshore wind, to meet the same energy requirement. The scenario shows a larger growth in Onshore Wind after 2030. In 2030, 14% of electricity is produced from Solar and 30% from wind, 44% in total. In 2040 18% of the electricity is generated from solar and 42% from wind 60% in total. The scenario also sees the least amount of electricity produced from nuclear out of the three scenarios, providing 16% of electricity in 2030 and 10% in 2040.

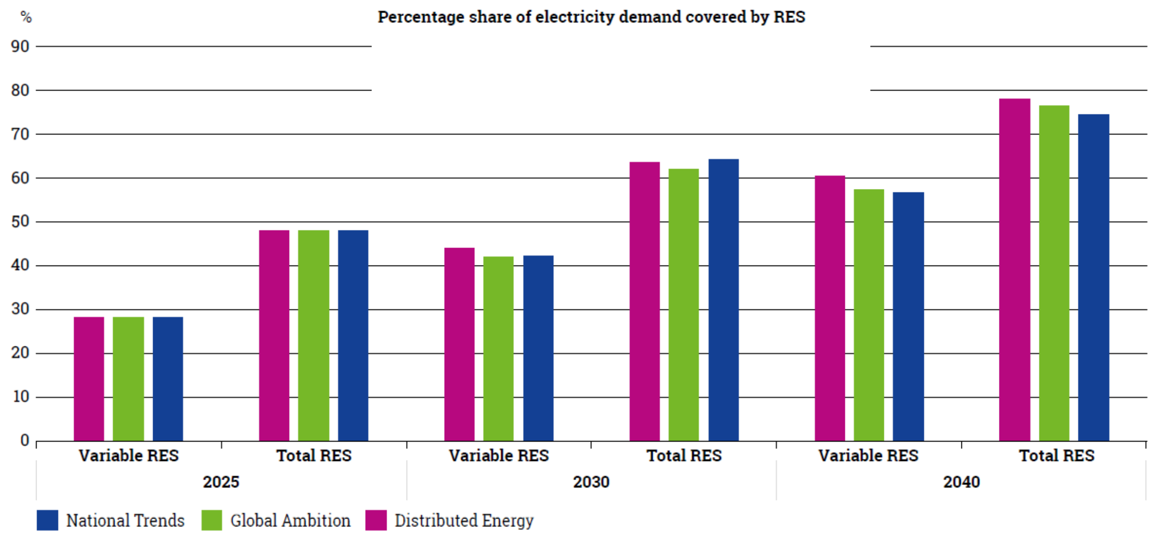


Figure 3-13 - Percentage share of electricity demand covered by RES

Global Ambition has a lower electricity demand, with a general trend of higher nuclear and reduced prices for offshore wind. Consequently, the capacity required for this scenario is the lowest as more energy is produced per MW of installed capacity in offshore wind, and nuclear is used as baseload technology providing 19% of energy in 2030 and reducing to 12% in 2040. In 2030, 10% of electricity is produced from Solar and 32% from wind, 42% in total. In 2040 13% of the electricity is generated from solar and 45% from wind, 58% in total.

National Trends is the policy-based scenario. The variable renewable generation is somewhere between the two top-down scenarios. In 2030, 12% of electricity is produced from solar and 30% from wind, 42% in total. In 2040 14% of the electricity is generated from solar and 42% from wind, 56% in total. A lot of electricity is still produced from nuclear in 2030, 17% reducing to 12% in 2040.

Shares of coal for electricity generation decrease across all scenarios

This is due to national policies on coal phase-out, such as those stated by the UK and Italy or planned by Germany. Coal generation moves from 10% in 2025, to 4%-6% in 2030 and negligible amounts in 2040 which represents an almost complete phase out of coal.

Considerations on other non-renewables (mainly smaller scale CHPs) sources are important for decarbonisation

As it stands, carbon-based fuels are still widely used in CHP plants throughout Europe. This includes oil, lignite, coal and gas. In order to follow thermal phaseout storylines, oil, coal and lignite should be phased out by 2040 and replaced with cleaner energy sources. Gas will contribute to decarbonisation by increasing shares of renewable and decarbonised gas.

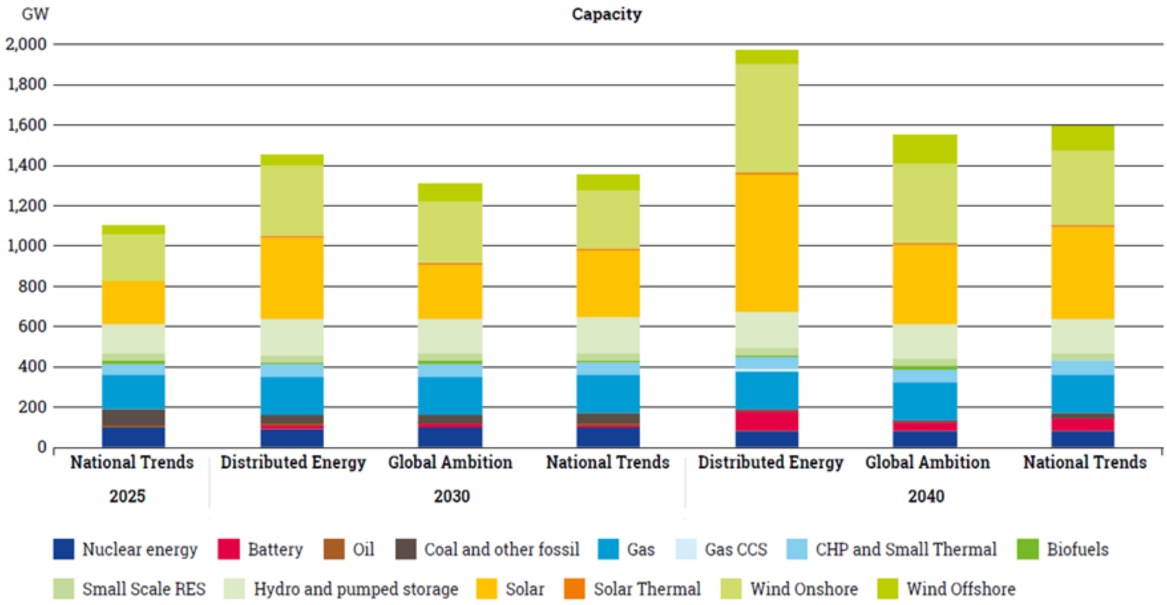


Figure 3-14 - Electricity Capacity mix

Sector Coupling - an enabler for (full) decarbonisation

For ENTSO-E and ENTSOG, sector coupling describes interlinkages between gas and electricity production and infrastructure. Major processes in this regard are gas-fired power generation, Power-to-Gas (P2G) and hybrid demand technologies. TYNDP 2020 scenarios rely on the further development of sector coupling, without these interlinkages, high or even full decarbonisation in the energy sector will not be reached.

Assuming a switch from carbon-intensive coal to natural gas in 2025, 150MtCO2 could be avoided in power generation. With increasing shares of renewable and decarbonised gases, gas-fired power plants become the main 'back-up' for variable RES in the long-term. Distributed Energy even shows a further need for Carbon Capture and Storage (CCS) for gas power plants to reach its ambitious target of full decarbonisation in power generation by 2040.

On the other hand, P2G becomes an enabler for the integration of variable RES and an option to decarbonise the gas supply. Hydrogen and synthetic methane allow for carbon-neutral energy use in the final sectors. Distributed Energy is the scenario with the highest need for P2G, requiring about 1500TWh of power generation per year with 493GW of capacities for wind and solar in 2040 to produce renewable gas. Sector coupling in National Trends, with the assumption that P2G generation is limited to 'curtailed electricity', considers 12TWh of power generation with 22GW of P2G to produce renewable gas.

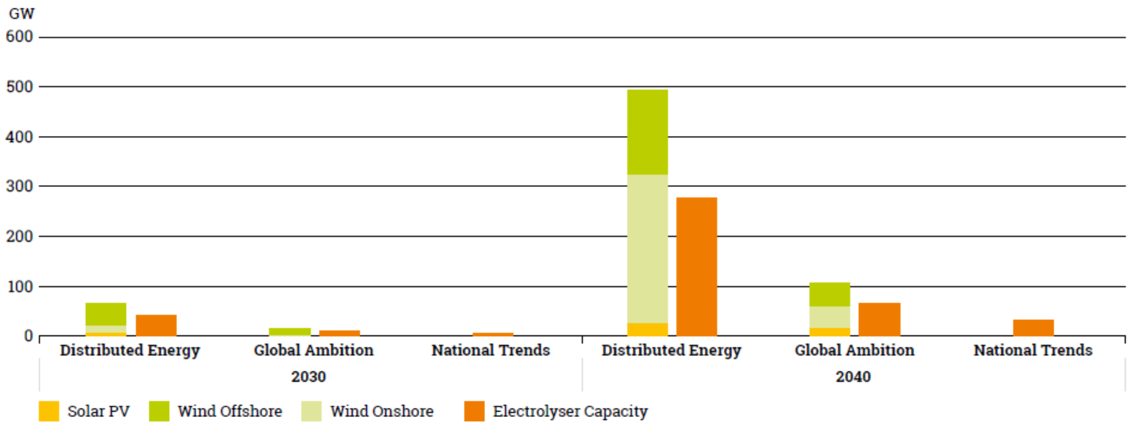


Figure 3-15 - Capacities for hydrogen production

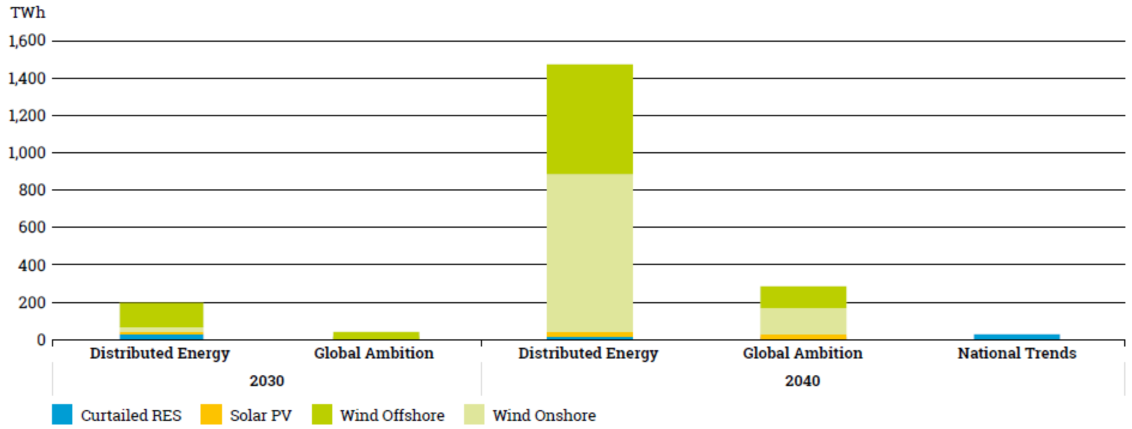


Figure 3-16 - Power to Gas generation mix

3.2.2 Key findings of the scenarios for the Baltic Sea region.

The main drivers for change in the regional generation portfolio are explained in this chapter as a basis for the regional scenarios. The challenges expected due to these changes are then elaborated on in Chapter 3.2.3. The main drivers of change in the Baltic Sea region relate to climate policy, which stimulates the development of more RES and a common European framework for the operation and planning of the electricity market. The main structural changes in the Baltic Sea region power system in the future, relate to the following:

- Strong increase in RES generation
    - The increased share of wind power - onshore and offshore - and solar PV in the power system is shown in all scenarios
    - Additional wind power generation mainly located in the northern and middle part of the region, which is located farther away from the load centres with large amounts planned for construction in the middle and southern part of the region

    - PV capacity to be mainly increased in the middle and southern part of the region
- Reduction of thermal power capacity
    - Decommissioning of old lignite, hard coal and oil-fired power plants
    - Full decommissioning of all nuclear power plants in Germany by the end of 2023
    - Decommissioning of four nuclear units in Sweden, with a total capacity of 2900MW being decommissioned in the period 2015-20. The remaining six units are expected to reach the end of their technical lifetime around 2040
- New large generating units
    - New nuclear capacity is being built in Finland, with one unit of 1600MW, planned to be commissioned in 2020 and another plant of 1200MW, planned for commissioning in 2028
    - Large wind power generation units are planned in the whole BS region

- Slight increase of storage technologies - hydro-pump storages, battery - in all scenarios to integrate the flexible RES power generation
- Remarkable increase of capacities for hydrogen production, mainly in the scenarios DE 2030/2040 and GA 2040.
- Visible increase of capacities for Power to gas generation, also mainly in the scenarios DE.

Growing share of variable renewable generation

The historical development of renewable generation is based on subsidies. Lower development costs, gradually improved solar cell efficiency and increasingly larger wind turbines with a higher number of full-load hours, will reduce the overall costs per MWh for both solar and wind power. Today, solar power and wind power, if located favourably, can be profitable without the need for subsidies. This results in changes in geographical distribution, as it is more profitable to develop solar and wind power in the locations with the best conditions and the lowest costs. For example, there is much interest in greater development in the Nordic and Baltic regions, which have some of the best wind resources in Europe. Development can proceed very rapidly, with some market participants already planning to build new wind turbines without subsidies.

Nuclear phase-out continues in Sweden, while Finland builds new capacity

Nuclear power in Sweden and Finland plays a key role in the Nordic power system. Annually, it represents 25% of overall power generation in the Nordic countries. Nuclear power delivers a stable and predictable baseload near consumption centres and their contribution during dry years is important. Moreover, the power plants contribute stability to the Nordic grid, and many of the power plants are also strategically located in areas where they can fully support the capacity of the power grid.

