Regional Investment Plan 2017

Baltic Sea

Final version after public consultation and ACER opinion - October 2019

entsoe

Reliable Sustainable Connected

Contents

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1 EXECUTIVE SUMMARY

1.1 Regional investment plans as the foundation for the TYNDP 2018

The Ten-Year-Network-Development-Plan (TYNDP) for electricity is the most comprehensive and up-to-date planning document for the pan-European transmission electricity network, and is prepared by ENTSO-E. This plan presents and assesses all relevant pan-European projects for a specific time horizon, as defined by a set of different scenarios that best describe the future development and transition of the electricity market.

The TYNDP is a biennial report published every even year by ENTSO-E and acts as an essential basis for deriving the Projects of Common Interest (PCI) list.

ENTSO-E is structured into six regional groups for grid planning and other system development tasks. The countries belonging to each regional group are shown in Figure 1-1.

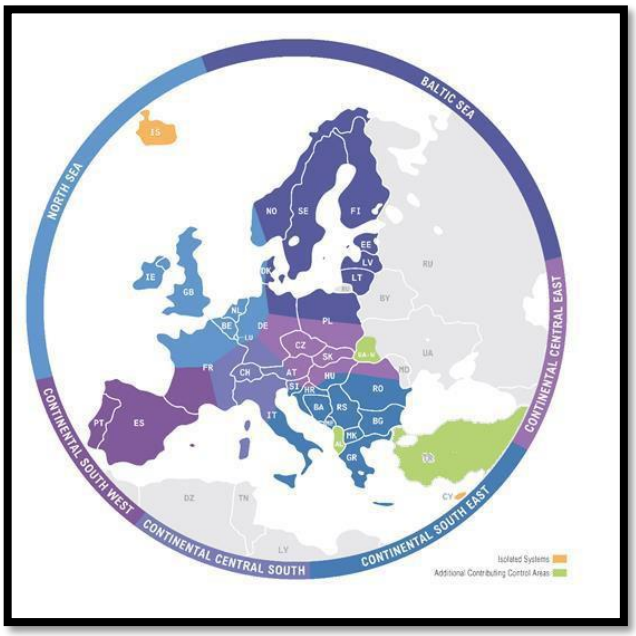

Figure 1-1 ENTSO-E System Development Regions.

The six regional investment plans (RegIPs) are part of the TYNDP 2018 package and are supported by regional and pan-European analyses, which take into account feedback received from institutions and other stakeholder associations.

The RegIPs address challenges and system needs at the regional level. They are based on the results of a pan-European market study combined with European and/or regional network studies. They present the present situation of the region as well as any future regional challenges, and consider different scenarios using a time horizon of 2040.

Besides illustrating the challenges leading up to the 2040-time horizon and the proper scenario grid capacities for solving these challenges, the RegIPs also show all relevant regional projects from the TYNDP project collection. The benefits of each of these projects will be assessed and presented in the final TYNDP publication package later in 2018.

Regional sensitivities and other available studies are included in the RegIPs to illustrate circumstances that are relevant for a particular region. The operational functioning of the regional systems and the future challenges facing them are also assessed and described in the reports.

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Due to the fact that the RegIPs are published every second year, the Regional Investment Plan 2017 builds on the previous investment plans and describes any changes and updates compared to earlier publications. As the RegIPs give a regional insight into future challenges, the main messages will also be highlighted in a pan-European System Need report. The studies of the regional plans and the pan-European System Need report are based on the scenarios described in the scenario report.

The RegIP will strongly support one of the main challenges facing ENTSO-E: to determine the most efficient and collaborative way to reach all the defined targets of a working internal energy market and a sustainable and secure electricity system for all European consumers.

1.2 Key messages for the region

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

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. At the same time, society's dependence 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 the flows to cover the deficit at the load centres due to closure of power plants and the growing flows between synchronous areas. In order to solve the challenges regarding balancing the load and power generation in all parts of the region in the short and long term – particularly when the power generation portfolio is becoming increasingly weather-dependent – further grid development is necessary.

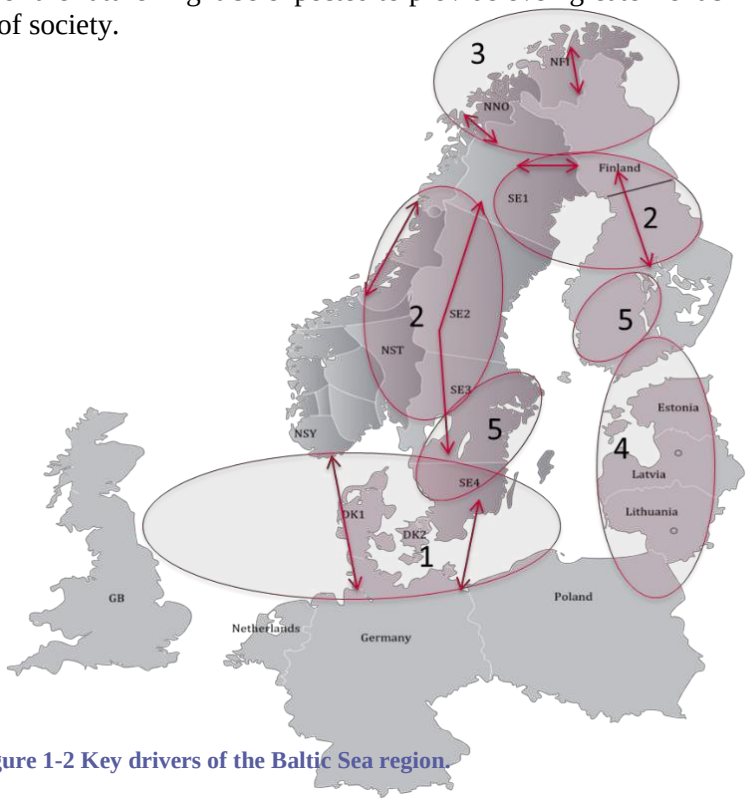

Figure 1-2 Key drivers of the Baltic Sea region.

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From a grid development perspective, the main drivers within the Baltic Sea region are as follows.

Driver 1: Flexibility – The need from other synchronous areas
→ Further integration between the Nordic countries and the continent/UK

The Nordic system is likely to increase the annual energy surplus (even if some nuclear power plants are decommissioned), which means it will be beneficial to strengthen the capacity between the Nordic countries and the UK/continental Europe. This increases market integration as well as furthering the value creation of renewables. In addition, for daily regulatory purposes, it will be beneficial to further connect the Nordic hydro-based system to the thermal-based continental system and the wind-based Danish system, particularly when large amounts of renewables are connected to the continental system.

Driver 2: Integration of renewables → North-South flows

Based on the political goals of reduced CO_2 emissions, and based on the cost development of wind and solar, further integration of renewables is expected within the Nordic countries. New interconnectors to the continent/UK/Baltic States in combination with substantial amounts of new renewable generation capacity is increasing the need to strengthen the 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 the demand for capacity in the north-south direction.

Driver 3: New consumption/electrification → reinforcements and upgraded level of security of supply

Depending on location and size, higher power demands may also trigger the need for investments in the existing power grids. In the far north, the establishment of new power-intensive industries such as mines, or the switch from fossil fuels to electricity in the petroleum industry, could create a need for substantial reinforcement. The general trends regarding electrical transportation, increasing power consumption in the larger cities, etc. will also put the focus on how to secure future supplies.

Driver 4: Baltic integration → Security of supply for the Baltic system

Since the last Baltic Sea Regional Investment Plan in 2015, the integration of Baltic countries with European energy markets has made great strides with the commissioning of the NordBalt and LitPol link. Baltic countries are now connected to Finland, Sweden and Poland via HVDC connections.

For historical reasons, the Baltic States are currently operated in synchronicity with the Russian and Belarussian electricity systems (the IPS/UPS system). The three Baltic TSOs are preparing to de-synchronise from IPS/UPS, and instead to synchronise with the Continental European Network (CEN) through current interconnections between Lithuania and Poland. Synchronisation of Baltic countries with the CEN will ensure energy security by connection to a grid that is operated following common European rules.

Driver 5: Nuclear and thermal decommissioning → Challenges to the security of supply

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

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1.3 Future capacity needs

The drivers for grid development described above are the basis for needing further grid developments. The grid development needs in the short term can be studied by analysing the current measurements, trends and plans of producers as well as consumption changes. The 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 the new infrastructure in the long term. It is not meaningful to try to forecast the future as 'one truth', because small changes, such as in policies or fuel prices, can have a major impact on the resulting view of the future. To be able to analyse future capacity needs, three scenarios for 2040 have been developed and the capacity needs are analysed in all these scenarios. The potential changes in both generation and consumption are described in the first phase of the TYNDP-2018 process, building new scenarios for 2025, 2030 and 2040 and assessing system needs for the long-term horizon of 2040. As part of this work, cross-border capacity increases, which have a positive impact on the system, have been identified. A European overview of these increases is presented in the European System Needs report developed by ENTSO-E in parallel with the RegIPs. Identified capacity increases, both within and at the borders of the Baltic Sea region, are shown in Figure 1-3 below.

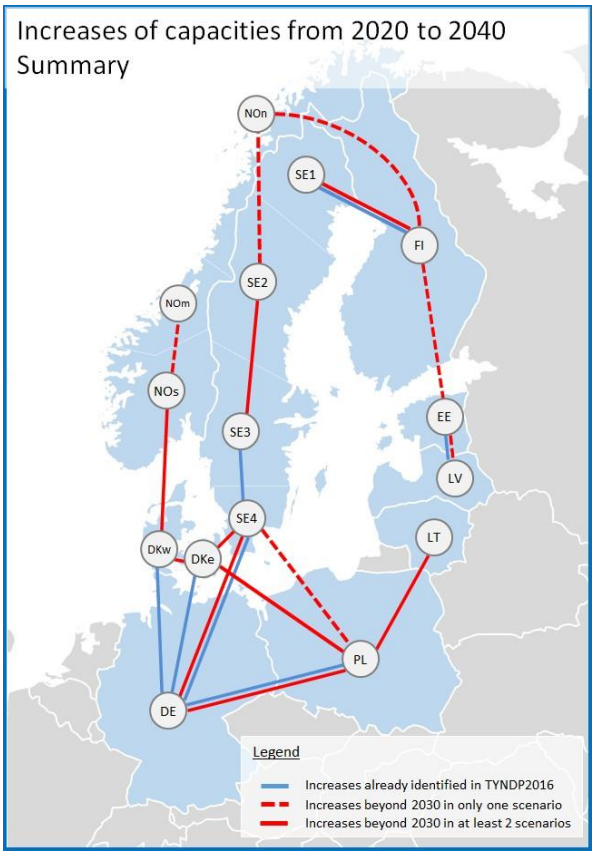

Figure 1-3 Identified capacity increase needs between 2020 and 2040 and projects in the reference grid of IoSN.[1]

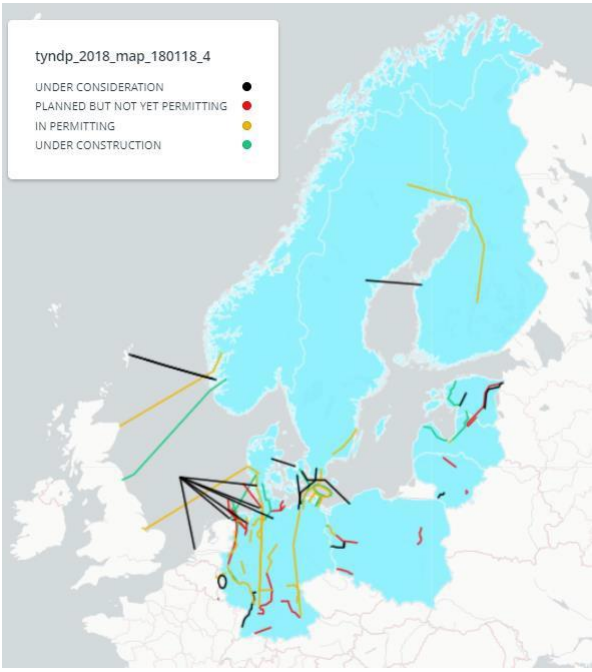

Figure 1-4 All project applications submitted to ENTSO-E.

[1] 'Increases already identified in TYNDP2016' refers to the reference capacities of TYNDP2016 from 2030, which for some borders had been adjusted for the TYNDP2018. Projects commissioned in 2020 are not included as capacity increases.

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The system needs for the 2040 horizon are being evaluated with respect to (1) market-integration/ socio-economic welfare, (2) integration of renewables and (3) security of supply.

For the Baltic Sea region the 2040 needs are mainly being determined through:

- Stronger integration Germany-Poland to increase market-integration and to facilitate decommissioning of thermal power plants in Poland;
- Further integration Sweden-Finland to increase market integration;
- Further integration Norway-Denmark due to price differences and to improve Danish security of supply during high demand and low variable RES (wind and solar) periods;
- Further integration between Sweden/Denmark and Germany due to price differences and better optimisation of RES generation (hydro/wind); and
- Further internal integration within the Baltics, mainly due to concerns with security of supply.