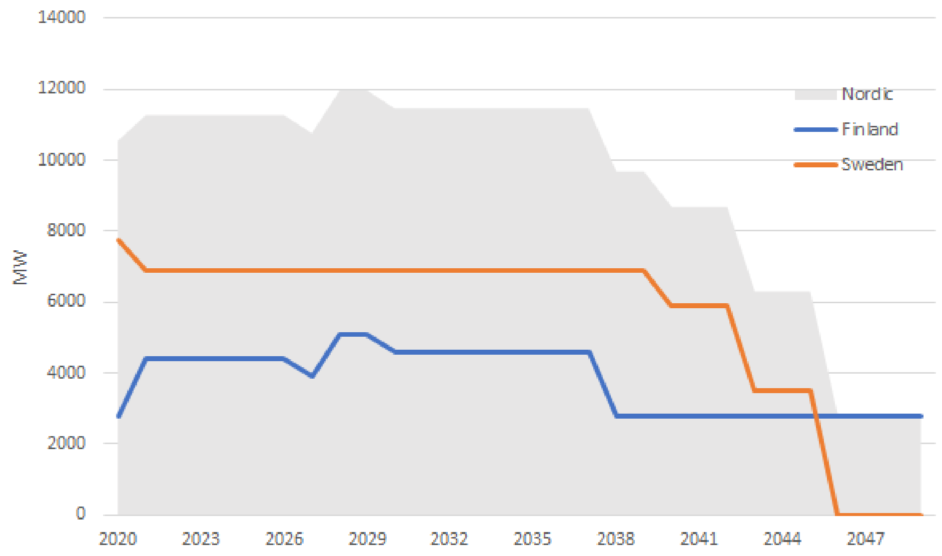


Figure 3-17 - Expected developments in Nordic nuclear power capacity from 2020 to 2050 used in the scenario-building based on an expected lifetime of 50 to 60 years

The further development of nuclear power in Sweden and Finland is a key uncertainty in the Nordic power system and the market. All the current active reactors started operating between 1972 and 1985, with a planned lifetime of 50 to 60 years. Swedish nuclear power plants have been under financial strain in recent years due to low power prices, increased taxes and high capital costs from earlier investments in maintenance and capacity extension. As a result, four reactors with a total capacity of 2900MW could be shut down as early as 2020. This means that energy generation will decline from 65TWh a year currently to approximately 50TWh. Furthermore, Swedish energy policy from the summer of 2016 includes the decision to remove the special tax on output, which had a severe impact on nuclear power.

In Finland, however, there is political support for further investment in nuclear power. In 2014, the authorities granted a licence to Fennovoima for the construction of a new nuclear plant in northern Finland called Hanhikivi 1. This means that overall installed capacity for Finnish nuclear power will increase from about 2,700 MW today to a peak of almost 5,500 MW after 2025. In Finland, Olkiluoto 3 will be in operation before any older nuclear plants are decommissioned. Realisation of the Hanhikivi 1 NPP would keep nuclear production in Finland at the pre-decommissioning level, but it will require extra grid investments, as it is planned to be built at a different location to the existing NPPs.

Reduced utilisation hours for thermal capacity and flexibility needs

The Continental and Nordic markets currently have sufficient thermal production capacity to cover demand during periods of low production from variable renewable sources, or during dry years with low hydro production. The increasing share of variable renewables reduces both the usage and profitability of thermal plants, and a significant share of thermal capacity will probably be shut down. This will, in turn, reduce the capacity margin (the difference between the available generation capacity and consumption) in the day-ahead market and will give tighter margins. This type of situation is particularly observed in Poland, where the capacity margin decreases drastically with the increase in installed RES in the country's system.

The high percentage of hydro production with reservoirs in the Nordic region provides large volumes of relatively cheap flexibility, both in the day-ahead market and during operational hours. In addition to hydropower, flexible coal and gas power plants also provide both long-and short-term flexibility, though at a higher cost than hydropower. Until now, the flexibility from hydro plants with reservoirs has been enough to cover most of the flexibility needed in Norway and Sweden, as well as a significant proportion of the flexibility demand in Denmark, Finland and the Baltic countries. This has resulted in relatively low-price volatility in the day-ahead market and in the balancing of costs. A higher market share of variable renewables will be the main driver of increased demand for flexibility because the flexibility provided by existing hydro plants is limited and thermal capacity is declining.

3.2.3 Technical challenges of the power system

There are two significant changes in the Baltic Sea region that challenge the power system operation and technical setup.

The major influence comes from the increasing share of RES in the generation portfolio, especially converter coupled generation modules - so called power park modules by definition of EU grid code RfG (Requirements for Generators. 'Power Park Module' (PPM) means a unit or ensemble of units generating electricity, which is either non-synchronously connected to the network, or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system or HVDC system (Article 2(17) of the Network Code on Requirements for Grid Connection of Generators (NC RfG))[1].

Due to converter coupling to the system and the variable character of RES based generation, the power park modules behave, in some important respects, differently than the conventional synchronous generators that have dominated since power systems were created. But their share is decreasing significantly, and at some future point we may see an exponential increase in the power park module type of generation and the rest of the system should be ready for that.

The second big technical challenge primarily influences the Baltic States and it is related to the Baltics power system synchronisation with the Continental Europe synchronous area. A more specific technical solution and plan is described in the separate Synchronisation project in Chapter 5.1. Regarding technical challenges to Baltics synchronisation project brings several new technical and system characteristic changes. Baltics separately is rather small power system with peak load roughly around 5GW. The Baltic power system historically is operated as part of the Russian power system IPS/UPS and the share of the responsibilities have been divided differently comparing to the EU system operation. In the Russian system the frequency is controlled centrally, while in the EU the responsibility is shared proportionally among the members connected to the same synchronous area.

Due to technical solution of the future synchronous interconnection between Lithuania and Poland there is a small but still considerable probability that the Baltics could be disconnected from the Continental synchronous system and stay in the island operation mode, due to an exceptional contingency when could trip the only one double-circuit high-voltage 400kV overhead line which is connecting the Baltics with the rest of Europe. This situation can be handled but it represents a significant technical challenge that will require additional technological investment in enabling sufficient system inertia and limiting RoCoF (Rate of Change of Frequency) on an acceptable level and allowing superfast activation of countermeasures to restore the system balance and frequency stability.

[1] *Source (footnote): https://www.emissions-euets.com/internal-electricity-market-glossary/830-power-park-module-ppm*

Technical challenges brought forward by increases in RES generation, and identified by TSO experts include:

- Frequency stability issues, due to reduced inertia, increased deviation range and ramp rate of generation and larger contingencies;
- Voltage stability issues, due to longer transmission paths and reduced voltage control near load centres; and
- Angular stability issues, due to reduced minimum short circuit current levels.

New interconnections are part of the solution when it comes to providing flexibility, while other factors such as energy and electricity storage and demand response can also help balance energy levels. From a dynamic stability perspective, the flexibility needed to keep the power system running when penetration of synchronous machines is reduced, can be provided by RES generation units, using flexible AC transmission (FACTS) devices, controlling HVDC links and using solutions such as dynamic line rating and special system protection schemes. Decreases in inertia, short circuit power and voltage regulation near load centres are a few of the main issues that must be solved as the generation portfolio becomes increasingly CO2 free.

Decreased inertia

One of the major challenges identified is the decrease in inertia when synchronous generation reduces, and converter-connected generation increases within the system. Inertia is the kinetic energy stored in the rotating masses of machines, and the inertia of a power system resists the change in frequency after a step change in generation or load. Figure 3-19 shows the impact of change in inertia to a frequency response of the system after loss of generation.

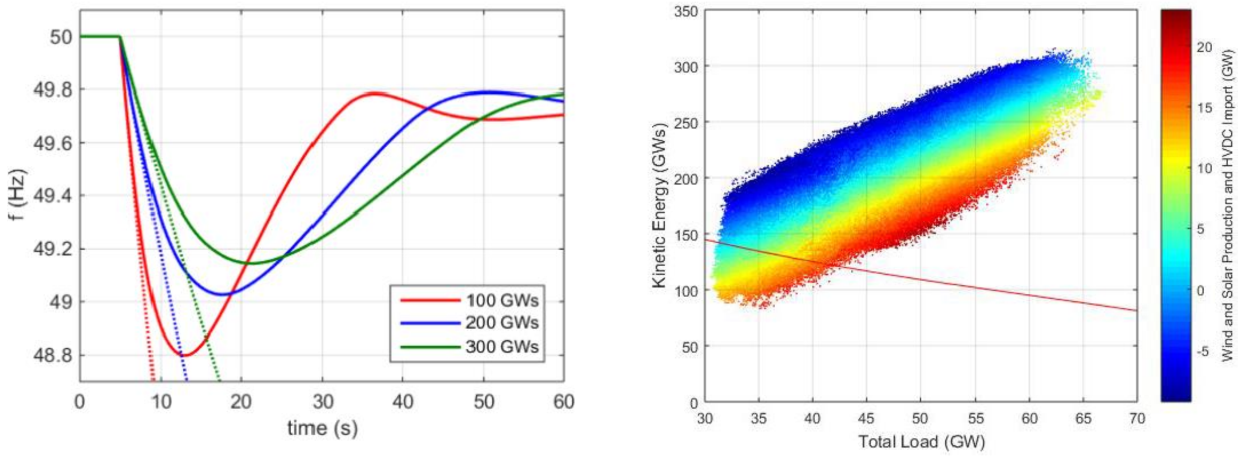


Figure 3-19 - On the left, the effect of the amount of kinetic energy (inertia) on the behaviour of frequency after a loss of production with (solid line) and without (dotted line) the Frequency Containment Reserve (FCR).[2] On the right, the estimated kinetic energy in 2025 as a function of total load in the synchronous area with wind and solar production and HVDC import including all the climate years (1962–2012) of the market simulation scenario. The red line shows the required amount of kinetic energy[3]

[2] *https://www.entsoe.eu/Documents/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf*
[3]*https://www.svk.se/contentassets/9e28b79d9c4541bf82f21938bf8c7389/stet0043_nordisk_rapport_hele_mdato1.pdf*

Too little inertia can lead to frequency instability, where a sudden change in generation and load balance can lead to unacceptable frequency deviation and potentially further lead to cascading tripping in the system elements, leading to possible blackouts - in worst-case scenarios. The low inertia situation is only expected in the Nordic synchronous system in the medium term, and in case of island operation, also in the Baltic system. The amount of inertia in future Nordic synchronous power systems has been analysed by the Nordic TSOs and is illustrated in Figure 3-19. More detailed information about the inertia issue is given in the ENTSO-E publication entitled 'Nordic Report Future System Inertia'.[4]

One of the possibilities to compensate for the decrease in system inertia is to provide a temporary, fast-response active power injection from the wind production units, decoupled from the grid with converter technology. The temporary boost of active power support following a sudden decrease in frequency could be achieved by utilising the kinetic energy stored in the wind turbine rotors and generators. Reaction time and control is not instantaneous, but with today's advanced power electronics it should be fast enough to support the system and to avoid sudden frequency drops. The problem with this control could be a slight decrease in power output after utilising the stored kinetic energy of the rotating turbines, as the wind turbine blades are not rotating with the optimal speed necessary for achieving maximum production at certain wind speeds. Maximum output will usually be restored in a very short time (several tens of seconds) after the synthetic inertia has been used. In case of further RES increases, synthetic system inertia as a basic function for rotating RES units decoupled through power electronics could be considered.

Decreased voltage regulation near load centres

Large amounts of planned wind power production are located far from load centres where the conventional units are, and have been, located. A large extension of reactive power compensation devices is expected due to the longer distance of transmission of power required, and the decreased dynamic voltage support, from conventional units. For example, in the Nordic countries, wind power from the northern areas need to be transmitted to load centres close to large cities in southern areas. Similarly, in Germany, wind power from northern areas needs to be transmitted to load centres in the southern part of the country.

Decreased minimum short circuit power

Directly connected synchronous generators provide short circuit current and voltage support regulation during faults that are necessary for the normal operation of certain types of converter technologies, to avoid commutation failures. Insufficient short circuit power support might lead to a tripping of the line commutated converters (LCC), which are technology-based converters. Furthermore, when the penetration level of converter-connected power generators is very high, the form of the fault current is determined by the controls of the converters and not by the short circuit output of rotating machines, which can cause issues with the protection devices that are designed to work in a system based on synchronous machines. When designing future power systems, those technical issues should be studied in more detail, and sufficient countermeasures need to be taken into account, based on the results.

[4] *https://www.entsoe.eu/Documents/Publications/SOC/Nordic/Nordic_report_Future_System_Inertia.pdf*

4. REGIONAL RESULTS

This chapter illustrates and explains the results of the regional studies and is divided into two sections. Subchapter 4.1 provides future capacity needs, revealed during the Identification of System Needs (IoSN) process, while subchapter 4.2 provides the detailed outcomes of market results from the IoSN study.

4.1 Future capacity needs

The Baltic Sea region's energy system is undergoing a transformation. Over recent years, onshore wind capacity has developed at an increasing rate. More recently, in parts of the region, offshore wind generation has been developed in significant quantities. The development of renewable generation, alongside existing hydro generation, provides the region with increased amounts of 'clean' energy. In addition, thermal generation may be phased out to a large extent. Finally, nuclear generation is undergoing major restructuring, being decommissioned in Germany, while in Sweden some nuclear units has been decommissioned due to economic reasons, remaining capacity is expected to be available until around 2040 when the technical lifetime is reached. All the above generation changes are assumed to increase in the future. In addition, electricity consumption is undergoing a transformation, both regarding electrification in industry and transportation as well as consumers becoming part of the production system themselves as prosumers.

To be able to analyse future capacity needs, different scenarios have been developed. Potential changes in both generation and consumption are described in the first phase of the TYNDP 2020 process, building new scenarios for 2030 and 2040 and assessing system needs for the long-term 2040 horizon. As part of this work, cross-border capacity increases, having a positive impact on the system, have been identified for the National Trend scenario in one climate year. A European overview of these increases is presented in the European System Needs report (IoSN), developed by ENTSO-E, in parallel with the Regional Investment Plans (RegIPs). In Figure 4-1, projects already part of the TYNDP 2020 reference grid are shown. Projects categorised as 'Under construction and 'In permitting' are part of Reference Grid 2025 and are assumed built by 2025. In figure 4-2 the identified capacity-increases between 2030 and 2040 for the Baltic Sea region are shown. The figure is based on the pan-European System Needs analyses 2040 and assumes that Reference Grid 2025 is already realised. Moreover, this figure also shows the effect for those boundaries where another IoSN grid solution would have similar benefits, that are not part of the IoSN SEW-based Needs solution. This so called 'upper bound' capacity do not represent an alternative grid solution, but a different combination of increased boundaries capacity, which would lead to only slightly more expensive benefits. Not all 'upper bound' capacity increases can be added to the IoSN SEW-based Needs solution at the same time. However, adding one or two provides benefits similar to that of the IoSN SEW-based Needs solution. The two figures show that based on the TYNDP 2020 projects, the project promoters and TSOs are partly covering the gap between today's grid and future needs. However, a lot of projects still need to be realised in order to meet future needs. The future needs of the interconnected European power systems in coping with such a long-term generation mix development that should be solved by the identified cross-border capacity increases are:

1. Insufficient integration of renewables into the power systems, as high amounts of curtailed energy occurred in a couple of power systems;
2. Insufficient market integration - high system costs, in particular market areas and high price differences between the market areas;
3. High CO2 emissions; and
4. Insufficient cross-border capacities.

The ‘future capacity needs’, identified as part of the IoSN process, are mainly due to the change of the overall situation in the power systems in future scenarios such as load-flow pattern changes. Therefore, the transmission system elements limiting cross-border capacity in the 2020 time horizon could change in 2040 due to generation mix change - installed capacities and location in the power systems - as well as the partial strengthening of the grid infrastructure.