In addition to these long-term increases, the high wind scenario (Global Climate Action) introduces huge wind power growth in the north of Norway. This scenario will lead to an increased capacity-need in the north-south direction towards Finland, Sweden and Southern Norway. The scenario is not based on a total economy review (grid+production-investments).

All of the scenarios being studied include a large increase in renewable generation and a decrease in CO_2 emissions, but without additional grid development the price spread between market areas in the region would explode and some of the climate benefits would not be realised. The benefits of increased capacities in the scenarios are clearly visible in the market results. Increasing the capacities at the borders, as shown in Figure 1-3 would have a significant impact on both the electrical system and on society. In summary, the main benefits of implementing the identified capacity needs, if the scenarios end up realising the summarised results, are shown below:

- Up to 27€ reduction in marginal costs per MWh;
- 13 to 77 TWh less curtailed energy;
- Up to 60 GWh reduction in energy not served;[2]
- A 9 to 30 MT reduction in CO_2 emissions.

The needs for the region that were discovered in the Pan-European System Needs analysis for 2040 are partly covered by projects that are already on the assessment list for TYNDP 2018 (Figure 1-4). For some of the corridors, there is a gap between the needs for 2040 and the projects being assessed in TYNDP 2018. However, projects for the Baltics, and those between Sweden and Finland, Sweden and Germany and Norway and the UK/continent covers some of the needs described above and therefore plugs some of the gaps.

[2] Energy not served without taking emergency reserves into account.

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2 INTRODUCTION

2.1 Legal requirements

The present publication is part of the TYNDP package and complies with Regulation (EC) 714/2009 Article 8 and 12, which states that TSOs shall establish regional cooperation within ENTSO-E and shall publish a RegIP every two years. TSOs may make investment decisions based on the RegIP, and ENTSO-E shall provide a non-binding community-wide ten-year network development plan, which is built on national investment plans and the reasonable needs of all system users, and also identifies investment gaps.

The TYNDP package complies with Regulation (EU) 347/2013 'The Energy Infrastructure Regulation'. This regulation defines new European governance and organisational structures, which will promote transmission grid development.

RegIPs are to provide a detailed and comprehensive overview on future European transmission needs and projects in a regional context and to a wide range of audiences:

- The Agency for the Cooperation of Energy Regulators (ACER), which has a crucial role in coordinating regulatory views on national plans, provides an opinion on the TYNDP itself and its coherence with national plans, and also gives an opinion on the EC's draft list of PCI projects;
- European institutions (EC, Parliament, Council) that have acknowledged infrastructure targets as a crucial part of pan-European energy goals will give insight into how various targets influence and complement each other;
- The energy industry, covering network asset owners (within ENTSO-E perimeter and the periphery) and system users (generators, demand facilities and energy service companies);
- National regulatory authorities and ministries that will place national energy matters in an overall European common context;
- Organisations having a key function in disseminating energy-related information (sector organisations, NGOs, press) for whom this plan serves as a 'communications toolkit'; and
- The general public, so that they can understand what drives infrastructure investments in the context of new energy goals (RES, market integration) while maintaining an adequate energy system adequacy and facilitating a secure system operation.

2.2 Scope of the report

The present RegIP is part of a set of documents (see Figure 2-1) comprising a first step in composing a Mid-Term Adequacy Forecast report (MAF), a Scenario report, a Monitoring report, a Pan-European System Needs report and six RegIPs.

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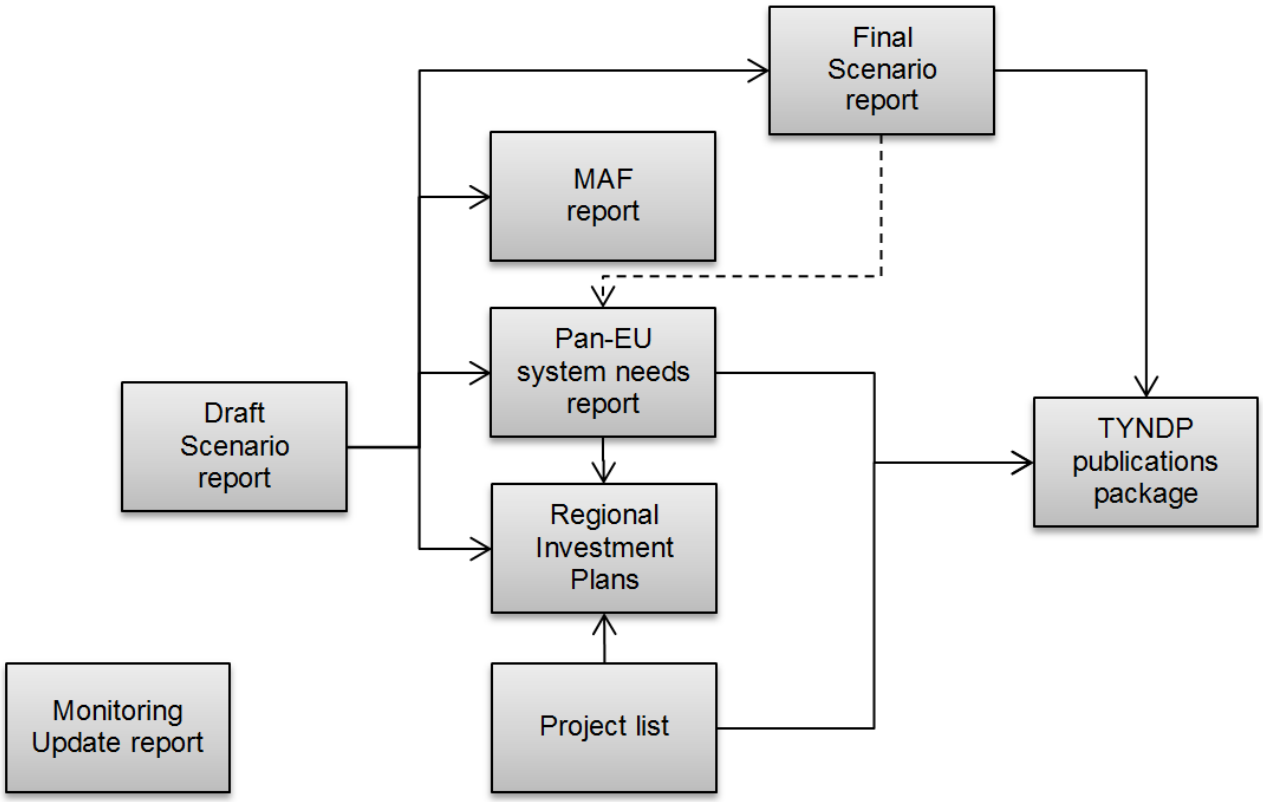

Figure 2-1 Document structure overview TYNDP2018.

The general scope of a RegIP is to describe the present situation as well as any future regional challenges. The TYNDP process proposes solutions which can help to mitigate future challenges. This particular approach is based on the five essential steps presented in the figure below:

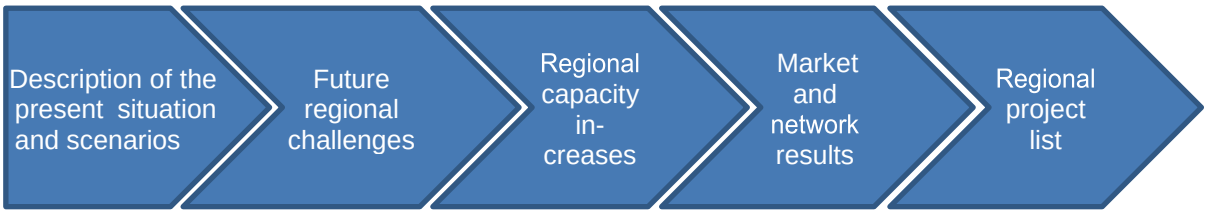

Figure 2-2 Mitigating future challenges – TYNDP methodology.

As one of the solutions to future challenges, the TYNDP project has performed market and network studies for the long-term 2040 scenarios to identify investment needs, i.e., cross-border capacity increases and related necessary reinforcements of the internal grid which can help to mitigate these challenges.

This document comprises seven chapters which contain detailed information at the regional level:

- Chapter 1 outlines the key messages for the region.
- Chapter 2 sets out the general and legal basis of the TYNDP work in detail and includes 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 in that chapter when describing the evolution of generation and demand profiles in 2040 horizon but considering a grid as expected by 2020 horizon.

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- Chapter 4 includes an overview of the regional needs in terms of capacity increases and the main results from the market and network points of view.
- Chapter 5 is dedicated to additional analyses carried out inside the regional group or by external parties outside the core TYNDP process.
- Chapter 6 links to the different national development plans (NDPs) of the countries within the region.
- Chapter 7 contains a list of projects proposed by promoters in the region at a pan-European level as well as important regional projects that are not a part of the European TYNDP process.
- Finally, Chapter 8 (the appendix) includes the abbreviations and terminology used in the whole report.

The current edition of this RegIP considers the experience from the last processes including improvements that were suggested, in most cases, by stakeholders during the last round of public consultations, such as:

- Improved general methodology (current methodology includes other specific factors relevant to investigation of RES integration and security of supply needs);
- A more detailed approach to determining demand profiles for each zone;
- A more refined approach of demand-side response and electric vehicles; and
- For the first time, several climate conditions have been considered as well.

The RegIP does not include the Cost Benefit Analysis (CBA)-based assessment of projects. These analyses are presented in the TYNDP 2018 package.

2.3 General methodology

The present RegIPs build on the results of studies called the 'Identification of System Needs', which were carried out by a team of European market and network experts coming from the six regional groups within ENTSO-E's System Development Committee. The results of these studies have been commented on, and in some cases have been extended with additional regional studies by the regional groups to cover all relevant aspects for each region. The aim of the joint study was to identify investment needs in the long-term time horizon triggered by market integration, RES integration, security of supply and interconnection targets, in a coordinated pan-European manner, which also aims to build on the grid planners' expertise of all TSOs.

A more detailed description of such a methodology is available in the TYNDP 2018 Pan-European System Needs report.

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Regional sensitivity studies

European market studies focus on market integration, RES integration and security of supply, while network studies identify additional (internal) capacity needs. Regional sensitivity studies of market simulations and network studies allow the capturing of additional views and model interpretations based on regional experts, and in many cases complementing the findings of NDPs and/or past studies.

In the Baltic Sea region, the member TSOs have cooperated to form regional scenarios and sensitivities to further study the impact of specific potential changes in the electricity market on the benefits of capacity increases in the region. The market integration and security of supply perspectives have been analysed, while the regional scenario and sensitivities are described in Chapter 3.2.3. One specific interest for the regional group is the impact of dry and wet years in the region. While the hydrological years are not setting price levels in the pan-European area, the impact can be very significant for the Nordic and Baltic markets, as detailed in Chapter 4.4. The sensitivity analyses do not clash with the pan-European analyses; instead, they provide further insight into the importance of regional analyses in conjunction with pan-European analyses.

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2.4 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 for grid planning and system development tasks. The countries belonging to each group are shown below.

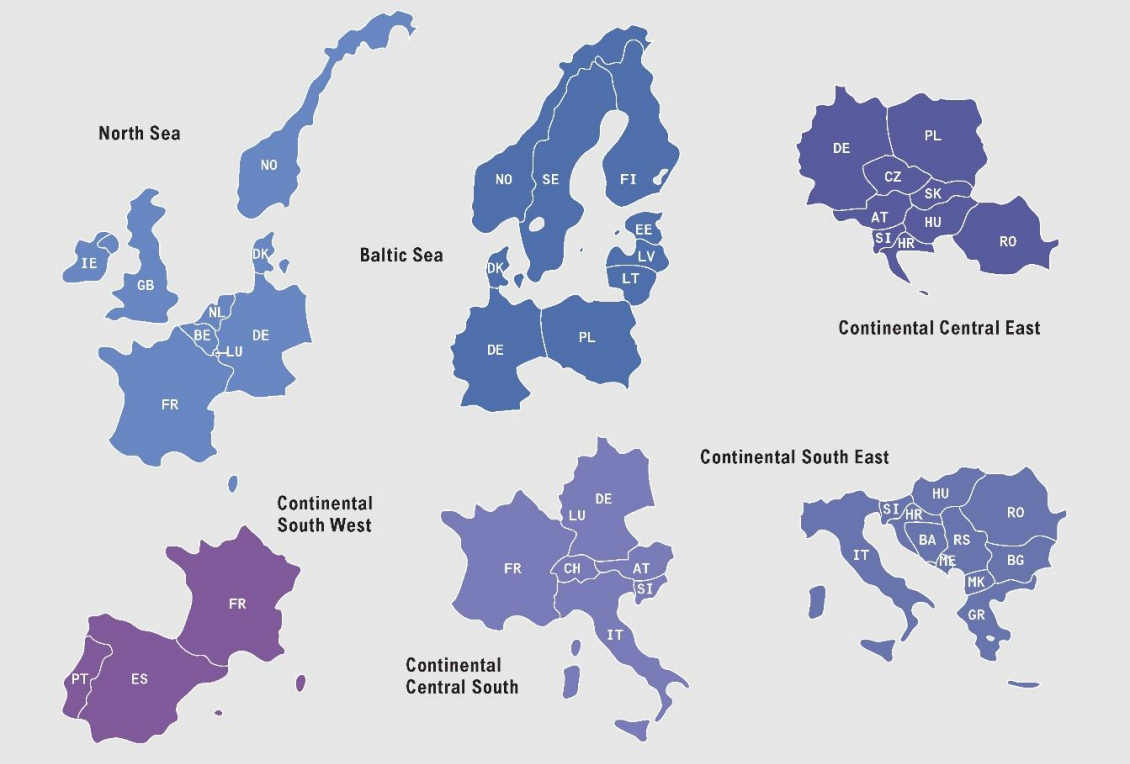

Figure 2-3 ENTSO-E regions (System Development Committee).