The identified future capacity needs on the cross-border profiles in the Baltic States region could potentially be covered, fully or partly, by the future transmission projects included in the TYNDP 2020 process or will remain necessary for future grid development. In addition, expectations on increased offshore wind might lead to new types of hybrid projects combining connecting offshore-wind and interconnections between countries. This is to be further investigated.

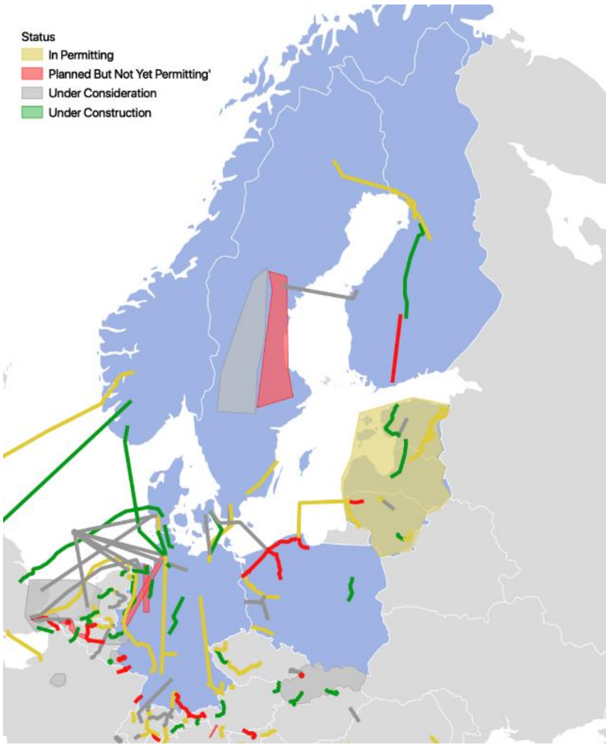


Figure 4-1 - TYNDP 2020 project-list (projects being categorised "Under construction" and the majority of projects "In permitting" are part of the Reference Grid 2025)

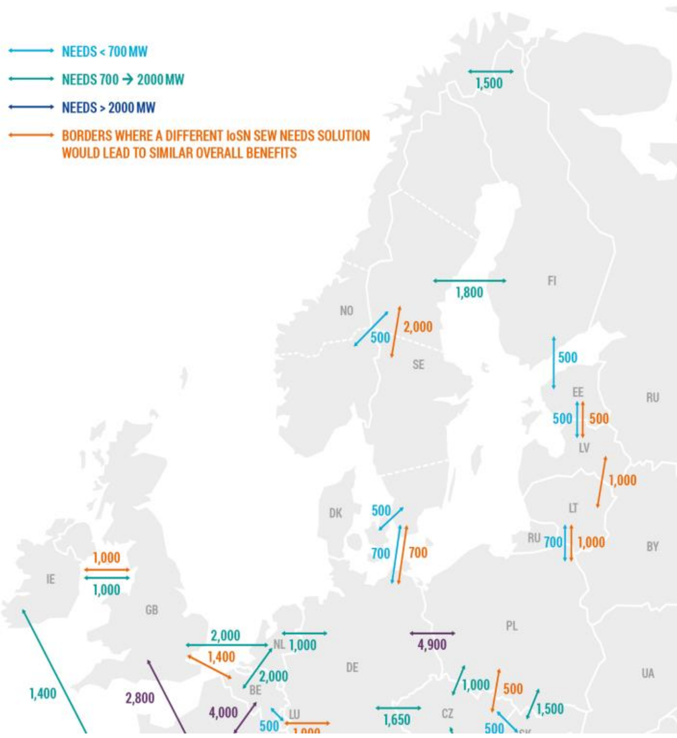


Figure 4-2 - Identified capacity-increase between 2025 and 2040

As part of this work, cross-border capacity increases were identified, that will have a positive impact on the system. A European overview of these increases is presented in the European System Need report developed by ENTSO-E in parallel with the RegIPs. The system needs for the 2040 horizon are being evaluated with respect to (1) market-integration/socio-economic welfare, (2) integration of renewables, (3) reduction of greenhouse gas emissions and (4) security of supply. For the Baltic Sea region, the 2040 needs are primarily described through:

- Synchronisation of the Baltic system towards the Continental system. This is in order to improve security of supply. In relation to this also further internal integration within the Baltics, mainly due to concerns with security of supply;
- If realisation of offshore wind parks, a need to transport the energy to the onshore system;
- Stronger Germany-Poland integration to increase market-integration and distribution of spillage energy from German RES;
- Further Sweden-Finland integration to increase market integration and to serve the negative Finnish energy balance;
- Further Norway-Finland integration to increase market integration and to serve the negative Finnish energy balance;
- Further integration between Sweden/Denmark and Germany due to price differences and better optimisation of RES generation (hydro/wind).

The IoSN-results are very much dependent on the scenario-assumptions. For some of the results the trends are not fully aligned with the scenario-assumptions made two years ago. This is most likely due to the IoSN analysis for only one climate year. For example, the Norway-Finland capacity-increase is based on rather high onshore wind development in northern Norway. The trend is far more restrictive regarding onshore wind, which would lead to a need for lower capacity than estimated in the IoSN analyses. Also, internal costs are not fully taken into account, both for Norway-Finland and Sweden-Finland. For these corridors further investigations need to be done. The huge spillage of renewable energy in Germany identifies the need to export to Poland in the IoSN analysis, where under the conditions of the scenarios used, energy from fossil sources is significantly reduced, affecting decreasing capacity margin in Poland. In addition, the IoSN analysis also identifies the need for a new DKe-PL connection in 2030, while in 2040 this need was not confirmed. This situation is most likely caused by the delay in the development of Polish offshore in 2030, compared to 2040. Further investigation of this corridor needs to be done. The potential to increase transmission capacity on the LT-PL connection relates to the possibility of unblocking these capacities on the existing LitPol Link connection. This is linked to increasing the resilience and robustness of the Baltic States grid, after synchronisation with continental Europe, through this connection and step by step release of transmission capacity for trade. A further increase of capacity on the Germany-Poland border is only possible if a connection is built, and both the Polish and German internal grids are strengthened accordingly. The identification of a need to further increase the capacity beyond the third interconnection is a theoretical approach, to give an indication about the future needs for system development, based on currently used assumptions. At this stage there is no existing agreement or planned project concerning these investments yet.

The needs for the region, discovered in the Pan-European System Needs analyses 2040, are partly covered by projects already waiting to be assessed in TYNDP 2020. Table 4-1 below shows cross-border capacities including increases identified during the TYNDP 2020 process. The initial columns show the 2020 capacities. The following columns show the capacities relevant for the CBA, which will be carried out on the 2025, 2030 and 2040 time-horizons. These columns show the capacities of the reference grid for CBA and the capacities if all projects per border are added together.

	NTC 2020		NTC 2025		NTC 2030		NTC 2040	
Border	=>	<=	=>	<=	=>	<=	=>	<=
DE-DEkf	400	400	400	400	400	400	400	400
DE-DKe	600	585	600	585	600	600	600	600
DE-DKw	1500	1780	3500	3500	3500	3500	3500	3500
DE-NSWPH	0	0	0	0	0	0	6000	6000
NSWPH-DKw	0	0	0	0	0	0	2000	2000
DEkf-DKkf	400	400	400	400	400	400	400	400
DE-NOs	1400	1400	1400	1400	1400	1400	1400	1400
DE-PLE	0	2500	0	3000	0	3000	0	3000
DE-PLI	500	0	2000	0	2000	0	2000	0
DE-SE4	615	615	615	615	1315	1315	2015	2015
DKe-DKkf	400	600	400	600	400	600	400	600
DKe-DKw	600	590	600	590	600	590	600	590
DKe-PL	0	0	0	0	600	600	0	0
DKe-SE4	1700	1300	1700	1300	1700	1300	1700	1300
DKw-NOs	1632	1632	1632	1632	1632	1632	1632	1632
DKw-SE3	715	715	715	715	715	715	715	715
EE-FI	1016	1016	1016	1016	1016	1016	1016	1016
EE-LV	879	879	879	879	1100	900	1100	900
LV-RU	950	950	950	950	0	0	0	0
FI-NOn	0	0	0	0	0	0	0	0
FI-SE1	1100	1500	2000	2000	2000	2000	2000	2000
FI-SE2	0	0	0	0	0	0	800	800
FI-SE3	1200	1200	1200	1200	1200	1200	800	800
LT-LV	950	950	800	950	800	950	800	950
LT-PL	500	500	500	500	700	700	700	700
LT-SE4	700	700	700	700	700	700	700	700
NL-NOs	700	700	700	700	700	700	700	700
NOm-NOn	1300	1300	1300	1300	1300	1300	1300	1300
NOm-NOs	1400	1400	1400	1400	1400	1400	1400	1400
NOm-SE2	600	1000	600	1000	600	1000	600	1000
NOn-SE1	700	600	700	600	700	600	700	600
NOn-SE2	250	300	250	300	250	300	250	300
NOs-SE3	2145	2095	2145	2095	2145	2095	2145	2095

PL-SE4	600	600	600	600	600	600	600	600
SE1-SE2	3300	3300	3300	3300	3300	3300	3300	3300
SE2-SE3	7300	7300	8100	8100	8100	8100	8100	8100
SE3-SE4	5400	2000	6200	2800	6200	2800	6200	2800
UK-NOs	0	0	2800	2800	2800	2800	2800	2800
DKw-NL	700	700	700	700	700	700	700	700
NSWPH-NL	0	0	0	0	0	0	4000	4000
DKw-GB	0	0	1400	1400	2800	2800	2800	2800

Table 4-1 - Cross-border capacities for 2020 and the capacities relevant for the CBA, which will be carried out on the 2025, 2030 and 2040 time-horizons

4.2 Market results of IoSN 2040

Table 4-1 shows the results of the pan-European IoSN market studies. The market simulations have been carried out by the Antares pan-European open source market model, with a publicly available expansion module. The market results show that the identified investments in the 2040 grid will significantly decrease the general price level, the amount of curtailed energy and reduce the amount of CO2 emissions compared to the '*No investment after 2025*' scenario. The three future grid development scenarios under the IoSN study have been analysed in detail and have been described and explained in the IoSN main report.

1. **No investment after 2025** - It is assumed that there is no capacity increase after 2025 and no further investments in the EU transmission network. The projects up to 2025 are realised with no additional investments after this time horizon.

2. **Copperplate** - This scenario looks at what would happen if there was zero limitation to transmitting electricity across Europe? It is, however, a theoretical scenario and the value of the Copperplate exercise is to reveal the maximum benefits that could be secured by reinforcing the grid. The Copperplate scenario indicates the absolute maximum benefits that could be obtained by increasing cross-border network capacity.

3. **IoSN SEW-based Needs** - To analyse system needs by 2040, ENTSO-E determined the combination of potential increases in cross-border network capacity that minimises the total system costs, composed of total network investment and generation costs. To do that, a panel of possible network increases was proposed to an optimiser, who chose the most cost-efficient combination. To take into account the mutual influence of capacity increases, the analysis was performed simultaneously for all borders. The final combination of cross-border capacity increase minimises costs.

Curtailed energy

The amount of curtailed energy decreases substantially in the IoSN SEW-based Needs and Copperplate scenarios compared to the '*No investment after 2025*' scenario. Figure 4-3 shows the curtailed amounts of energy for the Baltic Sea region countries. Among them, the most significant energy curtailments have been in Germany, Denmark and Sweden. The highest amount of energy curtailments have been identified for Germany, from 73TWh to 16TWh respectively, depending on the scenario. For Denmark and Sweden, the amount of curtailed energy varies from 14TWh to 1.5TWh a year. The new grid capacity up to 2040 helps in situations with a large RES share. In surplus situations in Germany and Denmark, surplus energy could be exported and stored in hydro reservoirs to a large extent. In Sweden, curtailed energy also decreases since hydro reservoirs could often be full in a RES surplus situation. Therefore, increasing exports to the rest of Europe will avoid curtailment issues. For the majority of Baltic Sea region countries, the amount of curtailed energy is very low and insignificant, varying from 2.4TWh to 0.15TWh a year.

The results indicate that there would still be relatively large amounts of energy curtailment with the Copperplate Scenario and IoSN SEW-based Needs. However, the results likely exaggerate the absolute level of curtailment since the modelling of wind power, in particular, does not fully consider the expected increase in full load hours, meaning that the same amount of energy can be produced by turbines with lower generation capacity. Even if the results are slightly exaggerated, the message is still clear: grid investments are needed to avoid large amounts of wasted renewable energy in the region, and even more capacity than the 2040 grid may be needed, particularly with a lot of variable renewable generation. However, in a future power system with a very large amount of variable generation, some curtailment needs to be accepted, as avoiding curtailment completely will be too expensive.

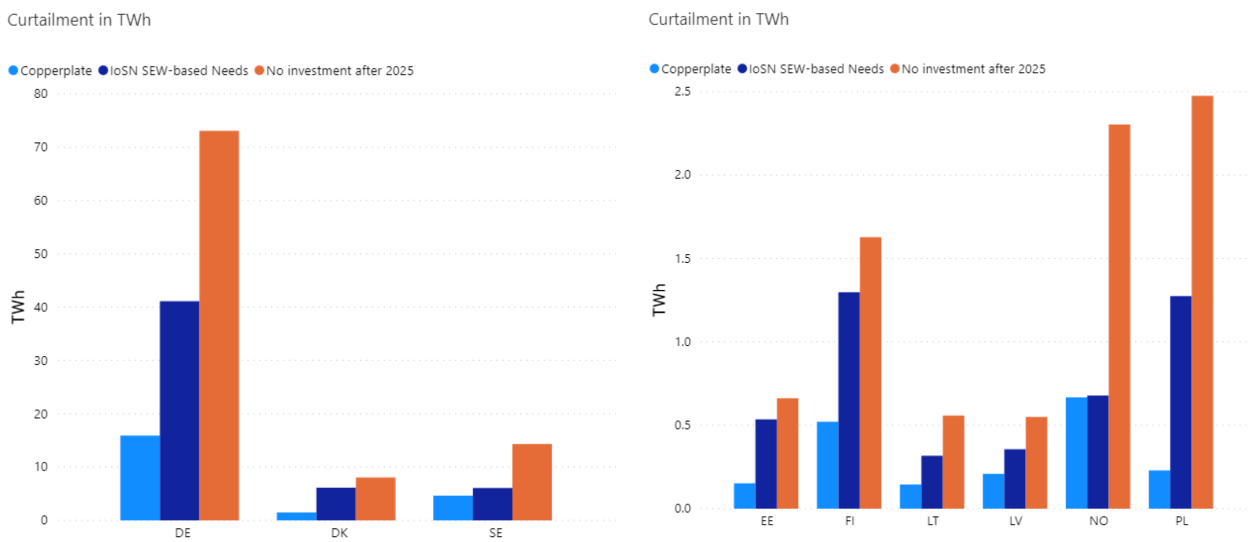


Figure 4-3 - The amount of curtailed energy in the Baltic Sea region with, and without, identified capacity increases in 2040

Decreased CO2 emissions

A higher interconnector capacity will also have an impact on CO2 emissions. This is due to the better integration of zero-emission renewables and the move towards carbon neutral Europe, as well as the increased use of gas in place of coal in thermal generation. There are some changes in Germany and Poland, but both countries still have a significant amount of thermal capacity in the 2040 scenario. The deployment of renewables has a greater effect on CO2 emissions than interconnectors as it can be seen in Figure 4-4.

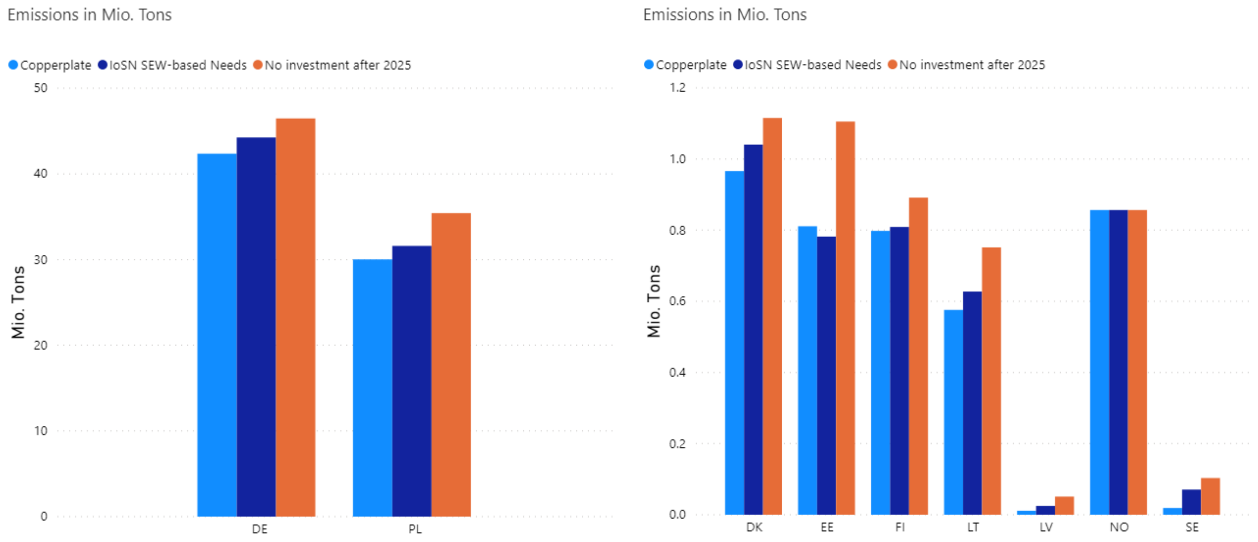


Figure 4-4 - CO2 emissions in the Baltic Sea region from the IoSN study

Figure 4-4 shows that the level of CO2 emissions is neither particularly high, nor particularly significant, for the Baltic States and the Nordic countries and that both regions emit very low levels of CO2 emissions. As CO2 emissions levels move towards zero, both regions are on course to meet their EU 2050 CO2 emissions reduction targets. In contrast, both Germany (on average 45 million tons) and Poland (32 million tons) have high CO2 emissions levels, which vary widely depending on grid expansion. The reason for these high CO2 emissions is the production of fossil fuels - lignite, coal and gas. Additional cross-border capacity increases from Germany to the Nordic countries could reduce these CO2 emissions levels. Comparing all scenarios for Germany and Poland, CO2 emissions are slightly reduced when cross-border capacity is increased. However more significant reductions can be seen where there is a reduction of generation from coal, gas and lignite, replaced with CO2-free generation sources. For the other countries additional capacity increases will not significantly reduce the level of CO2 emissions.

Improved market integration and decreased average prices

As shown in Figure 4-5, the average price difference decreases when the transmission network is expanded, and new cross-border capacities introduced. More interconnector capacity between countries will reduce price differences and will help develop a more effective and integrated market. Therefore, it will be possible to import/export more power within a shorter period when the price difference is high, such as during dry years with higher prices in the Nordic regions, or in periods when the variation in renewable production is high. The hydro-based power market in the Nordics will become more integrated than the more thermal-based market in continental Europe, and price variations between wetter and drier years will be lower.

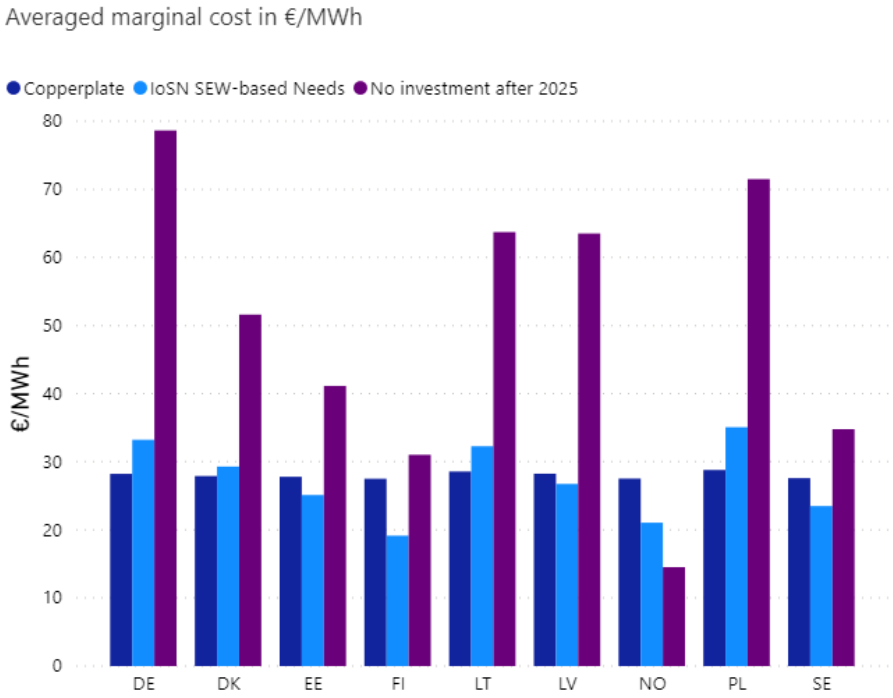


Figure 4-5 - Yearly average of marginal cost (€/MWh) identified in the Baltic Sea region from the IoSN study

On average, in 2040 in the Copperplate scenario, marginal cost levels in the Baltic Sea region countries are relatively close to each other, with marginal cost levels reaching €28/MWh. In the IoSN SEW-based Needs scenario in 2040, Estonia, Finland, Latvia, Norway and Sweden are slightly below the average marginal costs identified in the Copperplate scenario, while Poland, Germany, Denmark and Lithuania are slightly above. The average marginal cost level is around the same €30/MWh. However, it should be noted that the absolute level is very sensitive to assumptions made regarding fuel and CO2 pricing. To integrate electricity markets and to harmonise marginal costs between the country groups within the Baltic Sea region, additional capacity increases between these groups is necessary.

In the IoSN SEW-based Needs scenario, yearly average marginal costs for the Baltic Sea region vary from €19/MWh in Finland to €35/MWh in Poland. Without grid investment beyond 2025, average yearly marginal costs would vary from €79/MWh in Germany to €15/MWh in Norway, producing high price differences between Baltic Sea region countries. The yearly price variation in Norway is due to variations in inflow between wet and dry years, but in the IoSN study this has not been taken into account. Greater interconnector capacity will lift Nordic price levels during any wet years and reduce prices in dry years. Overall, price levels in all the Baltic Sea region countries will decrease, except for Norway where it will increase slightly as its hydro system is more integrated than the thermal-based system. The Nordic countries will export more electricity to the rest of Europe.

A surplus in the western part of the region and a deficit in the eastern part

The net annual country balance in different investment scenarios shows that the main electricity producers in the Baltic Sea region are Germany, Denmark, Estonia and Sweden as their export amounts exceeds import amounts and their energy is transmitted to Poland, Finland, Latvia and Lithuania (Figures 4-6 and 4-7). The exception is the *No investment after 2025* scenario where the main producers are Denmark, Estonia and Sweden, but due to limitations and grid constraints, Germany is moved to the importer side with Finland, Poland, Latvia and Lithuania (Figure 4-8). The IoSN-analyses is based on a very wet year (2007). For a country like Norway, energy-balances are far from representing a typical year, and therefore, the values for Norway are not part of the figures in this sub-chapter. In the IoSN study the assumptions were slightly different from previous ones, and the change between climate years didn't play as important a role as it should. Sweden will maintain a net annual surplus despite a significant reduction in nuclear capacity by 2040. Depending on the scenario, in general the annual country balance will hover around zero for Lithuania, Estonia and Latvia. The annual balance for these countries is very close to zero because they have relatively small power systems compared with Germany, Norway, Poland, Finland and Sweden. A significant amount of imported electricity is expected for Finland and Poland in all scenarios. In Poland, domestic coal-fired generation will be partially replaced by imports. In Finland, the balance is close to 2015 levels, as increases from new wind and nuclear generation will be offset by growth in demand, as well as the decommissioning of existing nuclear and CHP generation by 2040.

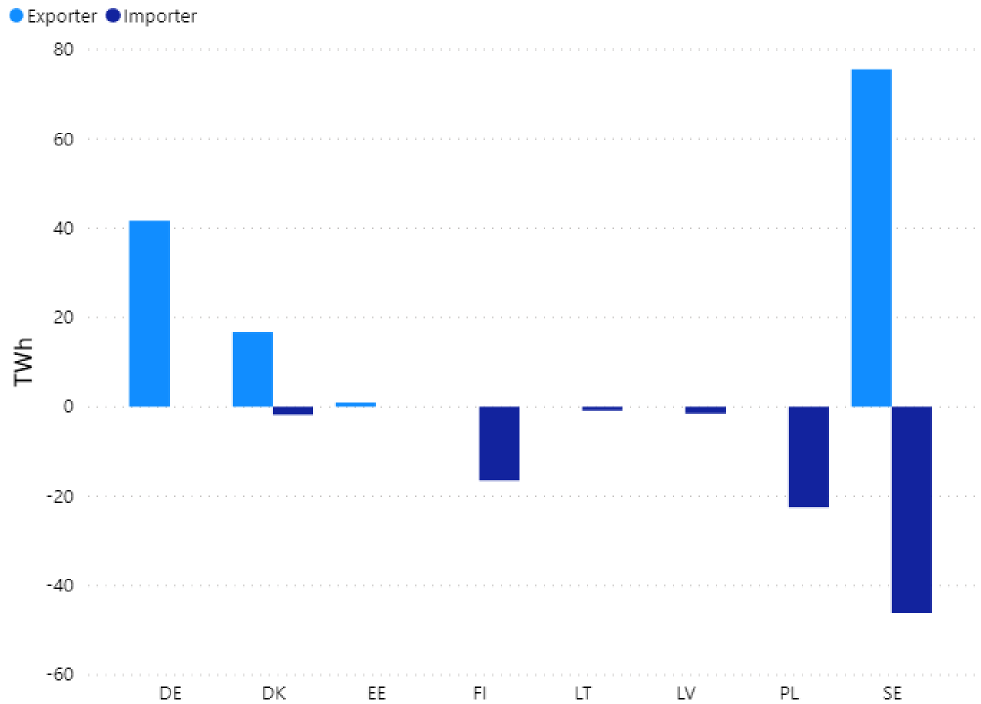


Figure 4-6 - Net annual country balance (export and import in wet climate year) in the Copperplate scenario (2040)

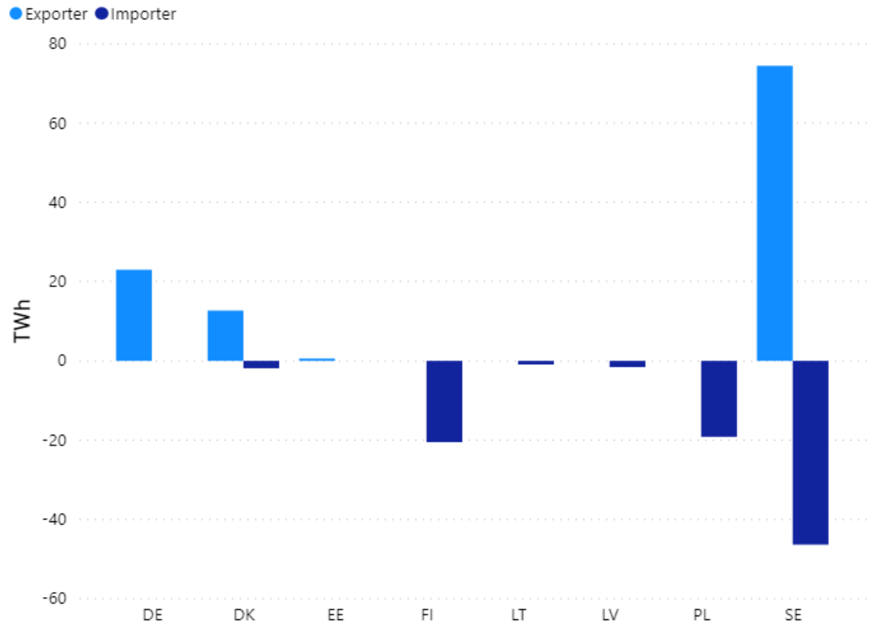


Figure 4-7 - Net annual country balance (export and import in wet climate year) in the IoSN SEW-based Needs scenario (2040)

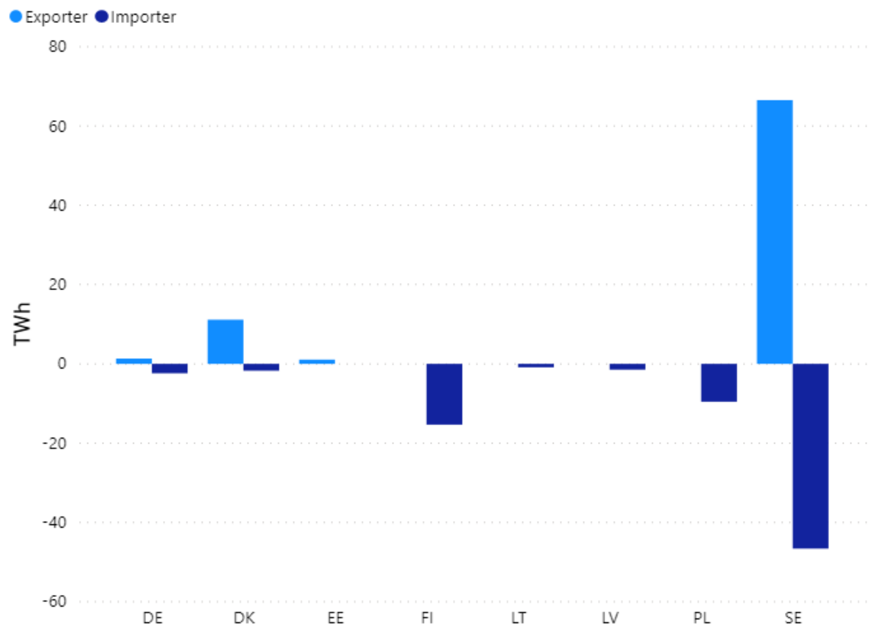


Figure 4-8 - Net annual country balance (export and import in wet climate year) in the No investment after 2025 scenario (2040)

Production in all these countries is based on off-shore and on-shore wind and solar energy, hydropower and hydro storage, as well as biomass generation. The production mix from the IoSN SEW-based Needs scenario

(2040) is presented in Figure 4-9. Hydro generation dominates in Finland and Sweden. Nuclear generation up to 2040 has been identified in Finland and Poland. The generation mix doesn't change significantly for most of the Baltic Sea region countries among scenarios, therefore only the IoSN SEW-based Needs scenario is presented here.