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

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

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

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3 REGIONAL CONTEXT

3.1 Present situation

3.1.1 The transmission grid in the Baltic Sea region

The Baltic Sea region is comprised of 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 power system, which is currently synchronous with the IPS/UPS system (i.e. 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 part of the Nordic system, and Denmark-West, which is part of the continental system.

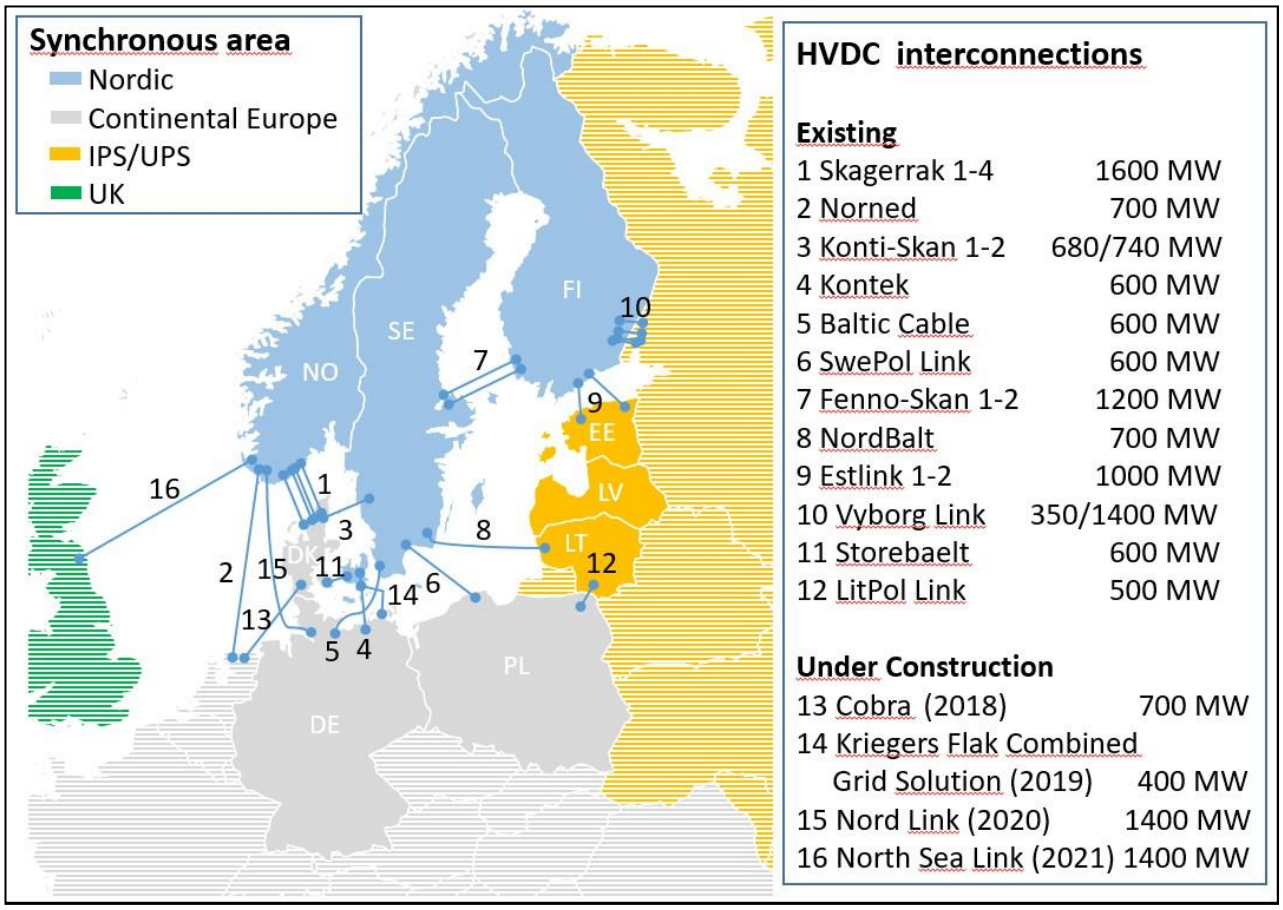

Figure 3-1 Synchronous areas and HVDC interconnections of the Baltic Sea region.

The Baltic countries 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.

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

Many new HVDC interconnectors since 2010

Five new interconnectors have been commissioned since 2010, which have increased total capacity by approximately 3,350 MW. These new interconnectors are Skagerrak 4 (Norway-Denmark), Fenno-Skan 2 (Sweden-Finland), Estlink 2 (Estonia-Finland), Nordbalt (Sweden-Lithuania), and LitPol link (Lithuania-Poland). The existing HVDC connections as well as the HVDC connections under construction are shown in Figure 3-1. Four new HVDC connections are planned to be commissioned in the region during the next five years. HVDC links from Norway to the UK and Germany and HVDC links from Denmark to Germany and the Netherlands are also under construction. The link between Denmark-East and Germany (Krieger's Flak) also connects Danish and German offshore wind farms.

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 400 kV AC as the main transmission voltage level and 220/130/110 kV AC as sub-transmission voltage levels. In the Baltic system, the main transmission voltage level is 330 kV. The map in Figure 3-3 shows the diverse level of Net Transfer Capacities (NTC) in the Baltic Sea region as of February 2017. 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.

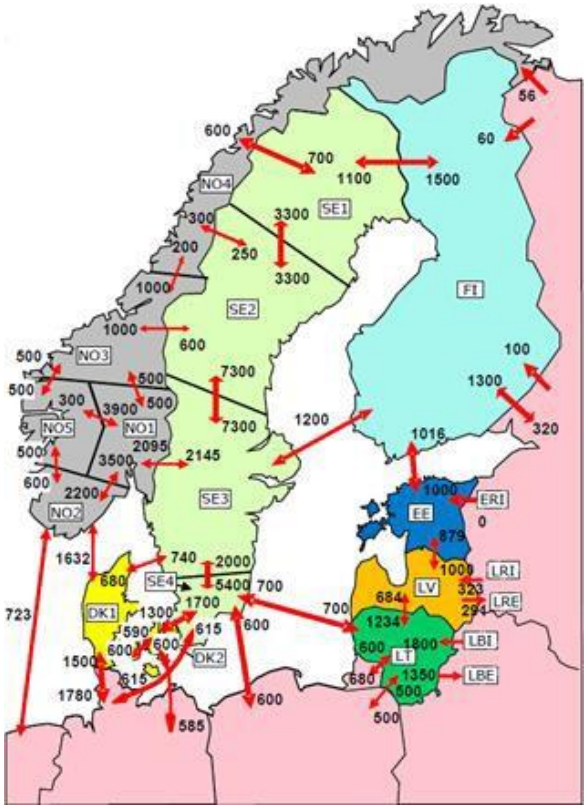

Figure 3-3 NTCs in the Baltic Sea region as of February 2017.[3]

[3] Source: Nord Pool, 2017.

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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 1,100 TWh, of which half is consumed in Germany. The peak load is much higher in winter than in summer due to colder weather in the Nordic and high share of electric heating in Nordic and Baltic countries. From 2010 until 2016, 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 increased in continental Europe. German nuclear phase-out is also clearly visible in the graphs.

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

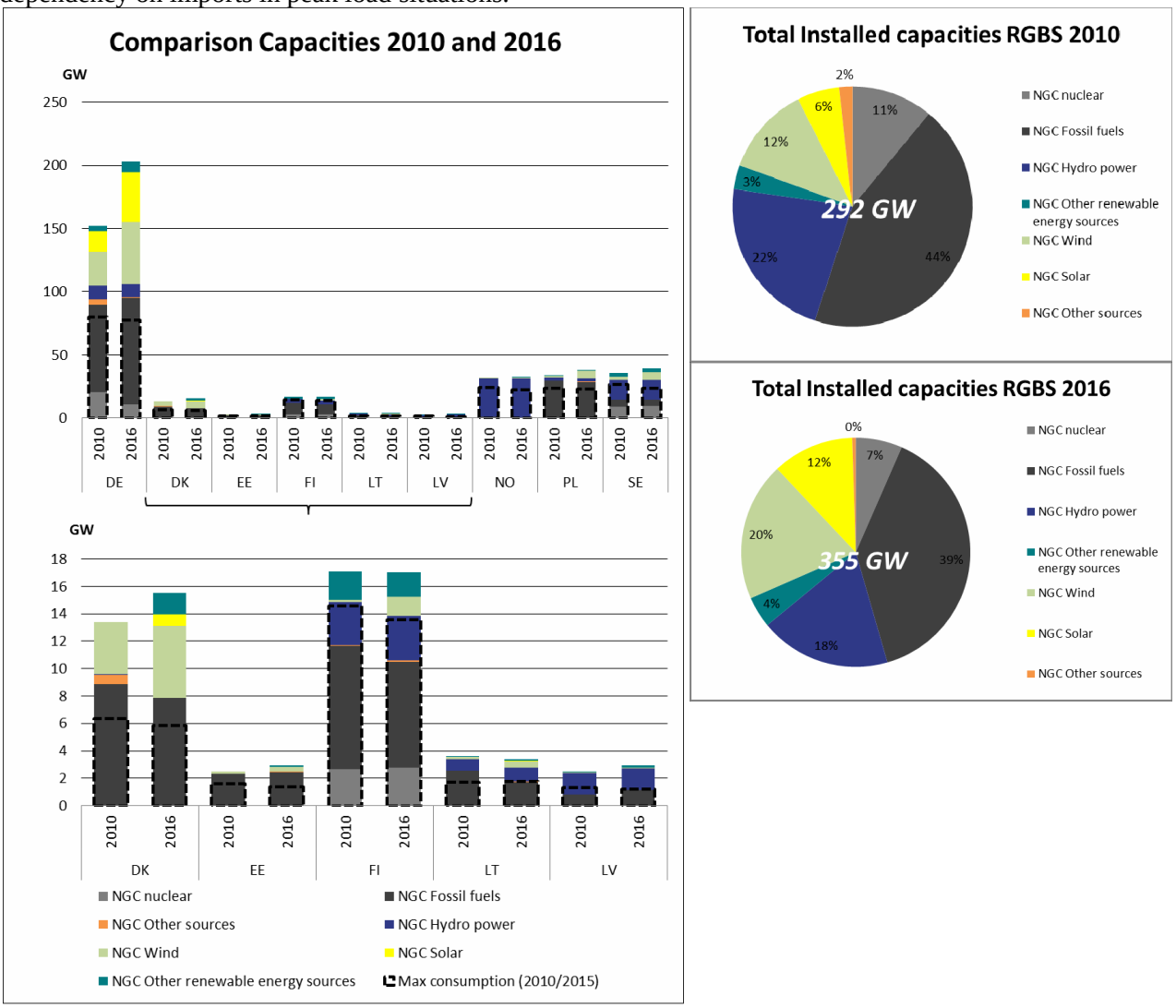

Figure 3-4: Installed generation capacities by fuel type and maximum consumption in the Baltic Sea region in 2010 and 2016.

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The Nordic power system is dominated by hydropower, followed by nuclear, combined heat and power (CHP), and solar and wind power. Most of the hydropower plants are located in Norway and northern Sweden and most of 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 60–70 TWh between a dry and wet year. Consumption in the Nordic countries is characterised by a high amount of electrical heating and energy-intensive industry. 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.