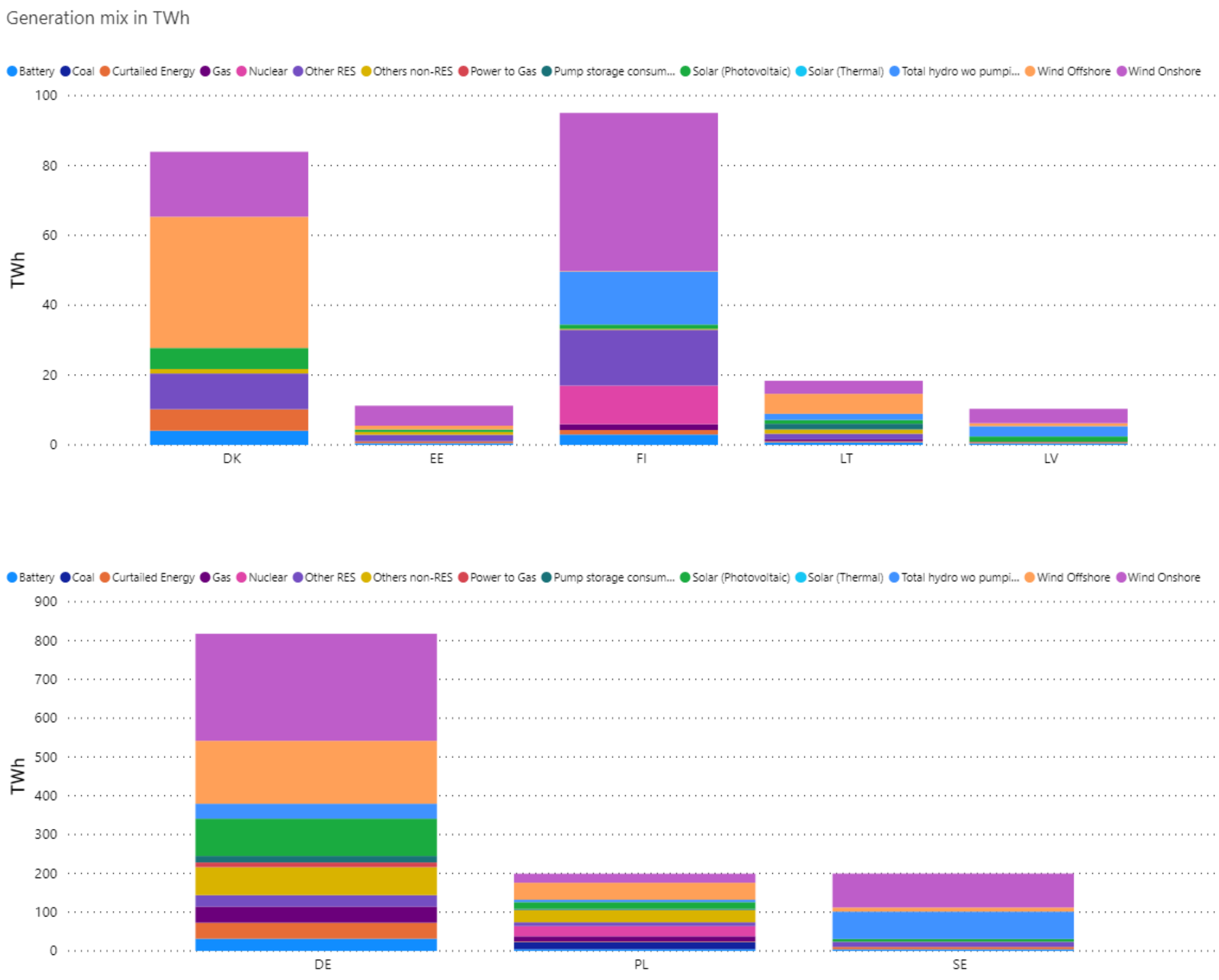


Figure 4-9 - Generation mix in TWh in the Baltic Sea Regional Group (wet climate year) in the IoSN SEW-based Needs scenario (2040)

Capacity increases improving the security of supply

The amount of Energy Not Served (ENS) decreases significantly in both Germany and Poland with the 2040 grid and this has been stated in previous TYNDPs. The level of unserved energy is very small. This is an expected result since the grid capacity to and from both Germany and Poland increases significantly up to 2040. With increased grid capacity, the adequacy for both Germany and Poland is strengthened, since flexible hydropower from the Nordic and Baltic countries could be used to reduce grid pressures in Central Europe. In all other countries the ENS is already very small, due to the large amount of flexible hydropower capacity' and the significant degree of interconnection between countries compared to other regions. Some amounts of ENS could be expected in Norway, which is unlikely to be due to the abundance of flexible hydropower.

The current IoSN study did not focus on analysing Energy Not Served (ENS) - the amount of final demand that cannot be supplied within a region due to any deficiency of generation or interconnector capacity. Studying ENS requires complex and time-consuming analysis - over multiple climate years - to obtain reliable values. Based on these small numbers, unserved energy is not considered to be a very important indicator of the need for more interconnector capacity. In addition, the new European Resource Adequacy Assessment (ERAA) substituting the former Mid-Term Adequacy Forecast (MAF 2019) will address this topic in detail. The first ERAA release will be published in 2021 and will analyse up to the 2030 horizon.

5. ADDITIONAL REGIONAL STUDIES AND MAF STUDY

This chapter gives an overview, important background information and the main outcomes of the most interesting studies performed outside the ENTSO-E RGBS cooperation.

5.1 Baltic synchronisation

For historical reasons, the Baltic States currently operate in synchronous mode with the Russian and Belarussian electricity systems (IPS/UPS), forming the so-called BRELL-ring (Belarus-Russia-Estonia-Latvia-Lithuania). The energy policy of the Baltic States is integrated with the energy strategy of the EU and must comply with major objectives such as sustainable development, electricity market competitiveness and security of supply. In addition to these objectives, the Baltic States have to continue developing competitive and fully integrated electricity markets, along with a sufficiently developed energy infrastructure to connect distributed RES (wind, biomass and biogas, solar etc.), possible high capacity power plants and to meet a Barcelona criterion (10-15%) on capacity interconnectors for cross-sections up to 2030, and towards 2050. The Baltic States must ensure implementation of the EU's *Clean energy for all Europeans* package and fulfil all directives linked to the EU energy sector.

The Baltic States have also politically endorsed the synchronisation of their power systems with the CEN as a common strategic goal. In 2014 the three Baltic TSOs proposed a roadmap for de-synchronisation from the IPS/UPS and synchronisation with the CEN. Following a request by the European Commission, an initial assessment carried out by ENTSO-E in 2015 concluded that synchronisation with the CEN would be technically feasible. However, it was then not thought to be economically profitable as it was based only on traditional cost/benefit evaluations, and did not consider geopolitical aspects such as SoS in any high-level strategic perspective. In 2015 the European Commission and those Baltic Sea Region Member States involved, concluded a Memorandum of Understanding on the reinforced Baltic Energy Market Interconnection Plan (BEMIP) and at the end of 2015, the European Commission - with the assistance of the Joint Research Centre (JRC), and in cooperation with ENTSO-E and the involved TSOs, launched a study on the 'Integration of the Baltic States into the EU electricity system'. The study was completed in 2017 and concludes that among the examined synchronisation options, the CEN option clearly emerges as the most technically feasible and most cost-effective. Also in 2017 - as a further step towards synchronisation of the Baltic countries' power systems into the interconnected networks of the CE - three Baltic TSOs, in cooperation with Tractebel, performed a multi-disciplinary study on the isolated operation of the Baltic power system. In this study, the technical, economic, legal and organisational aspects of the isolated operation of power systems of the Baltic countries were investigated in preparation for a real-life isolated test operation of their power systems. This was scheduled to take place in 2019. In the scheduled time frame the real-life isolated test operation for the Baltic States was cancelled due to fact that a Russian TSO, very close to the same time frame, did a real-life isolated test operation for the Kaliningrad area. Accordingly, and to ensure a security in power system, the Baltic States real-life isolated operation test has been postponed to an, as yet, unknown date, when all preparatory works will be done, and permits received.

In 2017-2018 the Baltic State TSOs and the Polish TSO (PSE), together with the Institute of Power Engineering in Gdansk, performed a Dynamic Study on the extension of the Continental Europe Synchronous Area for the Baltic States Transmission Systems, and identified several Baltic State synchronisation options with the CEN scenarios. After that the Baltic State TSOs together with ENTSO-E and PSE performed a Study assessing the frequency stability of the synchronously interconnected Baltic States and the Continental European electricity network. Three interconnection scenarios (identified from a previous Dynamic study - through existing Alternating Current line, Alternating Current+ additional Alternating Current line and Alternating Current + additional Direct Current line), including an evaluation of working in synchronous and isolated modes were analysed. Measures such as inertia and must run units and necessary market limitations were identified. According to ENTSO-E TYNDP the socio-economic loses of market limitations, CAPEX and OPEX for inertia and must run units calculated.

In 2018 the Baltic States TSOs together with PSE and the Institute of Power Engineering in Gdansk, ran a study to identify Necessary Measures and their Associated Costs in Securing the Safe Operation of the Baltic States Transmission System, after synchronisation with the Continental Europe Synchronous Area. Together they assessed Alternating Current + additional Direct Current (via the existing double-circuit 400kV overhead Alternating Current line and a new submarine High Voltage Direct Current link, Harmony link, 700MW), socio-economic scenario optimised and calculated using advanced measures as EPC, FFR, Demand Side Response and other.

In the second half of 2018 the BEMIP high-level group and the European Commission politically approved the synchronisation of the Baltic States with the power system of Continental Europe. The project received the ‘green light’, and ENTSO-E was nominated to begin all processual activities regarding the synchronisation process. The Baltic TSOs - Litgrid, AST and Elering, submitted an application to PSE, with a request to expand the Continental Europe Synchronous zone with Baltic power systems, whereas PSE submitted an application with the Baltic TSOs to the plenary of the Regional Group Continental Europe. Continental Europe defines the rights and obligations for Baltic State TSOs and Poland in implementing the necessary measures that will make it possible to connect the Baltic power systems for synchronous operation with the CEN. The Catalogue of Measures (CoM) defines indicators and measures which will ensure the operation of power transmission systems in each Baltic State - related to frequency management, activity planning and accountability and reliable operation of the transmission system.

A very important year from the project development point of view was 2018, when, based on technical studies prepared by the Baltic and Polish TSOs, the synchronisation scenario was selected (Alternating Current line + additional Direct Current line - Harmony link, 700MW). A list of measures to be delivered before synchronisation was also identified, taking into account possible Baltic State synchronisation with the EU. Following this, on 28 June 2018, European Commission President Jean-Claude Juncker - together with the Heads of State or Government of Lithuania, Latvia, Estonia and Poland - agreed on the Political Roadmap for synchronising the Baltic States’ electricity grid with the continental European network by the target date of 2025. The Roadmap which previously was signed and agreed in the high-level group on BEMIP, set the preferred scenario and further steps necessary for the implementation of the goal on time. The agreement is based on technical level Dynamic and Frequency (implemented in 2018) stability studies.

The Baltic States' Synchronisation project has been divided in three phases:

- **Phase I** - internal transmission network reinforcements in the Baltic States. The investments are necessary to strengthen the Baltic States' grid in order to avoid bottlenecks on the borders of these three countries regardless of the synchronisation scenario of the Baltic States Power System to the Continental Europe Power System. In 2019 the Grant Agreement for Synchronisation Phase I implementation was approved.
- **Phase II** - investment items recommended by the dynamic and frequency studies prepared by the Baltic and Polish TSOs. On 8 November 2019 the Transmission System Operators in Poland, Lithuania, Estonia and Latvia, submitted a jointly prepared Baltic Synchronisation project Phase 2 Investment Request, with all related Appendixes, to the National Regulatory Authorities for assessment. This was done in order to receive a cross-border cost allocation decision on investments related to the Baltic Synchronisation project. The Baltic State TSOs and PSE are currently waiting for the decision to move further with their application submission to the European Commission for EU funds and successful project implementation by 2025.
- **Phase III** - investment items connected with Baltic State desynchronisation with IPS/UPS. The scope of this phase is dependent on third parties' future decisions and is currently under discussion

Figure 5-1 - Topology of the investments for Baltic States and Poland included in Phase I and II of the Baltic Synchronisation project

The list of Projects of Common Interest has been developed on the basis of the European Parliament and Council Regulation (EU) No.347/2013 from 17 April 2013, on guidelines for trans-European energy infrastructure, and repealing Decision No 1364/2006/EC and amending Regulation (EC) No 713/2009, (EC) No 714/2009 and (EC) 715/2009. The Baltic synchronisation cluster is included in the third PCI list with No. 4.8 under the corridor, which includes the Baltic Sea Region projects from the Nordic countries, the Baltic States, Poland and Germany. Synchronisation Project 4.8 is titled *Integration and synchronisation of the Baltic States' electricity system with the European network*. Currently, the European Commission is drafting the fourth PCI list. Each of the synchronisation project Phase II planned investment items (except LV and LT BESS) are included as candidates for the fourth PCI list, under the same 4.8 cluster. The inclusion of synchronisation-related investment items in the list of updated PCI's enhances the importance of the synchronisation project for the whole Baltic Sea region and for Europe as well.

Currently, one of the most serious challenges standing in the way of the synchronisation project's development is clarity regarding the operation and status of the Kaliningrad electrical enclave - part of the Russian power system. This issue will require a lot of political willpower and might influence the technical outcomes and schedule of the synchronisation process. Because of this, Baltic State TSOs have to keep in mind and plan for some unexpected investments that could appear during project implementation. These can be allocated under Phase III of the Baltic Synchronisation project.