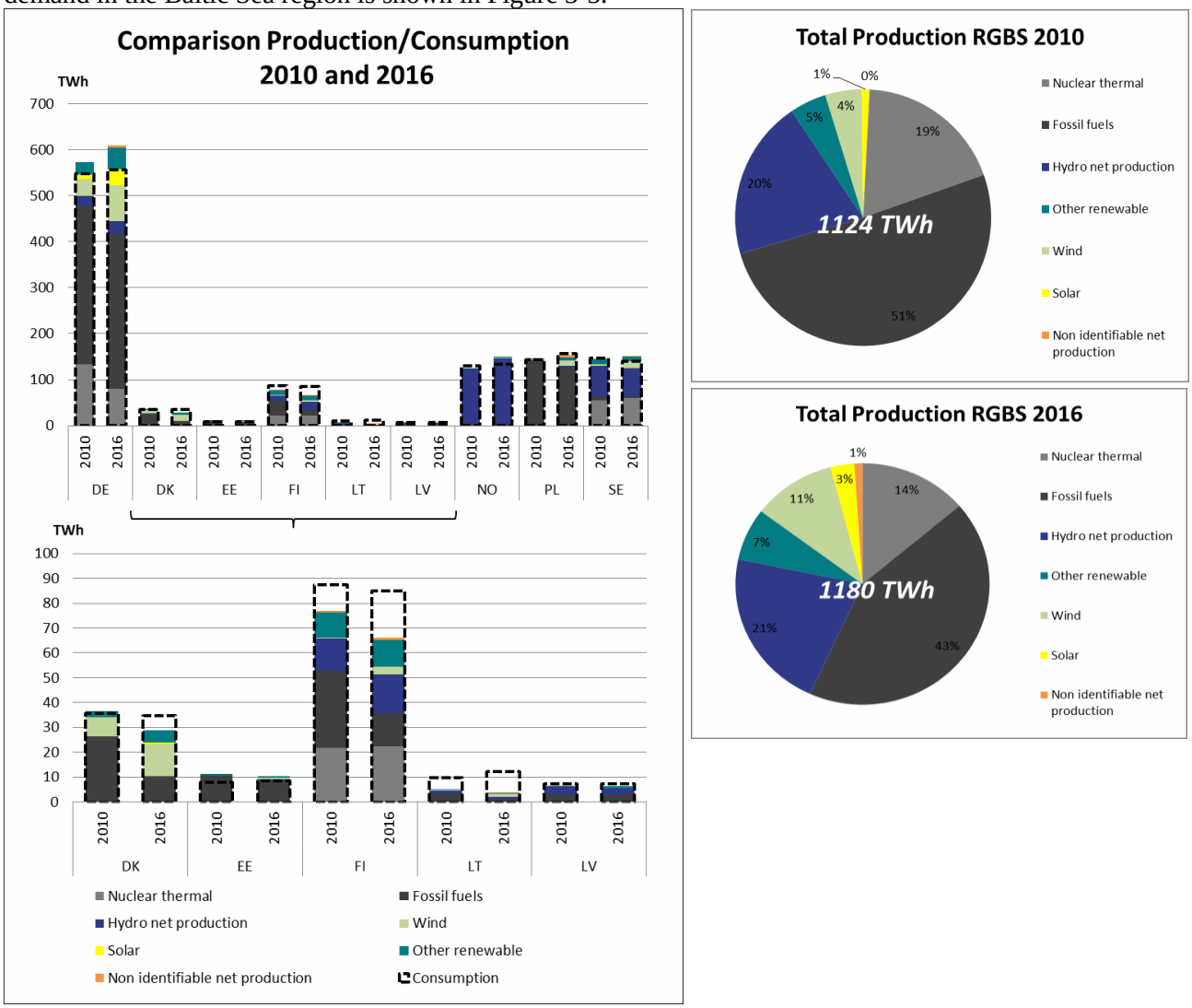
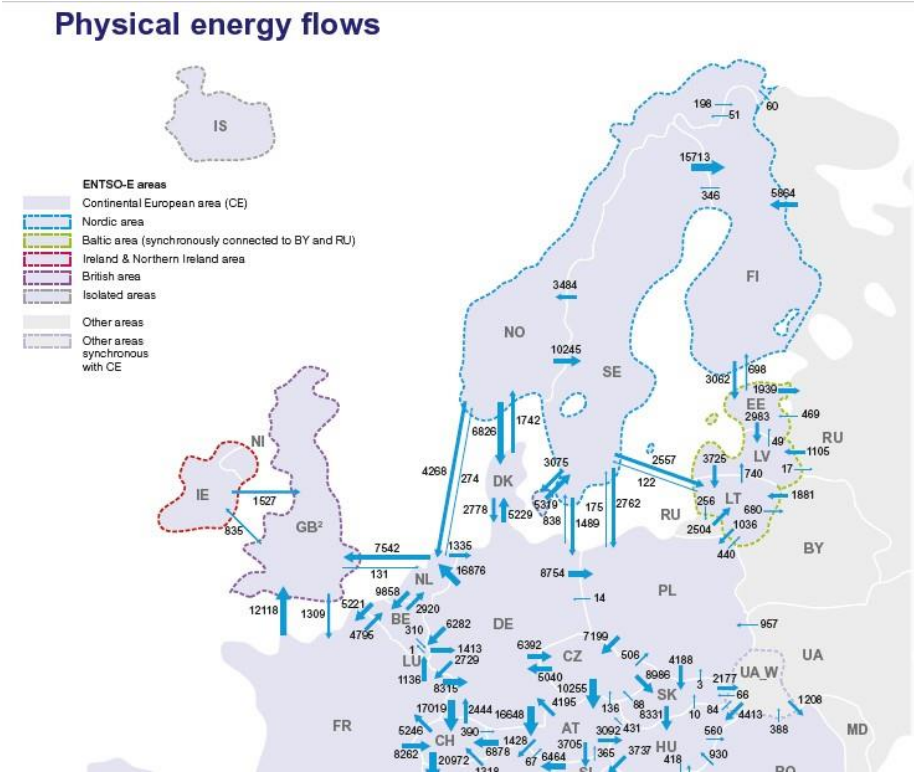


Figure 3-5: Annual generation by fuel type and annual consumption in the Baltic Sea region in 2010 and 2016.

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). Consumption in the area is less temperature-dependent compared with 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.



	Sum of imports¹	Sum of exports¹	Balance (imp–exp)
AT	28156	19434	8722
BA	3086	6841	–3755
BE	14654	8451	6203
BG	4570	10930	–6360
CH	33477	29052	4425
CZ	13815	24787	–10972
DE	27023	80767	–53744
DK	15130	9839	5291
EE	3580	5620	–2040
ES	21845	14175	7670
FI	22473	3459	19014
FR	19959	60939	–40980
GB²	21187	2275	18912
GR	9836	1039	8797
HR	12398	6057	6341
HU	17971	5240	12731
IE	835	1527	–692
IT	43133	6236	36897
LT	11107	2834	8273
LU	7728	1414	6314
LV	4828	3791	1037
ME	2909	2609	300
MK	5201	3154	2047
NL	24195	19009	5186
NO	5611	21537	–15926
PL	14018	12016	2002
PT	4616	9702	–5086
RO	2296	7311	–5015
RS	5559	7880	–2321
SE	17045	29080	–12035
SI	8360	9415	–1055
SK	13249	10598	2651
TR³	6413	1444	4969
ENTSO-E	**446263**	**438462**	**7801**

Physical flow values in GWh

Figure 3-6: Cross-border physical energy flows (GWh) in the Baltic Sea region in 2016.

The cross-border flows in 2016 are shown in Figure 3-6 and the development in cross-border exchanges from 2010 to 2015 are presented in Figure 3-7. The largest exchanges are from Norway, Sweden and Germany to neighbouring countries, while the largest increase in power flow from 2010 to 2015 is seen from Sweden to Finland and from Germany to the Netherlands, while a decrease is seen from Russia to Finland. In the Nordic countries, the flow pattern varies a lot from year to year as a result of variations in hydrological inflow, as 2010 was a dry year and 2015 was a wet year. In wetter years, exports from Sweden and Norway are 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.

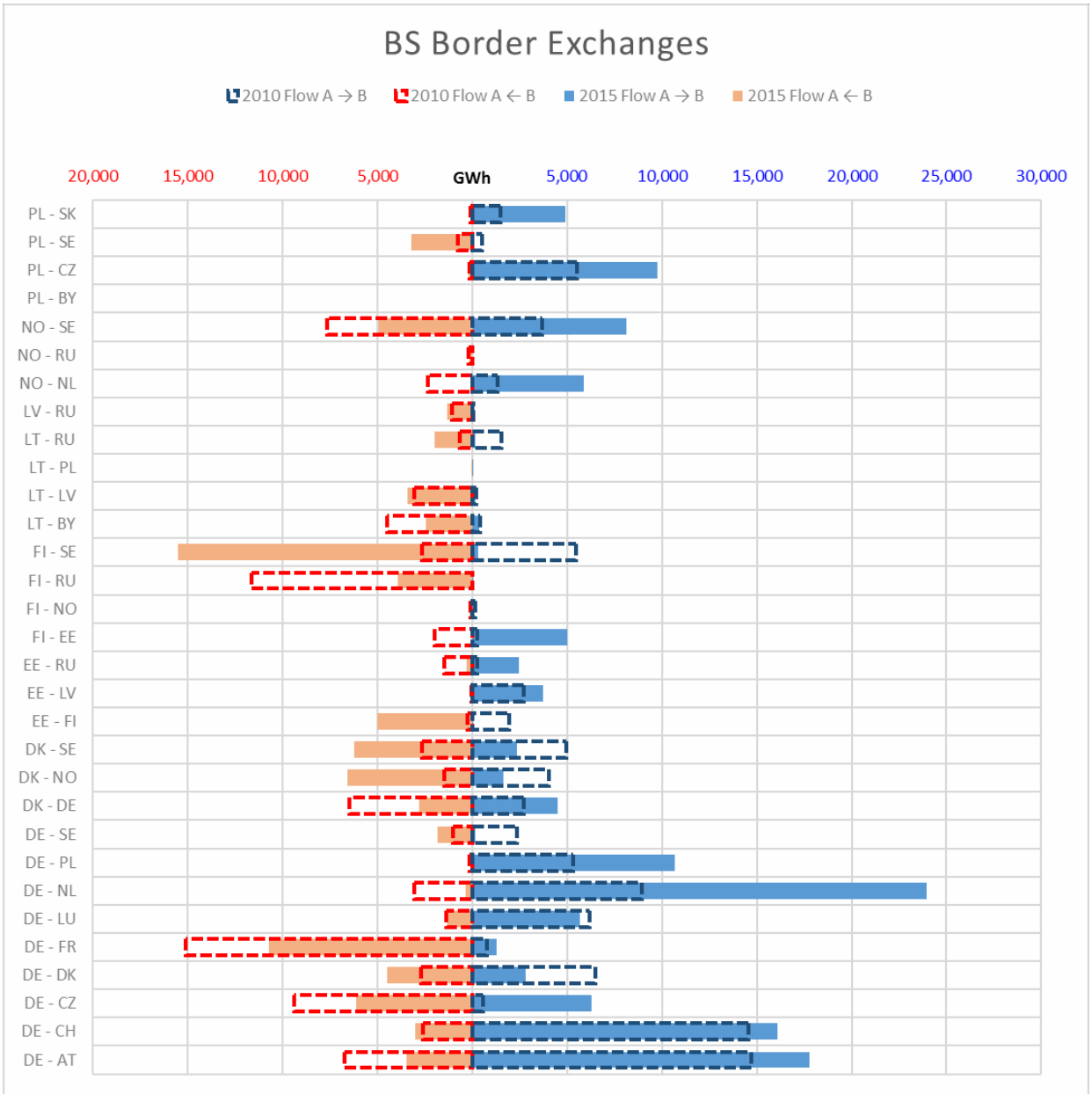


Figure 3-7: Cross-border physical flows (GWh) in the Baltic Sea region in 2010 and 2015.