5.2 ENTSO-E Mid Term Adequacy Forecast (MAF) 2019

The MAF is a pan-European monitoring assessment of power system resource adequacy, spanning a timeframe from one to ten years ahead. It is based upon state-of-the-art probabilistic analysis that aims to provide stakeholders with comprehensive support to take qualified decisions. Over the past decade, ENTSO-E has been improving its methodologies and will continue to ensure that further progress is made. MAF contributes to the harmonisation of resource adequacy methodologies across Europe by being a reference study for European TSOs and a target approach for the TYNDP and Seasonal Outlook studies. The MAF aims to provide stakeholders with the data necessary to make informed, quality decisions and promote the development of the European power system in a reliable, sustainable and connected way.

The MAF 2019 focus on the target years 2021 and 2025, chosen as pivotal years for evaluating adequacy due to the significant reductions in coal and nuclear capacity expected between 2021 and 2025. A comparison to the previous years' MAF 2018 was also included the MAF 2019. The full version of the MAF 2019 report and all details are available on the ENTSO-E web page.

Figure 5-2 below shows the estimated levels of resource adequacy for the target year 2021. It plots the Loss of Load Expectation (LOLE) and the 95th percentile of the Loss of Load Duration (LLD) that occurred among all simulated Monte Carlo years. The market-modelling results for 2021 do not indicate significant adequacy issues in most countries. As was the case in previous adequacy assessments, islands are vulnerable to loss of load. In the Baltic Sea Regional Group, the highest LOLE (h) in 2021 is expected in Sweden, Lithuania, Poland and Latvia. Problems with LOLE in the Baltic Sea Regional Group have been identified due to a data issue in Lithuania where 400 MW of hydro turbine capacity should be reserved for FRR. These additional resources were compensated by the removal of all thermal generation in the model which lead to a high capacity deficit in Lithuania. The LOLE figures are insignificant as far as they are lower than 3.0h a year and regarding Base

Case there are no critical issues with LOLE in the Baltic Sea Regional Group. In the 95th percentile (h) Base Scenario - the results for the risk of 1 in 20 years - the highest risk of LOLE has been identified in Poland. The value exceeds 3.0h per year also for Lithuania because both countries are directly linked with cross-border lines and they expect high generation capacity deficit. Some Loss-Of-Load-Probability (LOLP) could be identified in Latvia and Estonia, but it is insignificant as the values are lower than 3.0h a year.

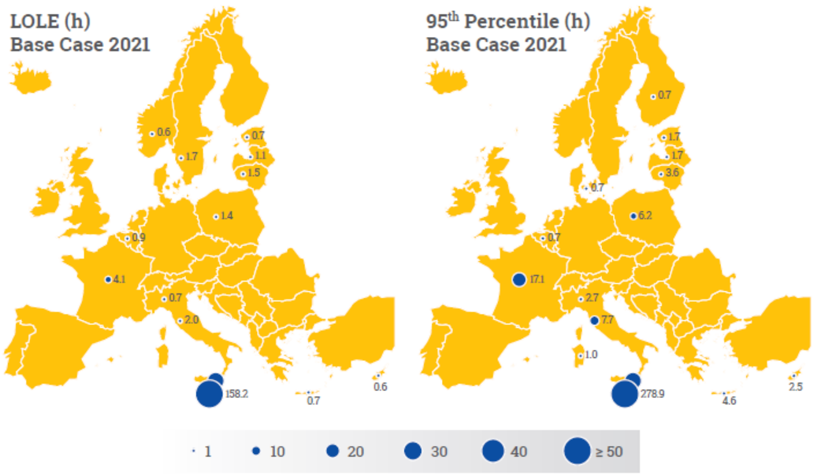


Figure 5-2 - Loss of load expectation (LOLE) values for the 2021 Base-Case scenario. Circle radii reflect the magnitudes of the LOLE values for the corresponding zones. Zones with missing circles have LOLE values of less than 0.5 h

Figure 5-3 presents the results for Base-Case target year 2025. Only a few zones have LOLE values greater than three hours a year. Very limited adequacy risks are predicted in continental Europe for the 2025 target year, provided the input assumptions taken for the different countries materialise. However, for 2025, the situation changes due to the large reduction in thermal power plant capacities, particularly in Poland and Estonia. In most cases, this decrease affects coal-fired plants for economic and/or political reasons. The reduction is primarily due to planned nuclear and coal-fired power plant decommissioning in these countries, or their replacement with much more environmentally friendly generation sources. All zones in the Baltic Sea Regional Group, with the exception of Lithuania, have LOLE values of less than three hours. Naturally, in terms of the 95th percentile (h) values on the map in Figure 5-3, (right-hand side), the number and radii of the circles is expected to increase but still remain insignificant, with the exception of the islands.

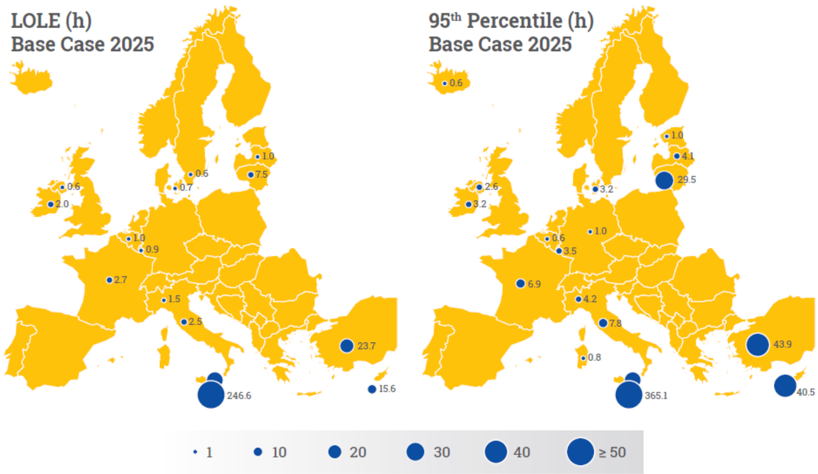


Figure 5-3 - Loss of load expectation (LOLE) values for the 2025 Base-Case scenario. Circle radii reflect the magnitudes of the LOLE values for the corresponding zones. Zones with missing circles have LOLE values of less than 0.5 h. *In these maps, outliers were removed before averaging the results of all tools for the zones consisting of Cyprus, Sicily, Lithuania and Turkey. Input data for Iceland have not been updated since MAF 2018, thus outcomes remain the same

Plotting the results of the two 2021 and 2025 investigated scenarios side-by-side allows a better exploration of the evolution of adequacy, as anticipated by the MAF models. For a few zones in the Baltic Sea Regional Group, we can see that changes between 2021 and 2025 will have an impact on ensuring adequacy. This is the case for Lithuania where LOLE values show increases of over six hours. For the rest of the Baltic Sea Regional Group countries, the LOLE increase is not so critical. We can also observe a reduction of LOLE for Poland in 2025, due to new generation developments and transmission network strengthening.

5.3 Challenges and opportunities for the Nordic power system

The Nordic TSO are working together, with their stakeholders, to address the common challenges identified in the 2016 report "*Challenges and opportunities for the Nordic Power System*". This report identified challenges within the five areas of system flexibility, transmission and generation adequacy, frequency quality and inertia. The key solutions needed to meet the challenges in the Nordic power system in the period leading up to 2025 were identified in the 2018 report "*The way forward - Solutions report*". The Nordic TSOs have updated the Solutions report and it was published in the spring of 2020.

The expected changes in the Nordic power system, identified in 2016, have progressed at a much faster pace than expected. At the same time, the Nordic TSOs and their stakeholders have successfully progressed several important previously identified solutions. For example, the Regional Security Coordinator (RSC) office has been established, and today it provides the first versions of four of the five core services identified in the previous report. The work related to the Nordic Balancing Model (NBM), which will renew the Nordic balancing process, continues. The Nordic TSOs, in close cooperation with stakeholders and through the stakeholder reference group, have drafted a roadmap that considers the complexity of shifting from a one hour imbalance settlement to a 15 minute imbalance settlement, implementing a single price settlement model and establishing several other balancing tools for the future. The Nordic TSOs and their stakeholders have also accelerated work related to coping with low inertia situations, as the system has changed more rapidly than expected. It was also determined that the most cost-efficient way to cope with low inertia situations was to establish a new Fast Frequency Reserve (FFR). To enable market participants to evaluate the need and future market of the FFR, The Nordic TSOs have begun publishing the real-time value of the inertia in the Nordic power system. To ensure that the challenges are still the same, and that the prioritised solutions continue to be the right ones, the Solution reports will continue to be updated every other year.

The full report can be found here: Solutions report 2020

5.4 Nordic Grid Development Plan 2019

The Nordic Grid Development Plan 2019 describes the ongoing and future investments in the Nordic countries (Norway, Sweden, Finland and Denmark) grid. The four TSOs publish a common Nordic Grid Development Plan (NGDP) every other year. The NGDP describes the main drivers of the changing Nordic power system, and planned and on-going grid development to meet future needs. The 2019 study includes preliminary analysis of five transmission corridors of special interest between countries, called bilateral studies. In order to ensure the transmission grid is sufficient to meet the needs of producers and consumers in the future energy system, the Nordic TSOs continue to evolve transmission system planning methods aimed at identifying future Nordic level transmission needs.

The Nordic TSOs are preparing the grid for a future energy system that is becoming more complex and integrated. Extensive project investments, totalling more than €15bn between 2016 and 2028, are being planned in the four countries. These investments are based on the expected requirements of connecting renewable resources with electricity demands, both for traditional use and for new and innovative use. The Nordic TSOs cooperate continuously on joint Nordic grid development, with both common grid plans and bilateral transmission investment studies. In addition, as the energy system evolves, system adequacy continues to be a major focus area for Nordic TSO planning.

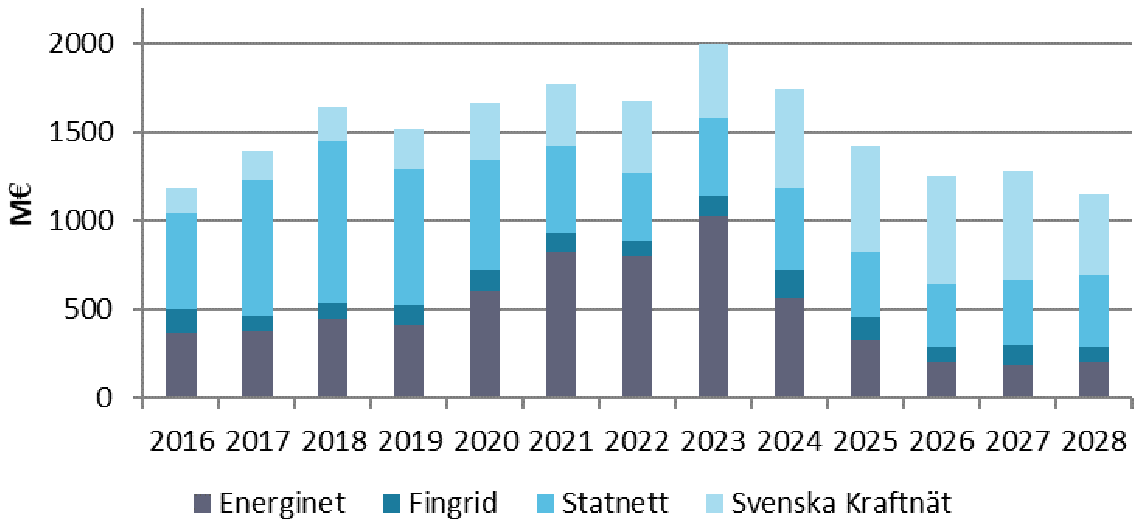


Figure 5-4 - Nordic TSO total investments in the transmission network up to 2025

Five corridors were identified in the Nordic Grid Development Plan (NGDP) 2017 between the areas SE-NO, SE-FI, SE-DK, NO-DK and NO-FI to be the most significant and further evaluated in NGDP 2019. The five bilateral studies were based on a common Nordic scenario and evaluation framework. The bilateral studies indicate a long-term need and the socio-economic benefit of both maintaining and expanding the interconnector capacity within the Nordic system.

Figure 5-5 - Nordic corridors that were analysed in the 2019 Nordic Grid Development Plan

The most important messages of the Nordic plan are summarised below:

- Many transmission projects are being built and commissioned. The main drivers are integration of an increasing number of renewables, security of supply and market integration, with entailed socio-economic welfare gains
- Historically high levels of investment in the Nordic region (Figure 5-4). The Nordic TSOs expect to invest more than €15bn from 2016 to 2028
- Variability of electricity production and consumption drives up the benefit of interconnectors in the bilateral analysis
- The Nordic power system is becoming more complex and interconnected due to the growth in renewable resources.

The full study can be found here: Nordic Grid Development Plan

APPENDICES

Appendix 1. Links to National Development Plans

Each Member State prepares its own National Development Plan that contains much more detailed information about power system and transmission network developments. The national development plans are harmonised with TYNDP and are in line with European Union regulations and guidelines. The national development plans for the Baltic Sea Regional Group countries are given below.

Country	Company/TSO
Denmark	https://energinet.dk/Om-publikationer/Publikationer/RUS-plan-2018
Estonia	https://elering.ee/sites/default/files/public/Elering_VKA_2017.pdf
Finland	https://www.fingrid.fi/globalassets/dokumentit/fi/kantaverkko/kantaverkon-kehittaminen/main_grid_development_plan_2019-2030.pdf
Germany	https://www.netzentwicklungsplan.de/
Latvia	http://www.ast.lv/sites/default/files/editor/Attiistiibas_plaans_2020_2029_ar_pielikumiem.pdf
Lithuania	https://www.litgrid.eu/index.php/tinklo-pletra/lietuvos-elektros-perdavimo-tinklu-10-metu-pletros-planas-/3850 https://www.litgrid.eu/index.php/grid-development-/-electricity-transmission-grid-ten-year-development-plan/3851
Norway	https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/nup-og-ksu/statnett-nettutviklingsplan-2019.pdf
Poland	https://www.pse.pl/documents/20182/8c629859-1420-432f-8437-6b3a714dda9c?safeargs=646f776e6c6f61643d74727565
Sweden	https://www.svk.se/siteassets/om-oss/rapporter/2018/svenska-kraftnat-system-development-plan-2018-2027.pdf

Table 6-1 - ENTSO-E Regional Group Baltic Sea National Development Plans

Appendix 2. Projects

The following projects were collected during the project calls and represent the most important projects for the region. In order to include a project in the analysis, it needs to meet several criteria. These criteria are described in the ENTSO-E practical implementation of the guidelines for inclusion in the TYNDP 2018[5]. The chapter is divided into pan-European and additional regional projects.