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3.1.3 Grid constraints in the Baltic Sea region

Figure 3-8 illustrates the price differences between market areas in the Baltic Sea region during 2015 and 2016. The average amount of bottleneck hours between price areas is dependent on the weather conditions during the period under observation. 2015 was a wet year throughout the whole Nordic region, which increased the flow of electricity from the northern hydro reservoir areas to the south.[4] A wet year means that the annual amount of precipitation is higher than normal. The increased flow resulting from a wet year increased the amount of bottleneck hours, for example, between northern Norway and Sweden. 2016 was also a wet year for Norway but was drier than normal for Sweden and Finland.[5]

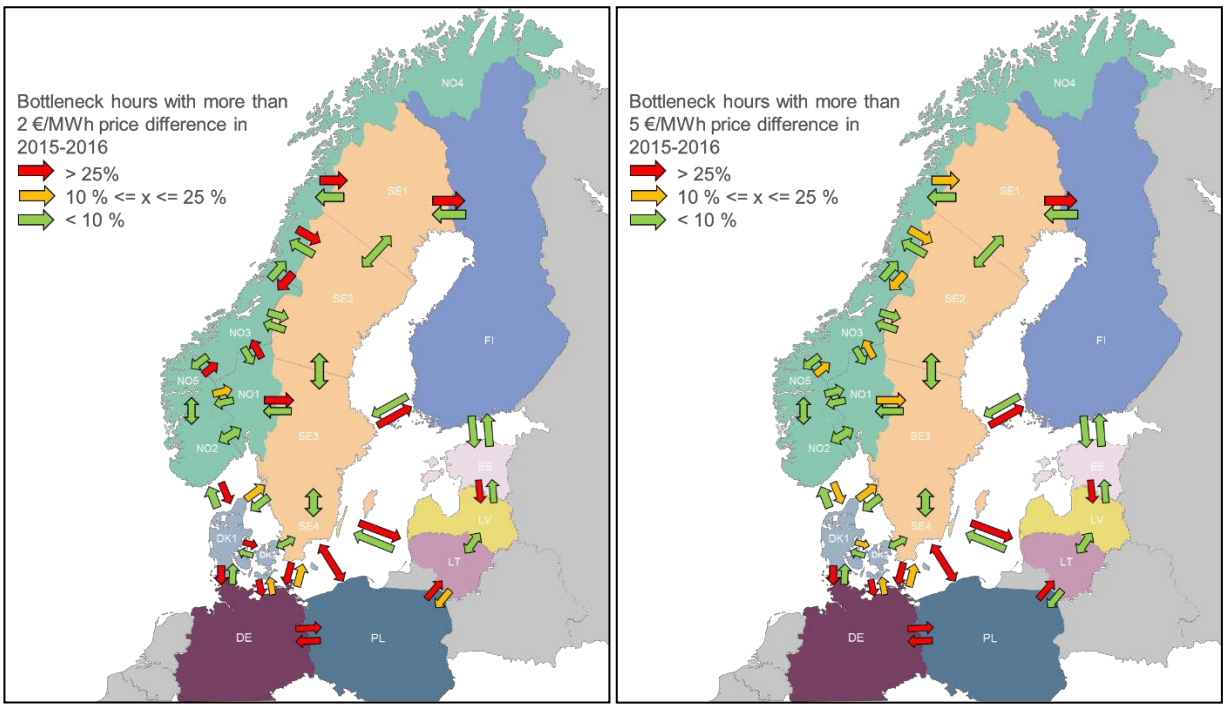

Figure 3-8: Percentage of hours with different market prices per market area border and direction.[6]

Some of the typical situations that can occur due to grid constraints today, which are also visible in Figure 3-7, are:

- Bottlenecks between Sweden and Finland;
- Bottlenecks from Estonia to Latvia, from Sweden to Lithuania, and from Poland to Lithuania, resulting in higher prices for Latvia and Lithuania;
- Grid issues in Northern Germany which puts limits on ATCs between Germany, Denmark and Sweden; 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.

4 Source: Nordpoolspot. 2016. LandsRapport. Norge, Energi Företagen. 2016. Kraftläget I Sverige. Vattensituation, Suomen ympäristökeskus (SYKE). 2016.

5 Source: Nordpoolspot. 2017. LandsRapport. Norge, Energi Företagen. 2017. Kraftläget I Sverige. Vattensituation, Suomen ympäristökeskus (SYKE). 2017.

6 Source: Nord Pool. 2017. Historical Market Data.

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, before the pan-European TYNDP scenarios as well as the regional scenarios used in the regional sensitivity analysis are presented. The regional scenarios are created and used in the studies to highlight the regional specifics and study sensitivities that have regional significance.

3.2.1 Expected changes in the generation portfolio

The main changes and drivers for the changes 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 3.3. The main drivers of the changes 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.

- Increase in RES generation:
  - The increased share of wind power and solar PV in the power system;
  - Additional wind power, which is located farther away from the load with large amounts planned for construction in the northern part of the region; and
  - PV capacity to be mainly increased in the southern part of the region.
- Reduction of thermal power capacity:
  - Decommissioning of coal and oil shale-fired power plants;
  - Decommissioning of all nuclear power plants in Germany by 2022; and
  - Decommissioning of four nuclear reactors in Sweden, with a total capacity of 2,900 MW being decommissioned by 2020.
- New large generating units
  - New nuclear capacity is being built in Finland, with one power station of 1,600 MW, which will be commissioned in 2018 and another plant of 1,200 MW, which is planned for commissioning in the mid-2020s.

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. We already have a situation where solar power and wind power, if located favourably, become profitable without the need for subsidies. This could potentially cause some changes in geographical distribution, as it would then be more profitable to develop solar and wind power in the locations with the best conditions and the lowest costs. For example, there could be 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 the 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

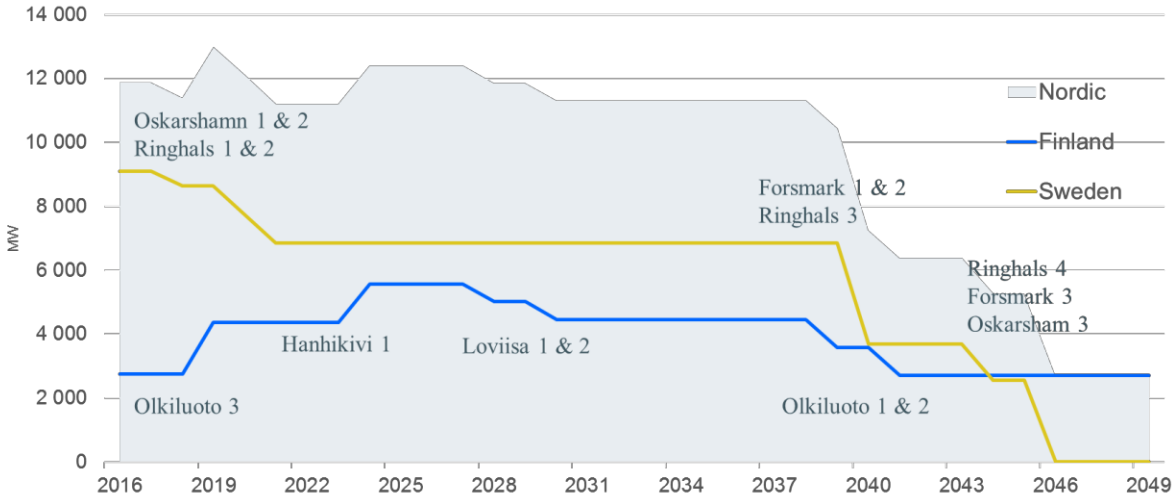

Figure 3-9 Expected developments in Nordic nuclear power capacity from 2016 to 2050 used in the scenario building based on an expected lifetime of 50 to 60 years.

What will happen with nuclear power in Sweden and Finland is a key uncertainty in the Nordic power system and the market. All of 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 2,900 MW[7] could be shut down as early as 2020. This means that energy generation will decline from 65 TWh a year today to approximately 50 TWh. Furthermore, the 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 operational 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.

Tighter margins in the power system after 2020

The Nordic power system has a positive annual capacity margin today and it will continue to be positive in the long term, although less positive during colder periods and during hours with high consumption. The Baltic power system, on the other hand, has a negative annual energy balance, particularly in Lithuania.

Weaker earnings will eventually lead to the phasing out and shutdown of thermal power plants, and thus the increased likelihood of a rationing during hours with high residual demand, especially in the Baltics. This creates a dilemma. How can an acceptable security of supply at a reasonable cost be ensured? So far, different countries in Europe have chosen different solutions.

[7] Oskarshamn 1 &2, Ringhals 1 & 2 of which Oskarshamn 1 &2 has already ended the production.

The UK and France have introduced capacity markets (where adequate capacity in the power system is secured by giving thermal power plants, and other providers of power output, earnings in a separate market or auctions outside the energy markets). Germany has chosen to let the market secure the investments itself. These different solutions are most likely somewhat dependent on the actual situation. The UK today has a tight margin and an extreme price peak, whereas Germany has significant surplus capacity.

Reduced profits for thermal capacity and flexibility

The Continental and Nordic markets currently have sufficient thermal production capacity to cover demand during periods of low production from intermittent renewable sources, or during dry years with low hydro production. The increasing share of intermittent renewables reduces both the usage and profitability of thermal plants, and a significant share of the 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.

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 a relatively low-price volatility in the day-ahead market and in the balancing of costs. A higher market share of intermittent 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.

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3.2.2 TYNDP 2018 scenarios and the regional scenario for 2030

Figure 3-10 gives an overview regarding the time-related classification and interdependencies of the scenarios in the TYNDP 2018 and shows the transition from the actual situation, including the time points of 2025 and 2030, to 2040.

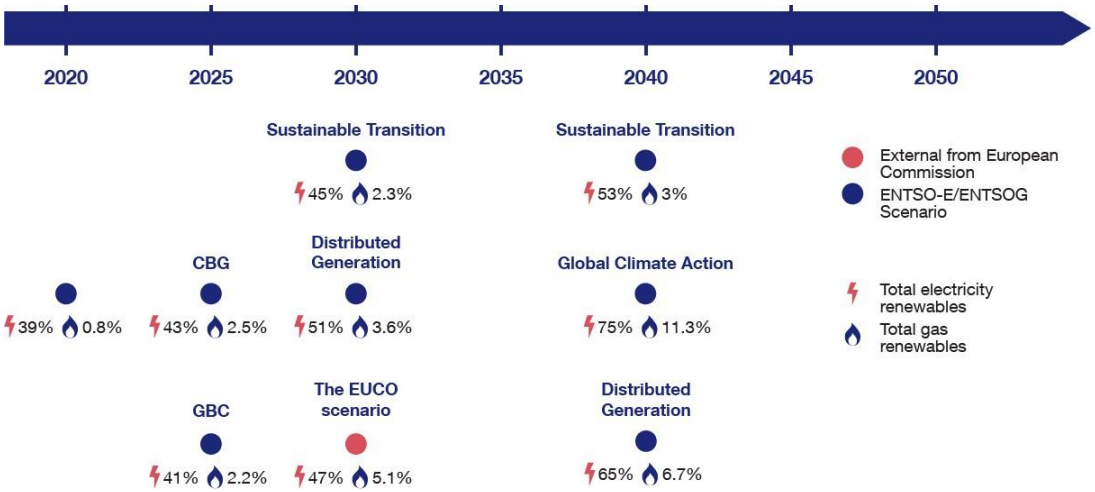

Figure 3-10: Scenario building framework indicating bottom-up and top-down scenarios.

Inthe scenario building process, two types of optimisation are applied: thermal optimisation and RES optimisation.

1. Thermal optimisation optimises the portfolio of thermal power plants. Power plants that are not earning enough to cover their operating costs are removed and new power plants are built depending on a cost and benefit analysis. The methodology ensures a minimum adequacy of production capacity in the system, giving a maximum of three hours of energy not served per year per country (ENS).
2. RES optimisation optimises the location of RES (PV, onshore and offshore wind) in the electricity system in order to utilise the value of RES production. This methodology was also usedin TYNDP2016 but has been improved by utilising higher geographical granularity (more market nodes) and by assessing more climate years.

The above-mentioned scenarios for the 2040 timeframe consist of a top-down approach and the data will be derived from the 2030 database.

A more detailed description of the scenario creation is available in the TYNDP 2018 Scenario Report.[8] Furthermore, the following scenarios at the time point 2040 have to be highlighted:

'Global Climate Action' Scenario

The 'Global Climate Action' (GCA) scenario is based on a high growth of RES and new technologies, with the goal to keep the global climate efforts on track with the EU's 2050 target.

[8] TYNDP2018 Scenario Report: http://tyndp.entsoe.eu/tyndp2018/

The GCA storyline considers global climate efforts. Global policies regarding CO_2 reductions are in place, and the EU is on track towards its 2030 and 2050 decarbonisation targets. An efficient ETS trading scheme is a key enabler in the electricity sector's success in contributing to global/EU decarbonisation policy objectives. In general, renewables are located across Europe where the best wind and solar resources are to be found. As it is a non-intermittent renewable, biomethane is also developed. Due to the focus on environmental issues, no significant investment in shale gas is expected.