Pan-European projects

The map below shows all project applicants submitted by project promoters during the TYNDP 2020 first call for projects. In the final version of this document - after the second call for project submission and the consultation phase - the map will be updated showing the approved projects concerning TYNDP 2020. The Projects are divided into four different states, described in the CBA-guidelines as:

- In Permitting
- Planned but not permitting
- Under Consideration
- Under Construction

Depending on the status of a project, it will be assessed according to a Cost-Benefit Analysis.

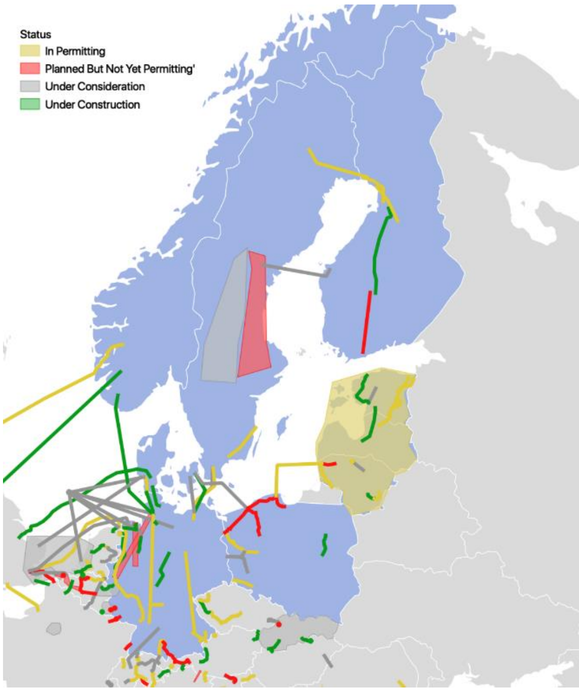


Figure A21 Projects submitted to the TYNDP 2020

[5] https://tyndp.entsoe.eu/Documents/TYNDP%20documents/Third%20Party%20Projects/171002_ENTSO-E%20practical%20implementation%20of%20the%20guideliens%20for%20inclusion%20of%20proj%20in%20TYNDP%202018_FINAL.pdf

Regional projects

The table below lists the projects of regional and national significance in the Baltic Sea region. They are listed as they need the substantial and inherent support of the pan-European projects in order to be included in future transmission systems. All these projects include appropriate descriptions, the main driver, why they are designed to be realised in future scenarios, together with the expected commissioning dates and evolution drivers if they were introduced in past RegIPs.

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

Country	Project Name	Investment		Expected Commissioning year	Description	Main Drivers	Status in RepIP 2017	Status in RepIP 2020
		From	To					
Finland	Huittinen-Forssa 400kv + 110kv	Huittinen (FI)	Forssa (FI)	2025	New 400kV + 110kV AC OHL (one circuit each voltage level) of 69km between substations Huittinen and Forssa.	Security of supply	Not included	
Finland	Länsisalmi -Viikinmäki 400kV cable and grid reinforcements in the capital area	Länsisalmi (FI)	Viikinmäki (FI)	2021-2035	New 400kv cable between Länsisalmi and Viikinmäki substations and other grid reinforcements in the capital area of Finland	Security of supply	Not included	
Finland	Fennovoima NPP connection	Valkeus (FI)	Lumijärvi (FI)	2028	This project involves a new double-circuit 400kv OHL line between Valkeus (FI) and Lumimetsä (FI). The new line is required for connecting the new Fennovoimas nuclear power plant planned to be built in Pyhäjoki. The power plant has a planned generation capacity of 1,200 MW. The decision to build the connection and schedule depends on the progress of the Hanhikivi NPP project.	Connection of new NPP	Not included	
Norway	Voltage upgrades through north and central Norway				Will increase the capacity in the north-south direction. Detailed information given in Statnett's Grid Development Plan 2017 and 2019.	Increase of capacity and RES integration	Not included	

							Not included	
Norway	Ofoten–Balsfjord–Skillemoen-Skaidi			2016-2022	A new 420kV line (ca. 450km) will increase the capacity in the north of Norway, mainly to serve increased petroleum-related consumption, as well as increase the security of supply. In addition, the project will prepare for some new wind power production. A line further east (Skaidi Varangerbotn)	Security of supply and increase of capacity	Not included	
					is under consideration; however, no decision has yet been taken.			
Norway	Western corridor			→2021/22	Voltage upgrades in the south western part of Norway. The project will increase the north-south capacity as well as facilitate higher utilisation of the planned interconnectors. Detailed information given in Statnett's Grid Development Plan 2017 and 2019.	Increase of capacity and utilisation of interconnectors	Not included	
Sweden	South west Link			2020	Will increase the internal Nordic capacity in a north-south direction between areas SE3 and SE4. This will make it possible to handle an increased amount of renewable production in the north part of the Nordic area as well as increase trade on Nord-Balt and the planned Hansa Power Bridge with less risk for limitations. The project has been delayed several times due to difficulties with the implementation phase.	Market integration, Securit y of supply	Not included	
Sweden	Ekhyddan - Nybro -Hemsjö			2025	This is currently a PCI project included in the third PCI list. The project consists of a new 400kV AC single circuit OHL of 70km between Ekhyddan and Nybro and a new 400kV AC single circuit OHL of 85km between Nybro and Hemsjö. The reinforcements are necessary to fully and securely utilise the NordBalt interconnection that is connected in Nybro.	Security of supply, Market integrat ion	Not included	

Sweden	North-South SE2 - SE3			2017 and beyond	New shunt compensation and upgrades of existing series compensation between price areas SE2 and SE3 are planned for installation between 2017 and 2025. The oldest of the 400kv lines between SE2 and SE3 are expected to be replaced with new lines with a higher transfer capacity. The first replacement is planned for 2027–2030. These reinforcements will significantly increase the north-south capacity in the internal Nordic transmission grid.	Market integration, Security of supply, RES integration	Not included	
Sweden	Skogssäter – Stenkullen Swedish West Coast			2025	A new 400kv single circuit overhead line that will increase capacity on the Swedish west coast. This will lead to a greater trading capacity between Sweden, Denmark and Norway.	Market integr ation, RES integr ation	Not included	
Denmark	Endrup-Idomlund Revsing-Lander upgaard Bjæverskov-Hovegaard			2019-2024	All projects are 400kv domestic transmission lines. The purpose of the investments is to integrate both ongoing and planned connections of renewable generation (offshore wind farms) and to connect new interconnectors (COBRA, Viking Link, DK West Germany, etc., see Section 4.3.3 in https://en.energinet.dk/-/media/.../Presse.../Nordic-Grid-Development-Plan-2017.pdf) to the domestic grid.	Market integration, Security of supply, RES integration	Not included	

Germany		Pulgar (DE)	Vieselbach (DE)	2024	Construction of new 380kV double-circuit OHL in existing corridor Pulgar-Vieselbach (104km). Detailed information given in Germany's Grid Development.	RES integration/Security of supply		In Permitting
Germany		Hamburg/Nord (DE)	Hamburg/Ost (DE)	2030	Reinforcement of existing 380kv OHL Hamburg/Nord - Hamburg/Ost and Installation of Phase Shifting Transformers in Hamburg/Ost. Detailed information given in Germany's Grid Development.	RES integration		In permitting /under consideration

Germany		Hamburg/Ost (DE)	Krümmel (DE)	2030	New 380kv OHL in existing corridor Krümmel - Hamburg/Ost. Detailed information given in Germany's Grid Development.	RES integration		In permitting /under considera tion
Germany		Elsfleht/West (DE)	Ganderkesee (DE)	2030	New 380kv OHL in existing corridor for RES integration between Elsfleth/West, Niedervieland and Ganderkesee	RES integration		Planned, but not yet in permitting
Germany		Dollern (DE)	Alfstedt (DE)	2029	New 380kv OHL in existing corridor in Northern Lower Saxony for RES integration	RES integration		Planned, but not yet in permitting
Germany		Alfstedt (DE)	Elsfleth/West (DE)	2029	New 380kv line Alfstedt - Elsfleth/West in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Emden (DE)	Halbemond (DE)	2029	New 380kv line Emden - Halbemond for RES integration. Construction of new substation Halbemond	RES integration		Planned, but not yet in permitting
Germany		Conneforde (DE)	Unterweser (DE)	2030	New 380kV OHL in existing corridor for RES integration in Lower Saxony	RES integration		Planned, but not yet in permitting
Germany		Wolmirstedt (DE)	Klostermansfeld (DE)	2030	New 380kV OHL in existing corridor for RES integration between Wolmirstedt - Klostermansfeld	RES integration		Planned, but not yet in permitting
Germany		Klostermannsfeld (DE)	Schraplau/Obhausen - Lauchstädt (DE)	2030	New 380kv OHL in existing corridor between Klostermannsfeld - Schraplau/Obhausen - Lauchstädt. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Point Kriftel (DE)	Farbwerke Höchst-Süd (DE)	2022	The 220kV substation Farbwerke Höchst-Süd will be upgraded to 380kV and integrated into the existing grid.	RES integration/Security of supply		Planned, but not yet in permitting
Germany		Several		2030	Vertical Measures in the Amprion zone	RES integration/Security of supply		Planned
Germany		Büttel (DE)	Wilster/West (DE)	2030	New 380kv line in existing corridor in Schleswig - Holstein for integration of RES especially wind on- and offshore	RES integration		Planned, but not yet in

								permitting
Germany		Brunsbüttel (DE)	Büttel (DE)	2030	New 380kv line Brunsbüttel - Büttel in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Wilster/West (DE)	Stade/West (DE)	2030	New 380kv line Wilster/West - Stade/West in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		junction Mehrum (DE)	Mehrum (DE)	2021	New 380kv line junction Mehrum (line Wahle - Grohnde) - Mehrum including a 380/220kv transformer in Mehrum	RES integration		under constructi on
Germany		Borken (DE)	Mecklar (DE)	2023	new 380kv line Borken - Mecklar in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Borken (DE)	Gießen (DE)	2030	new 380kv line Borken - Gießen in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Borken (DE)	Twistetal (DE)	2023	new 380kv line Borken - Twistetal in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Wahle (DE)	Klein Ilsede (DE)	2021	new 380kv line Wahle - Klein Ilsede in existing corridor for RES integration	RES integration		under considera tion
Germany		Birkenfeld (DE)	Ötisheim (DE)	2021	A new 380kV OHL Birkenfeld-Ötisheim (Mast 115A)	Security of supply		Permitting /Under constructi on
Germany		Bürstadt (DE)	BASF (DE)	2021	New line and extension of existing line to 400kv double circuit OHL Bürstadt - BASF including extension of existing substations.	RES integration/Security of supply		Planned, but not yet in permitting
Germany		Neuenhagen (DE)	Vierraden (DE)	2022	New 380kV double-circuit OHL Neuenhagen-Vierraden-Bertikow with 125km length as prerequisite for the planned upgrading of the existing 220kV double-circuit interconnection	RES integration/Security of supply		In Permitting

					Krajnik (PL) - Vierraden (DE Hertz Transmission).. Detailed information given in Germany's Grid Development.			
Germany		Neuenhagen (DE)	Wustermark (DE)	2021	Construction of new 380kV double-circuit OHL between the substations Wustermark and Neuenhagen with 75km 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		In Permitting /Under constructi on
Germany		Pasewalk (DE)	Bertikow (DE)	2023	Construction of new 380kV double-circuit OHLs in North-Eastern part of 50HzT control area and decommissioning of existing old 220kV double-circuit OHLs, incl. 380kv line Bertikow-Pasewalk (30km).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		In Permitting
Germany		Röhrsdorf (DE)	Remptendorf (DE)	2025	Construction of new double-circuit 380kv OHL in existing corridor Röhrsdorf-Remptendorf (103km)	Security of supply		In Permitting
Germany		Vieselbach (DE)	Mecklar (DE)	2027	New double circuit OHL 380kv line in existing OHL corridor. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Area of Altenfeld (DE)	Area of Grafenrheinfeld (DE)	2029	New double circuit OHL 380kv in existing corridor (27km) and new double circuit OHL 380kv (81km). Detailed information given in Germany's Grid Development Plan.	RES integration		Planned, but not yet in permitting ;
Germany		Gießen/Nord (DE)	Karben (DE)	2025	new 380kv line Gießen/Nord - Karben in existing corridor for RES integration	RES integration		Planned, but not yet permitting
Germany		Herbertingen/Area of Constance/Beuren (DE)	Gurtweil/Tiengen (DE)	2030	Upgrade of the existing grid in two circuits between Gurtweil/Tiengen and Herbertingen. New substation in the Area of Constance	Security of supply		Planned, but not yet in permitting
Germany		Schraplau/Obhausen (DE)	Wolkramshausen (DE)	2030	New 380kv OHL in existing corridor between Querfurt and Wolkramshausen. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting

Germany		Marzahn (DE)	Teufelsbruch (DE)	2030	AC Grid Reinforcement between Marzahn and Teufelsbruch (380kv cable in Berlin). Detailed information given in Germany's Grid Development.	Security of supply		Planned, but not yet in permitting
Germany		Güstrow (DE)	Gemeinden Sanitz/Dettmannsdorf (DE)	2025	New 380kv OHL in existing corridor between Güstrow - Bentwisch - Gemeinden Sanitz/Dettmannsdorf. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Bentwisch (DE)	Bentwisch (DE)	2025	This investment includes a new 380/220kV transformer in Bentwisch	RES integration		Planned, but not yet in permitting
Germany		Güstrow (DE)	Pasewalk (DE)	2030	New 380kv OHL in existing corridor between Güstrow – Siedenbrünzow - Alt Tellin - Iven - Pasewalk. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Wolkramshausen (DE)	Vieselbach (DE)	2030	New 380kv OHL in existing corridor between Wolkramshausen-Ebeleben-Vieselbach. Detailed information given in Germany's Grid Development.	Security of supply		Planned, but not yet in permitting
Germany		Bürstadt (DE)	Kühmoos (DE)	2023	An additional 380kv OHL will be installed on existing power poles	RES integration/Security of supply		Planned, but not yet in permitting
Germany		Wolmirstedt (DE)	Wahle (DE)	2026	New 380kv OHL in existing corridor between Wolmirstedt - Helmstedt -Hattorf - Wahle. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Wolmirstedt (DE)	Mehrum/Nord (DE)	2030	New 380kv OHL in existing corridor between Wolmirstedt - Helmstedt - Gleidingen/Hallendorf - Mehrum/Nord. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		Oberbachern (DE)	Ottenhofen (DE)	2029	Upgrade of the existing 380kv lined. Detailed information given in Germany's Grid Development.	RES integration/Security of supply		Planned, but not yet in permitting
Germany		Urberach (DE)	Daxlanden (DE)	2024	Upgrade of existing 380kv lines in the region Frankfurt-Karlsruhe	Res integration		In Permitting
Germany		Daxlanden (DE)	Eichstetten (DE)	2028	Upgrade of existing 220kv lines from Daxlanden via Bühl,	Res integration		In Permitting

					Kuppenheim and Weier to Eichstetten to 380kv			
Germany		Kreis Segeberg (DE)	Siems (DE)	2026	New 380kv line Kreis Segeberg - Siems in existing corridor for RES integration	RES integration		In Permitting
Germany		Lübeck (DE)	Göhl (DE)	2027	New 380kv line Lübeck - Göhl for RES integration. Construction of new substation in Göhl	RES integration		In Permitting
Germany		Grafenrheinfeld (DE)	Großgartach (DE)	2025	Additional 380kv circuit and reinforcements in existing corridor between Grafenrheinfeld and Großgartach	RES integration		In Permitting
Germany		Raitersaich (DE)	Altheim (DE)	2028	New 380kv line Raitersaich - Altheim in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Redwitz (DE)	Schwandorf (DE)	2025	New 380kv line Redwitz - Schwandorf in existing corridor for RES integration	RES integration		In Permitting
Germany		Güstrow (DE)	Wolmirstedt (DE)	2022	New 380kv OHL in existing corridor between Güstrow - Parchim/Süd- Perleberg - Stendal/West - Wolmirstedt. Detailed information given in Germany's Grid Development.	RES integration		In Permitting /under constructi on
Germany		Grid of TransnetBW		2035	Construction of several reactive power compensation systems in the area of the TransnetBW GmbH	Res integration		Planned, but not yet in permitting
Germany		Krümmel (DE)	Wahle (DE)	2030	Including Ad-hoc-Maßnahme Serienkompensation Stadorf-Wahle	RES integration		Planned, but not yet in permitting
Germany		Bechterdissen	Ovenstädt	2030	Reinforcement of existing 380kv line between Bechterdissen and Ovenstädt	RES integration		Planned, but not yet in permitting
Germany		Großkrotzenburg (DE)	Urberach (DE)	2027	Reinforcement of existing 380kv line between Großkrotzenburg and Urberach	RES integration		Planned, but not yet in permitting
Germany		Wilhelmshaven 2 (DE)	Fedderwarden (DE)	2030	New 380kv line Wilhelmshaven 2 - Fedderwarden for RES integration	RES integration		Planned, but not yet in

								permitting
Germany		Redwitz (DE)	Border Bayern/Thüringe n	2021	Reinforcement of existing 380kv line between Redwitz - Border Bayern/Thüringen	RES integration		In permitting
Germany		point Blatzheim (DE)	Oberzier (DE)	2025	Reinforcement of existing 380kv line between point Blatzheim and Oberzier	Res integration		Planned, but not yet in permitting
Germany		Landesbergen (DE)	Mehrum/Nord (DE)	2030	New 380kv line Kreis Segeberg - Siems in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Höpfingen (DE)	Hüffenhardt (DE)	2030	Additional 380kv line between Höpfingen and Hüffenhardt	Res integration		Planned, but not yet in permitting
Germany				Up to 2030	Phase-shifting transformers in the Saarland	Res integration		Planned
Germany		Hanekenfähr (DE)	Gronau (DE)	Up to 2030	Reinforcement of existing/ new 380kv line between Hanekenfähr and Gronau	Res integration		Planned, but not yet in permitting
Germany				2023	Ad-hoc phase-shifting transformers in the Ruhr region	Res integration		Planned
Germany		Hamburg/Ost (DE)		2022	Four PST in substation Hamburg/Ost	RES integration		Planned, but not yet in permitting
Germany		Hanekenfähr (DE)		2023	Ad-hoc-phase-shifting transformers in Hanekenfähr	Res integration		Planned
Germany		Oberzier (DE)		2023	Ad-hoc-phase-shifting transformers in Oberzier	Res integration		Planned
Germany		Wilster/West (DE)		2023	New phase-shifting transformers in Wilster/West	RES integration		Planned, but not yet in permitting

Germany		Würgau		2023	New phase-shifting transformers in Würgau	RES integration		Planned, but not yet in permitting
Germany		Pulverdingen(DE)		2023	New phase-shifting transformer in Pulverdingen	Res integration		Planned, but not yet in permitting
Germany		Twistetal		2025	New phase-shifting transformers in Twistetal	RES integration		Planned, but not yet in permitting
Germany		Güstrow (DE)		2025	Four PST in substation Güstrow	RES integration		Planned, but not yet in permitting
Germany		Lauchstädt + Weida (DE)		2025	This investment includes two new 380/220kV transformers in Lauchstädt and a new 380/220kv transformer in Weida	RES integration		Planned, but not yet in permitting
Germany		Osterburg (DE)	Wolmirstedt (DE)	2030	New 380kv OHL in existing corridor between Osterburg - Stendal/West - Wolmirstedt. Detailed information given in Germany's Grid Development.	RES integration		Planned, but not yet in permitting
Germany		(substations Lauchstädt, Altenfeld, Röhrsdorf, Ragow, Siedenbrünzow, Hamburg, Neuenhagen) (DE)		2030	Installation of reactive power compensation (eg MSCDN, STATCOM) in 50Hertz control area (substations Lauchstädt, Altenfeld, Röhrsdorf, Ragow, Siedenbrünzow, Hamburg, Neuenhagen)	RES integration/Security of supply		Planned, but not yet in permitting
Germany		Audorf/Süd	Ottenhofen (DE)	2025	100 MW grid booster in substations Audorf/Süd and Ottenhofen	RES integration		Planned, but not yet in permitting
Germany		Grid of TenneT (DE)			Construction of several reactive power compensation units in grid of TenneT (DE)	RES integration		Planned, but not yet in permitting
Germany		Hattingen (DE)	Linde (DE)	Up to	reinforcement of existing OHL between Hattingen and Linde	Res integration		Planned, but not

				2030				yet in permitting
Germany		Enniger		2025	phase-shifting transformers in Enniger	Res integration		Planned
Germany					several reactive power compensation systems in the area of the Amprion GmbH	Res integration		Planned
Germany		Kühmoos			Upgrade of substation Kühmoos in Southern Germany	Res integration		Planned, but not yet in permitting
Germany		Kupferzell			500MW grid booster in substation Kupferzell	Res integration		Planned, but not yet in permitting
Germany		Siedenbrünzow (DE)	Osterburg (DE)	2025	Siedenbrünzow - Güstrow - Putlitz – Perleberg - Osterburg	RES integration		Planned, but not yet in permitting
Germany		Graustein (DE)	Bärwalde (DE)	2025	Reinforcement of existing 380kv OHLGraustein - Bärwalde	RES integration		Planned, but not yet in permitting
Germany		Ragow (DE)	Streumen (DE)	2025	Reinforcement of existing 380kv line Ragow - Streumen	RES integration		Planned, but not yet in permitting
Germany					Grid reinforcements in the region Büscherhof	Res integration		Planned
Germany					Grid reinforcements in the region Aachen	Res integration		Planned
Germany					Grid reinforcements in western Rhein region	Res integration		Planned
Germany		Conneforde (DE)	Samtgemeinde Sottrum (DE)	2030	New 380kv line Conneforde - Sottrum in existing corridor for RES integration	RES integration		Planned, but not yet in permitting
Germany		Großgartach (DE)	Endersbach (DE)	2030	Grid reinforcements in existing corridor between Großgartach	Security of supply		Planned, but not

					and Endersbach. Extension of substation Wendlingen is included			yet in permitting
Germany		Pulverdingen(DE)		2030	Upgrade of substation Pulverdingen in Southern Germany	Security of supply		Under considera tion
Germany		Conneforde(DE)	Cloppenburg (DE)	2026	New 380kv line Conneforde - Cloppenburg	RES integration		Planned, but not yet in permitting
Germany		Cloppenburg (DE)	Merzen(DE)	2026	New 380kv line Cloppenburg - Merzen	RES integration		Planned, but not yet in permitting
Germany		Mecklar (DE)	Bergrheinfeld/We st (DE)	2031	New 380kv line Mecklar - Bergrheinfeld/West	RES integration		Planned, but not yet in permitting
Germany		Dollern (DE)	Landesbergen (DE)	2026	New 380kv line Dollern - Landesbergen	RES integration		Planned, but not yet in permitting

Appendix 3. Abbreviations

The following list shows abbreviations used in the Regional Investment Plans 2019.

- AC - Alternating Current
- ACER - Agency for the Cooperation of Energy Regulators
- CCS - Carbon Capture and Storage
- CBA - Cost-Benefit-Analysis
- CHP - Combined Heat and Power Generation
- DC - Direct Current
- EH2050 - e-Highway2050
- EIP - Energy Infrastructure Package
- ENTSO-E - European Network of Transmission System Operators for Electricity
- ENTSOG - European Network of Transmission System Operators for Gas
- EU - European Union
- GTC - Grid Transfer Capability
- HV - High Voltage
- HVAC - High Voltage AC
- HVDC - High Voltage DC
- IEA - International Energy Agency
- IEM Internal Energy Market
- KPI - Key Performance Indicator
- LCC - Line Commutated Converter
- LOLE - Loss of Load Expectation
- MAF - Mid-term Adequacy Forecast

- MS - Member State
- MWh - Megawatt hour
- NGC - Net Generation Capacity
- NRA - National Regulatory Authority
- NREAP - National Renewable Energy Action Plan
- NTC - Net Transfer Capacity
- OHL - Overhead Line
- PCI - Projects of Common Interest
- PINT - Put IN one at a Time
- PST - Phase Shifting Transformer
- RegIP - Regional Investment Plan
- RES - Renewable Energy Sources
- RG BS - Regional Group Baltic Sea
- RG CCE - Regional Group Continental Central East
- RG CCS - Regional Group Continental Central South
- RG CSE - Regional Group Continental South East
- RG CSW –Regional Group Continental South West
- RG NS –Regional Group North Sea
- SEW - Socio-Economic Welfare
- SOAF - Scenario Outlook & Adequacy Forecast
- SoS - Security of Supply

- SSI - Smart Sector Integration
- TEN-E - Trans-European Energy Networks
- TOOT - Take Out One at a Time
- TSO - Transmission System Operator
- TWh - Terawatt hour
- TYNDP - Ten-Year Network Development Plan
- VOLL - Value of Lost Load
- VSC - Voltage Source Converter

Appendix 4. Glossary

The following list describes a number of terms used in this Regional Investment Plan.

Term	Acronym	Definition
Agency for the Cooperation of Energy Regulators	ACER	EU Agency established in 2011 by the Third Energy Package legislation as an independent body to foster the integration and completion of the European Internal Energy Market, both for electricity and natural gas.
Baltic Energy Market Interconnection Plan in Electricity	BEMIP 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.
Carbon Capture and Storage	CCS	Process of sequestrating CO2 and storing it in such a way that it will not enter the atmosphere.
Carbon Capture and Usage	CCU	The captured CO2, instead of being stored in geological formations, is used to create other products, such as plastic.
Combined Heat and Power	CHP	Combined heat and power generation.
Congestion revenue/rent		The revenue derived by interconnector owners from the sale of interconnector capacity through auctions. In general, the value of 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	The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, organised in 2015, where participating states reached the Paris Agreement.
Cost-benefit analysis	CBA	Analysis carried out to define to what extent a project is worthwhile from a social perspective.

Cluster		Several investment items matching the CBA clustering rules. Essentially, a project clusters all investment items that have to be realised in total to achieve a desired effect.
Corridors		The CBA clustering rules proved to be challenging for complex grid reinforcement strategies: the largest investment needs may require some 30 investments items, scheduled over more than five years but addressing the same concern. In this case, for the sake of transparency, they are formally presented in a series - a corridor - of smaller projects, each matching the clustering rules.
Curtailed electricity		Curtailment is a reduction in the output of a generator from otherwise available resources such as 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.
Demand side response	DSR	Consumers have an active role in softening peaks in energy demand by changing their energy consumption according to the energy price and availability.
e-Highway2050	EH2050	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).
Energy not served	ENS	Expected amount of energy not being served to consumers by the system during the period considered due to system capacity shortages or unexpected severe power outages.
Grid transfer capacity	GTC	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.
Internal Energy Market	IEM	To harmonise and liberalise the EU's internal energy market, measures have been adopted since 1996 to address market access, transparency and regulation, consumer protection, supporting interconnection, and adequate levels of supply. These measures aim to build a more competitive, customer-centred, flexible and non-discriminatory EU electricity market with market-based supply prices.

Investment (in the TYNDP)		Individual equipment or facility, such as a transmission line, a cable or a substation.
Mid-term adequacy forecast	MAF	ENTSO-E's yearly pan-European monitoring assessment of power system resource adequacy spanning a timeframe from one to ten years ahead.
Marginal costs		Current market simulations, in the framework of TYNDP studies, compute the final 'price' of electricity taking into account only generation costs (including fuel costs and CO2 prices) per technology. In the real electricity market not only the offers from generators units are considered but taxes and other services such as ancillary services take part as well (reserves, regulation up and down…) which introduce changes in the final electricity price.
Net transfer capacity	NTC	The maximum total exchange programme between two adjacent control areas compatible with security standards applicable in all control areas of the synchronous area and taking into account the technical uncertainties on future network conditions.
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.
National Energy and Climate Plan	NECP	National Energy and Climate Plans are the new framework within which EU Member States have to plan, in an integrated manner, their climate and energy objectives, targets, policies and measures for the European Commission. Countries will have to develop NECPs on a ten-year rolling basis, with an update halfway through the implementation period. The NECPs covering the first period from 2021 to 2030 will have to ensure that the Union's 2030 targets for greenhouse gas emission reductions, renewable energy, energy efficiency and electricity interconnection are met.
North Seas offshore grid	NSOG	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.
North-south electricity interconnections in central eastern and south eastern Europe	NSI East Electricity	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.
North-south electricity interconnections in western Europe	NSI West Electricity	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 renewable energy sources and

		reinforce internal grid infrastructures to promote market integration in the region.
Power to gas	P2G	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.
Project candidate		Investment(s) considered for inclusion in the TYNDP.
Project of common interest	PCI	A project which meets the general and at least one of the specific criteria defined in Article 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.
Put IN one at the Time	PINT	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.
Take Out One at the Time	TOOT	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.
Ten-Year Network Development Plan	TYNDP	The Union-wide report carried out by ENTSO-E every other year as (TYNDP) part of its regulatory obligation as defined under Article 8, paragraph 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.
Transmission capacity/Total Transfer Capacity	TTC	The maximum transmission of active power in accordance with the system security criteria which is permitted in transmission cross-sections between the subsystems/areas or individual installations.
Trans-European Networks for Energy	TEN-E	Policy focused on linking the energy infrastructure of EU countries. It identifies nine priority corridors - including four for electricity - and three priority thematic areas.
Vision		Plausible future states selected as possible wide-ranging alternatives.

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