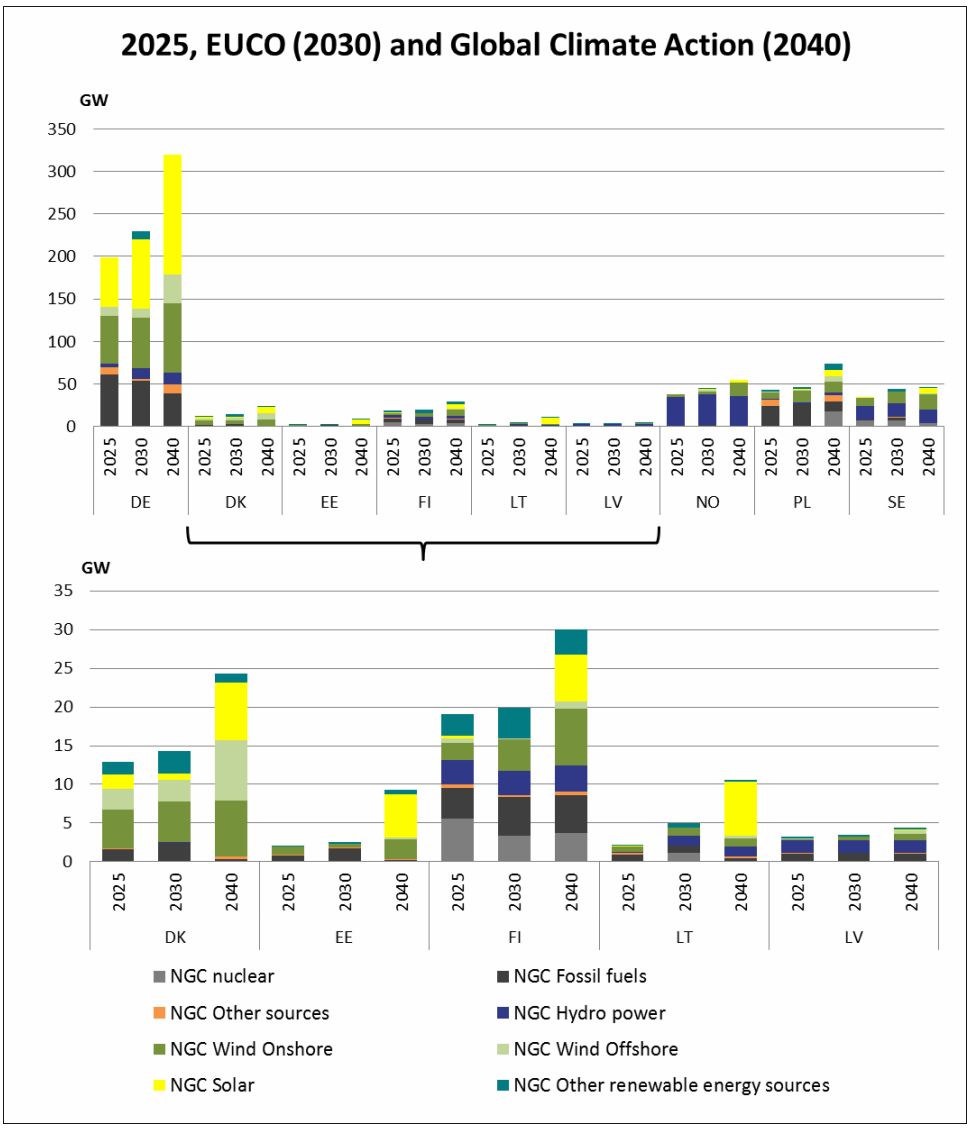

Figure 3-11: Installed net generation capacities at the regional level in the 'Global Climate Action' scenario.

From the graph above we can see that solar is expected to be the fastest-growing generation type in Germany between 2025 and 2040. In the other countries, solar capacity increase accelerates between 2030 and 2040. In Latvia and Norway, the hydro capacity will remain the largest source of electricity in terms of installed capacity. The capacity of wind generation will increase rapidly in Germany, Denmark, Finland, Norway, Poland and Sweden. Therefore, installations of new big wind power plants up to 2040 in all these countries are expected. In the Baltic States, solar and wind developments are also expected. From 2025 there will be no more nuclear generation in Germany as all nuclear power plants will have been decommissioned. A decrease in nuclear power is also foreseen in Sweden and Finland up to 2040, but new nuclear developments are forecast for Poland in 2040. The new nuclear developments are significant for replacing some old fossil fuel plants that have high CO_2 emissions.

Newer, more efficient and carbon-neutral generation plants are also necessary for Poland's power balance. From 2025 up to 2040, other generation sources will be developed which will also have a part to play in the power balance.

The 'EUCO' Scenario

Additionally, for 2030, there is a third scenario based on the European Commission's (EC) EUCO Scenario for 2030 (EUCO 30). The EUCO scenario is a scenario designed to reach the 2030 targets for RE, CO_2 and energy savings taking into account current national policies such as the German nuclear phase-out.

The EC's EUCO 30 scenario was an external core policy scenario, created using the PRIMES model and the EU Reference Scenario 2016 as a starting point and as part of the EC impact assessment work in 2016. The EUCO 30 already models the achievement of the 2030 climate and energy targets as agreed by the European Council in 2014 but also includes an energy efficiency target of 30%.

The 'Sustainable Transition' scenario

The 'Sustainable Transition' (ST) scenario assumes only moderate increases of RES and moderate growth in new technologies, in line with the EU 2030 target, but slightly behind the EU 2050 target. In the ST scenario, climate action is achieved by a mixture of national regulations, emissions trading schemes and subsidies. National regulation takes the shape of legislation that imposes binding emissions targets. Overall, the EU will just be able to keep on track with the 2030 targets, while being slightly behind its 2050 decarbonisation goals. However, the targets will still be achievable if rapid progress is made in decarbonising the power sector during the 2040s.

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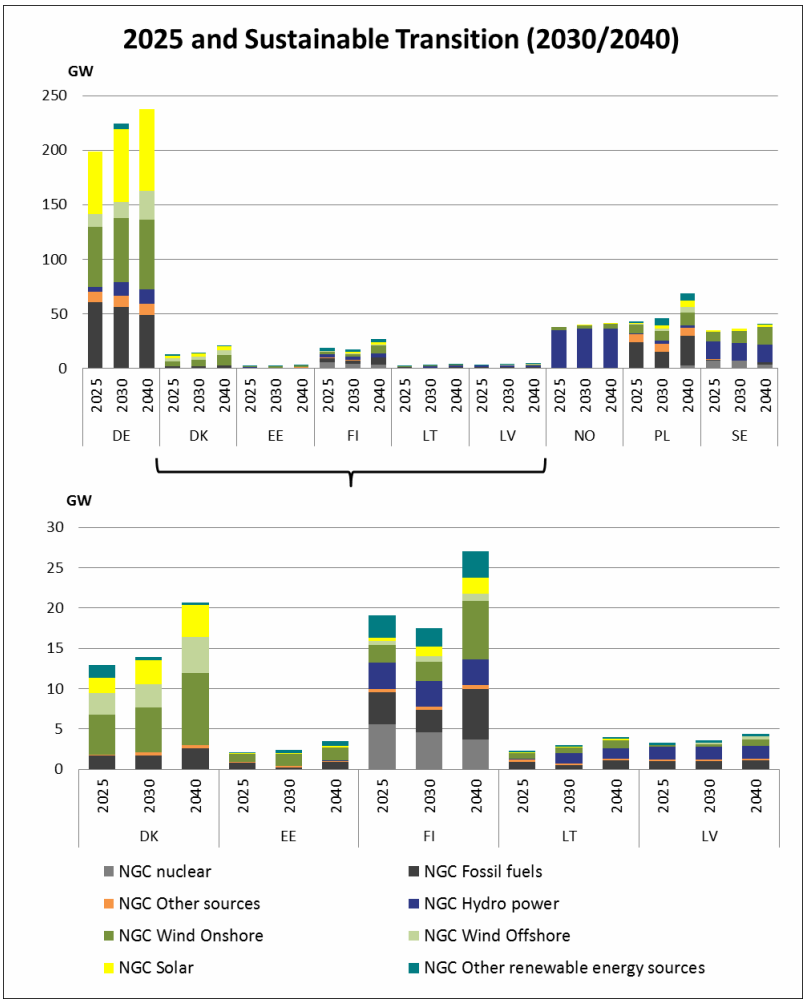


Figure 3-12: Installed net generation capacities at the regional level in the Sustainable Transition' scenario.

In the ST scenario, the highest generation capacity increase is expected to be around 50 GW in Germany and developments are being seen in solar, hydro and wind generation. Wind and solar generation will play a very significant role in the power balance in Germany up to 2040. All nuclear power plants will Germany are decommissioned, and no new significant nuclear capacity developments are expected in the Baltic Sea region. From 2030 until 2040, a significant share of the existing coal and lignite power plants will have to be replaced due to ageing, and the main replacement technology in Poland, in addition to renewables, will be CCGT. In countries other than Poland, the main reason for increased fossil capacity between 2030 and 2040 will be due to increases in flexible peaking capacity, which is categorised in Figure 3-12 as fossil gas turbines, but can actually be demand response, short-term storage or other similar sources of flexibility. Rapid capacity increases in the Baltic States are not expected to occur, and the power system balance will remain very similar to what it is today. In the region in general, only small wind and solar capacity developments are foreseen in all countries.

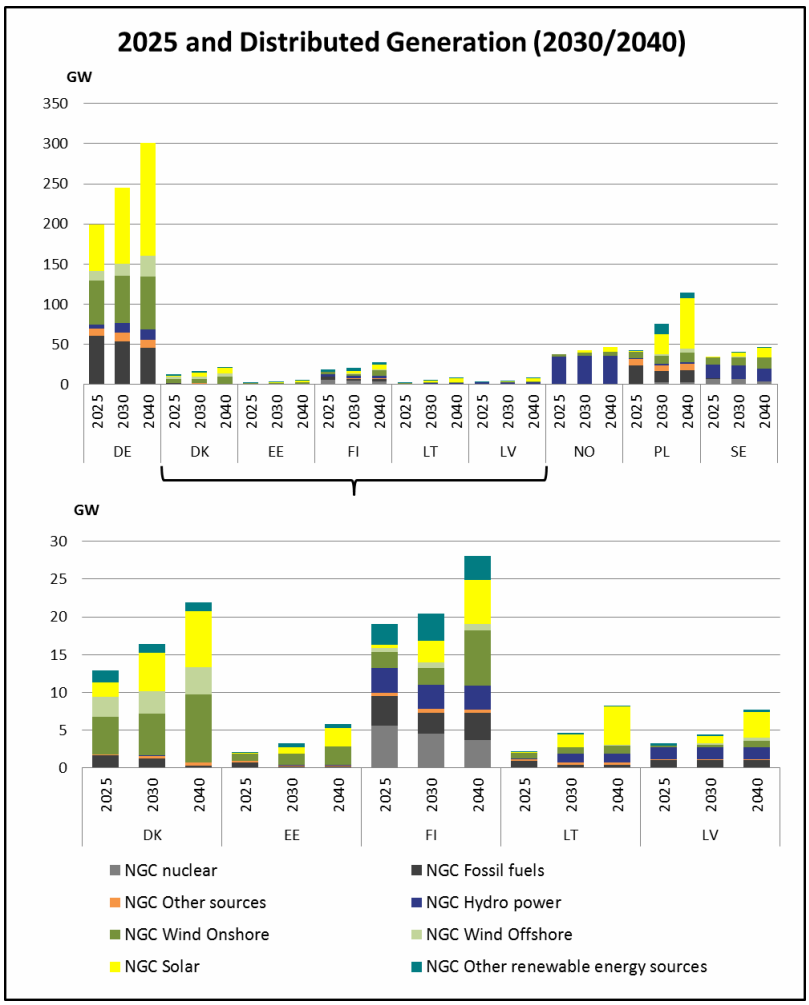
The 'Distributed Generation' scenario

The 'Distributed Generation' (DG) scenario covers a very high growth of small-size and decentralised renewable-based energy generation and energy storage projects including an increase in new technologies in related areas that are largely in line with both the EU's 2030 and 2050 goals.

In the DG scenario, significant leaps in innovation of small-scale generation and residential/commercial storage technologies are a key driver in climate action. An increase in small-scale generation will keep the EU on track to meet its 2030 and 2050 targets. The scenario assumes a 'prosumer' focus, meaning that society is engaged and empowered to help achieve a decarbonised power system.

As a result, no significant investment in shale gas is expected.

Figure 3-13: Installed net generation capacities at the regional level in the 'Distributed Generation' scenario.



In the DG scenario, the high solar and wind developments are foreseen in all countries throughout the region, given the high increases in domestically generated solar power. The overall capacity increases in Germany, consisting mainly of wind in addition to solar, will be around 100 GW up to 2040, and around 80 GW up to 2040 in Poland. All nuclear power plants in Germany will be decommissioned by 2023, and nuclear capacity will also be reduced in Sweden and Finland by 2040, as no new nuclear power plants will be built in the region after 2030. However, new nuclear power plants in Finland and Poland are expected to be built before 2030. In the Baltic States, solar developments are expected, and offshore wind generation will also increase. Fossil fuel generation will decrease in almost all countries and DG will come in place in the power balance. Hydropower will remain an important part of the region's energy balance, particularly in Norway, Sweden, Latvia and Finland.

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3.2.3 Regional scenario 2030

This scenario is a compilation of the best estimate scenarios of the TSOs operating in the Baltic Sea region. The regional scenarios and sensitivities have been calculated to show the importance of dry and wet weather years and to study the impact of more radical nuclear and/or conventional thermal phase-outs. Additionally, the impact of nuclear generation in Lithuania and additional wind generation development in the Baltics has also been analysed. The regional scenario was created for all countries in the region except for Poland and Germany. However, Germany and Poland, as well as all the other countries outside the Nordic and Baltic region were modelled as having fixed prices.[9] The reason for this is that the approach used will provide some more insights and regional specifics for Nordic and Baltic countries and not for continental Europe; those issues were covered in pan-European scenarios or in regional sensitivities in other RegIPs. The scenario contains somewhat more renewables and somewhat less fossil generation compared to the ST 2030 scenario. The aim of the regional scenario is to be able to model the region with some additional details that were excluded from the pan-European analyses in order to capture the specific behaviour of the region, and moreover, to perform sensitivity analyses on important parameters. An overview of the installed capacities in the scenario is displayed in Figure 3-14.

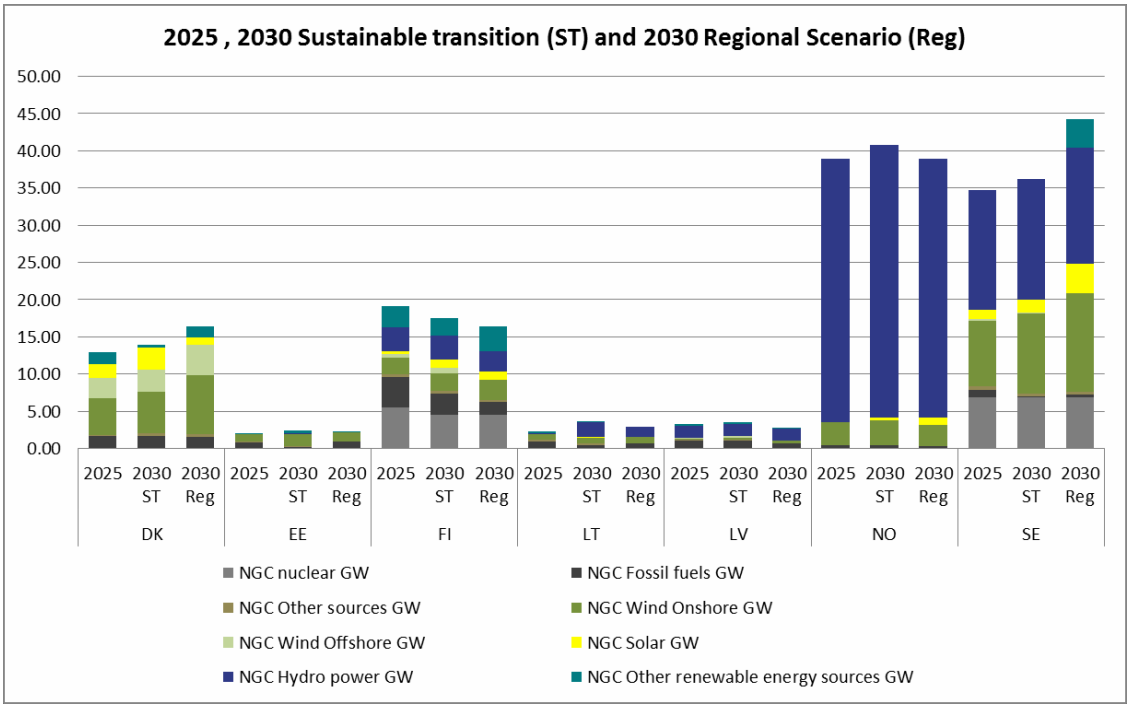

Figure 3-14 Summary of the regional scenarios compared to 2025 best estimate and 2030 sustainable transition.

Regional specifics

The region is characterised by a large share of hydropower with annual seasonal storage capability as well a large share of temperature-dependent consumption. In particular, the hydrological inflow changes significantly across the years. However, the demand (temperature) and wind power production also vary significantly. Figure 3-15 illustrates the variation in the region for weather years from 1980 to 2012. Hydropower production varies the most, with an approximately 90 TWh difference between the driest and wettest weather years. The load that needs to be satisfied by thermal generation and imports (residual load) varies even more since a dry year is usually also cold with high demand and low RES generation.

[9] Continental countries were simulated in the BID market model in a scenario close to ST 2030 and resulting hourly prices for all 33 weather years were used for countries adjacent to the Nordic-Baltic region (Germany, Poland, the Netherlands and the UK).

It is typically during the most extreme years weather-wise where the need for interconnection capacity is most significant. Therefore, it is needed to use a large range of different weather years to analyse the transmission needs in the Baltic Sea region.

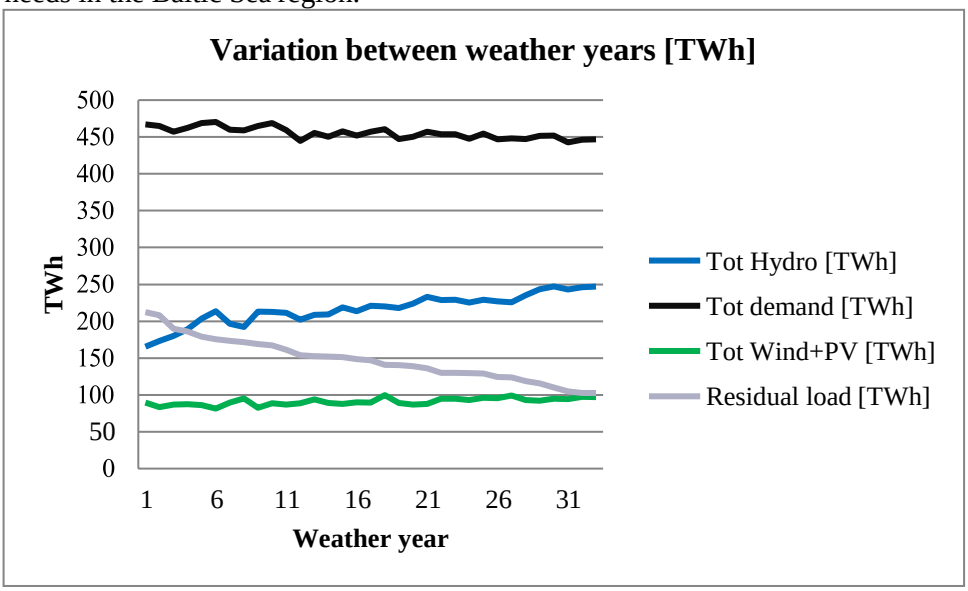

Figure 3-15 Variation of demand, hydro RES, and residual load (demand-hydro-RES) in the Nordic and Baltic countries in for the Regional Scenario 2030 for weather years 1980 to 2012 sorted from the year with the greatest residual load to the year with the lowest.

The 'Reduced Nuclear' sensitivity

In the 'Reduced Nuclear' sensitivity, it is assumed that some Swedish nuclear power plants will be decommissioned prematurely compared to the base case for the Regional Scenario 2030. This could happen as a result of national regulation, or that any necessary reinvestments will not be profitable for the owners who could decide to decommission these plants instead. In Finland, some of the new projects in the Regional Scenario base case were not built.

Table 3-1: Changes in nuclear capacities in the 'Reduced Nuclear' sensitivity

Country	Nuclear capacity (MW), Base Case	Nuclear capacity (MW), sensitivity
Sweden	7142	3310
Finland	4560	3360
Lithuania	0	0

This sensitivity was analysed in two ways.

- One case could be where the capacity was just removed from the base case with no other change.
- However, as this would lead to a significantly higher price level in the Nordic countries where more production would be profitable without any subsidies, more production was added consisting mainly of wind power. Also, some thermal plants that were assumed to be decommissioned in the base case were assumed to still be in operation.

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Sensitivity "Low fossil fuel prices and reduced thermal baseload power"

In this sensitivity, it was assumed that fossil fuel and CO_2 prices did not rise significantly from today's levels. However, the same development of renewable generation as in the base case was assumed. The low fuel prices result in low wholesale prices on electricity, which affects the profitability of production. It was assumed that RES would be driven by subsidies, and hence, they could be on the same level as in the regional scenario base case. For condensing thermal plants, the lower fuel and CO_2 prices alone will not be significantly affected since this will lower their costs as well. However, for thermal baseload production units, such as CHP and nuclear plants, the low electricity prices will reduce their profitability, thereby accelerating the decommissioning of those plants. The accelerated decommissioning of thermal and nuclear plants could lead to issues with supply and could change the need for new transmission capacity.

Table 3-2: Changes in fuel and emission prices in the 'Low Fuel Price' sensitivity

Fuel/emissions	Regional scenario-Base case	Low fuel price Sensitivity
CO_2(EUR/tonne)	28	5
Coal (EUR/MWh)	9	4.5
Gas (EUR/MWh)	22	18

Table 3-3: Changes in thermal capacities in the "Low fuel price" sensitivity

Country	Reduction thermal (MW)	Nuclear
Denmark	-1500 (Bio 510 Coal 620, Gas 120, Oil 250)	0
Norway	0	0
Sweden	-730 (+400 Gas -1130 Bio)	-1400
Finland	-600 (Bio 500 Peat 100)	0
Estonia	0	0
Latvia	0	0
Lithuania	0	0

Sensitivity 'NPP in Lithuania'

There have been plans for a new nuclear plant in Lithuania, which would mark a big change for regional generation adequacy, as Lithuania currently imports more than 60% of its electricity to cover national demand. A new unit with a capacity of 1,350 MW could have a large impact on the relatively small Baltic market both in terms of adequacy and the need for additional transmission capacity. Currently, the nuclear power plant project in Lithuania is static, and will not be operational before 2030.

Sensitivity 'Baltic offshore wind farms'

Large amounts of new wind capacity in addition to what is expected in the base case could be another possible development, as the Baltic countries in the base case would have a large deficit and the highest prices in the region. Further, the Baltic countries also depend on imports from non-ENTSO-E countries. In this sensitivity, 1,000 MW of additional wind capacity was added in both Estonia and Lithuania, and trading possibilities with non-ENTSO-E countries were removed. Such developments could affect the need for both transmission capacity within the Baltics as well as to other countries.

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3.3 Future challenges in the region

The changes expected in the generation portfolio of the power system described in Chapter 3.2 are challenging the system operations. Expected changes are increasing the variations of generation according to the weather, the decreasing adequacy of generation in situations with low RES generation, the increasing size of contingencies, the increasing number of contingencies with high impacts and the decreasing amount of inertia and fault current in situations with high RES generation. For all these reasons, there is a need for more flexibility to keep the energy balance and system stable at all times. In the subchapters below the market challenges (3.3.1), grid constraints (3.3.2) and system technical challenges (3.3.3) in the Baltic Sea region due to changes in generation portfolio are illustrated.

3.3.1 RES extension without a new grid would cause problems for the electricity market

The ENTSO-E European Market and the Network Study Teams have carried out simulations of all three 2040 scenarios (Sustainable Transition, Global Climate Action and Distributed Generation) with the expected grid of 2020. Even if these simulations were somewhat artificial (in the real world, the market and the grid develop in close interaction with each other), the study revealed future challenges such as:

- Poor integration of renewables (high amounts of curtailed energy);
- Security of supply issues;
- High CO_2 emissions;
- High price differences between market areas; and
- Bottlenecks both between and within market areas.

The graphs in Figure 3-16 show the results of the simulations and illustrate the extent of the challenges if the grid would not be developed in conjunction with the generation portfolio. These figures are available in full size and per scenario in the Appendix 8.1.1.

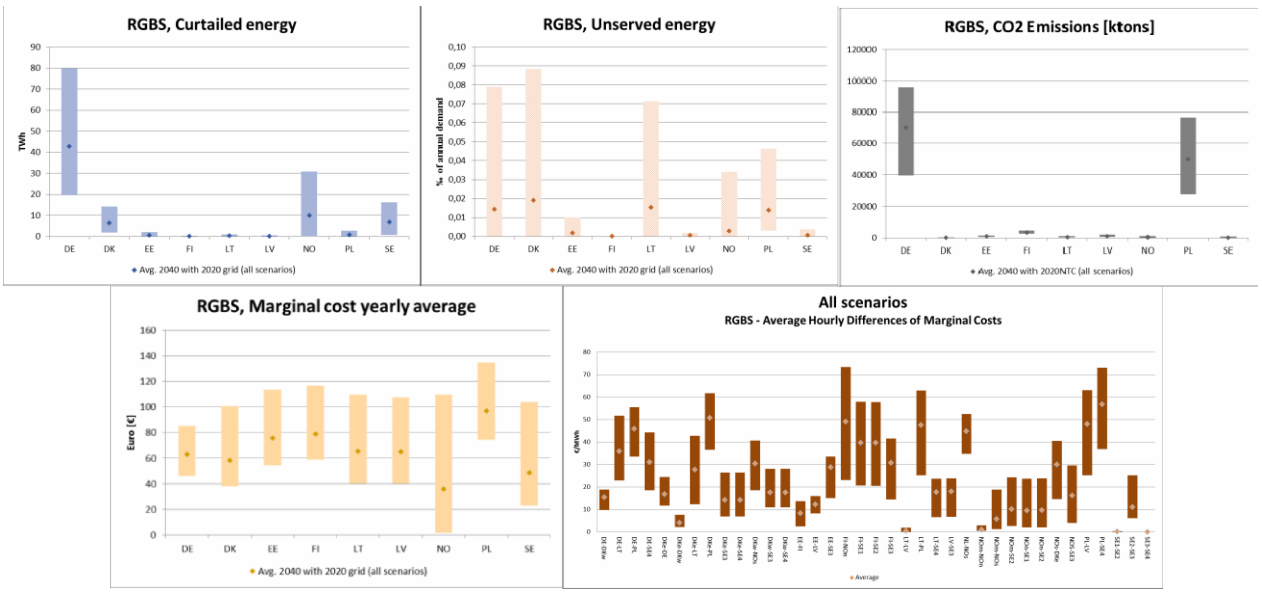

Figure 3-16: Span and average of curtailed and unserved energy, CO_2 emissions, marginal cost yearly average and hourly differences of marginal costs in RGBS Region in 2040 scenarios with 2020 grid capacities.

The above graphs show the average results and ranges of simulations of three different climate years for all of the three long-term 2040 scenarios. All of the simulations have been carried out by several market models and the results should be compared with the similar charts in Chapter 4, showing the 2040 market data simulations combined with an appropriate 2040-scenario grid.

When comparing the results with 2020 grid capacities with 2040-scenario capacities. it can be clearly seen that increasing the grid capacity helps to increase integration of renewables while maintaining the security of supply on a good level and the price differences on a moderate level.

Thermal decommissioning challenging the security of supply – the need for flexibility

The main challenge with increased solar and wind power is the substantial variations in total power generation. On the one hand, the availability of intermittent generation could be very low for relatively long periods, even when we consider the overall contribution from other parts of Europe. This is seen in the previous figure showing a high level of unserved energy in some parts of the region. Without the grid development, the flexibility possibilities of large hydro reservoirs cannot be utilised to serve the RES-based system. More transmission capacity between areas clearly contributes to a more effective integration of solar power and wind power, as can be seen when analysing the results with the increased capacities in Section 4.2, but it may not be enough by itself. There will also be a need for flexible thermal generation, demand response and different types of energy storage such as batteries, power-to-gas or hydrogen.

The unserved energy simulations revealed the security of supply issues without grid development after 2020, particularly for Germany, Poland, Lithuania and Denmark. The reason for this situation in Poland is due to very high demand growth (around 2% annually) and pressure to reduce CO_2 emissions, as most of its power generation is currently based on coal and lignite. The evolution presented in scenarios from coal and lignite generation to gas and nuclear generation is uncertain and requires adjustment in generation patterns to cover the high demand of Poland during certain hours. In Germany, the above-mentioned situation can be explained by the high growth of renewable power in-feeding in the northern and north-eastern part of Germany and increasing electricity demand in the southwestern part of Germany in line with the energy turn-around. The energy deficit in the southern part of Germany will rise with the shutdown of nuclear power stations until 2023. Therefore, a radical overhaul of the grid in the north-south direction is necessary.

Very high reduction in CO_2 emissions – grid constraints can still limit the reductions

All the scenarios assume very high reductions in CO_2 emissions compared with today. Therefore, if the grid is not strengthened, then some of the available CO_2-free production will be scrapped and replaced by fossil fuel-based production in other areas. Since 2040 scenarios also prefer gas over coal in thermal merit order, a reduced grid capacity will result in higher coal-based production levels, whereas an extended grid would promote gas-based production and will reduce CO_2 emissions.

Wind energy curtailment is mostly seen in Germany, Denmark, Norway and Sweden. The wind penetration levels are expected to be highest in Germany and Denmark, while some of the curtailed energy in Sweden and Norway can also be due to challenges with modelling the flexibility of hydro reservoirs in some of the market simulation tools being used. Wind energy curtailment in Denmark is mostly due to the fact that the grid situation in the southern part of DKw makes it necessary to curtail wind power in DKw. Curtailment in DKe is due to either an internal outage in northern parts of the grid or is due to imports from Germany because of its surplus of wind energy.

Germany and Poland have the largest fossil fuel-fired power plant capacity in the region, which translates in the figures in high CO_2 emission, on average and in extreme weather year and scenario.

Grid constraints limiting the functionality of the region-wide market

The high price differences seen in the 2040 simulations without grid reinforcements reveal that a lot of time the market is not able to utilise the cheapest generation available in the region due to inadequate development in NTCs between market areas. The high price differences between Finland and Sweden and between Finland and Norway in the case of the 2040 scenarios and 2020 grid will significantly converge with the building of the planned third 400 kV AC line between the FI and SE1 price areas. Fingrid and Svenska Kraftnät are also looking at replacing the existing Fenno-Skan 1 line, which will reach the end of its lifespan around 2027. The marginal costs differences in the northern directions of Poland in the 2040 scenarios and the grid in 2020 are due to a lack of planned cross-border capacity increase on LT-PL

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and a potential future link between DKe and PL, which will have a positive impact on price difference reduction.

The very high prices in some of the 2040 scenarios with a 2020 grid indicate that without new interconnections, the new generation in the region would probably be built in the countries with the highest prices, despite operating conditions for wind and solar being better elsewhere. Investment in new capacity depends on the cost and income for new thermal plants. In the 2040 GCA scenario, the CO_2 price is set at above 100 EUR/tonne and will give a high average price level. However, running hours for thermal power plants are generally reduced due to high proportion of renewables in the energy mix.

3.3.2 Reinforcing national grids needed to serve the change towards CO_2 free generation portfolio

Figure 3-17 shows the network study results of the 2040 scenario market data implemented in a 2020 network model. The upper left map shows thermal congestions on cross-border lines. In general, the interconnections are challenged in the 2040 scenarios by larger and more volatile flows and on greater-distance flows crossing Europe due to intermittent renewable generation. The other maps show a need for internal reinforcements in the three scenarios (2040) for some of the same reasons as for the cross-border connections and also to integrate the considerable amount of additional renewable power generation.

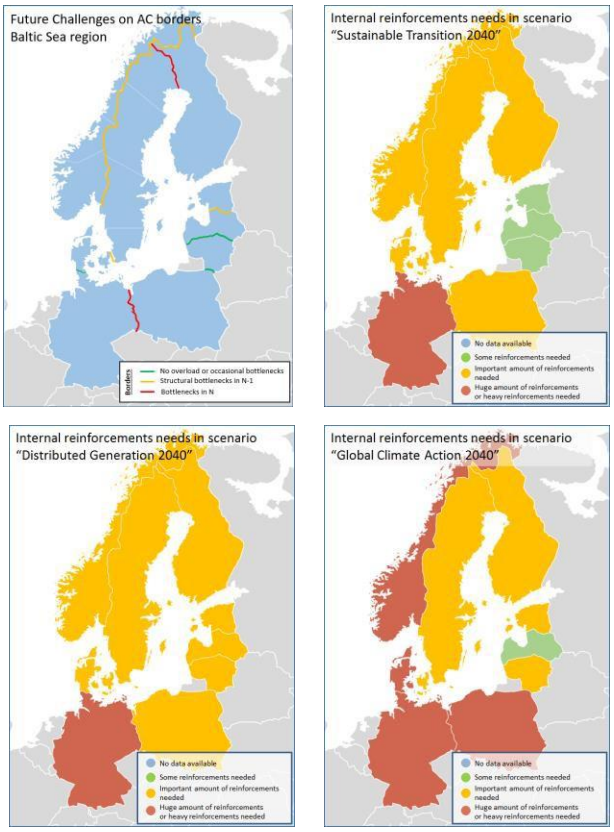

Figure 3-17: Grid constraints in RGBS Region in 2040 scenarios with 2020 grid capacities.

The screening indicates a bottleneck on the DKe-SE border, because of increased market flow at the 2040 level, which is more than the current (2020) NTC for this border. Because of these same reasons, border EE-LV is constrained in this scenario and the market scenario for 2040 has increased flow on the EE-LV cross-border. According to market studies, the main trend of power flow is from the north Nordic to the south Baltic States, and to Lithuania, which is the most deficient country in the Baltic States. Currently, the EE-LV cross-border is the most overloaded and has its weakest point in the Baltic States. Therefore, additional cross-border reinforcement is necessary.

In 2020, there is already a planned new interconnection line on the EE-LV cross-border, which will increase border capacity and reduce overloads, but further cross-border EE-LV capacity development is nevertheless the most favourable option. Some internal reinforcements for 2040 market flows with the 2020 network are also needed in Estonia and Latvia, but together with the development of the 3rd interconnection between Latvia and Estonia, many internal overloads must be eliminated.

The 2040 screening indicates that the 2020 level grid in Sweden might not be sufficient to meet the 2040-level market flows. Thus, some internal reinforcement needs to be done between 2020 and 2040. However, within that time period, several internal transmission lines will have to be replaced due to ageing, which will result in more internal capacity. It is impossible to say at this stage whether or not the capacity will be enough to meet the future market needs of 2040. In Finland, a moderate increase in north-south capacity is needed in all scenarios to deliver the wind power production from the north to the load centres in the southern areas.

3.3.3 Technical challenges of the power system due to physics

Technical challenges brought forward by increases in RES generation, which are identified by TSO experts are discussed in this section, including:

- Frequency stability issues, due to reduced inertia increased ramping 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 solutions for providing flexibility, while other solutions such as energy and electricity storage and demand response can also be part of the solution to 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 controlling RES generation, 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 is becoming increasingly CO_2 free.

Increased ramping

Another issue that emerges when adding large amounts of intermittent generation to the system is that change in residual load from one hour to the next can be higher when the load ramps up at the same time as RES generation ramps down. Figure 3-18 shows the maximum ramping in the 2040 scenarios. Compared to the peak load and the installed flexible capacity, the future ramping rates will be difficult to cope with. Grid reinforcements will be a part of the solution for this issue since the ramping-up of total renewable generation is less than the sum of the renewable ramping-up in all area, since renewable generation might ramp up in one area at the same time as another area ramps down.

The following chart shows the 99.9 percentile highest hourly ramp (up and down) of residual load. This residual load is the remaining load after subtracting the production of variable RES (wind and solar production). Again, the results are presented for every country as previously mentioned, i.e., the average and the maximum values in the ranges for all simulations for the three different climate years and the three different long-term 2040 scenarios.

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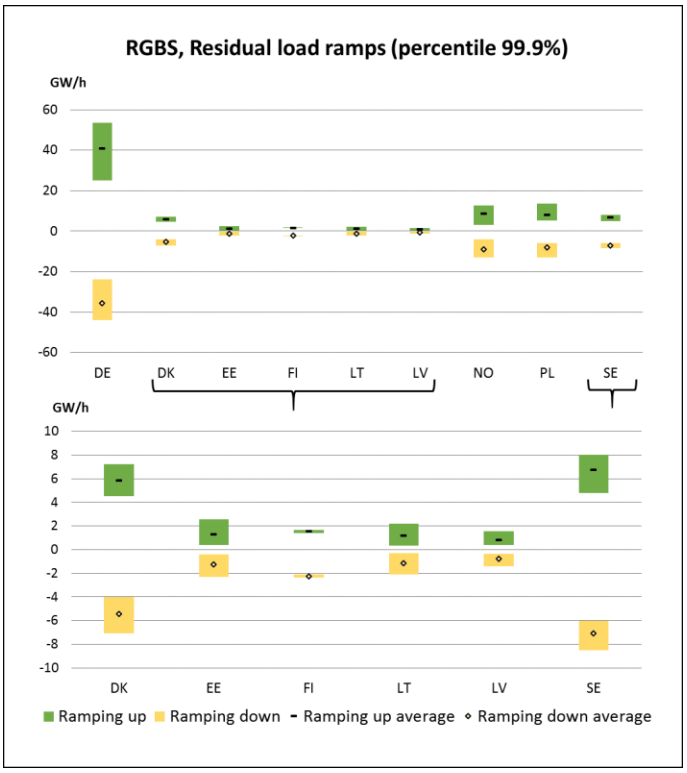

Figure 3-18: Residual load ramp rates in RGBS region in 2040 scenarios with 2020 grid capacities.

According to the simulations, very high ramping rates compared to the size of the system will be seen in Denmark, Norway, Germany and the Baltic countries.

Decreased inertia

One of the major challenges identified is the decrease in inertia when synchronous generation is decreasing, and converter-connected generation is increasing 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.

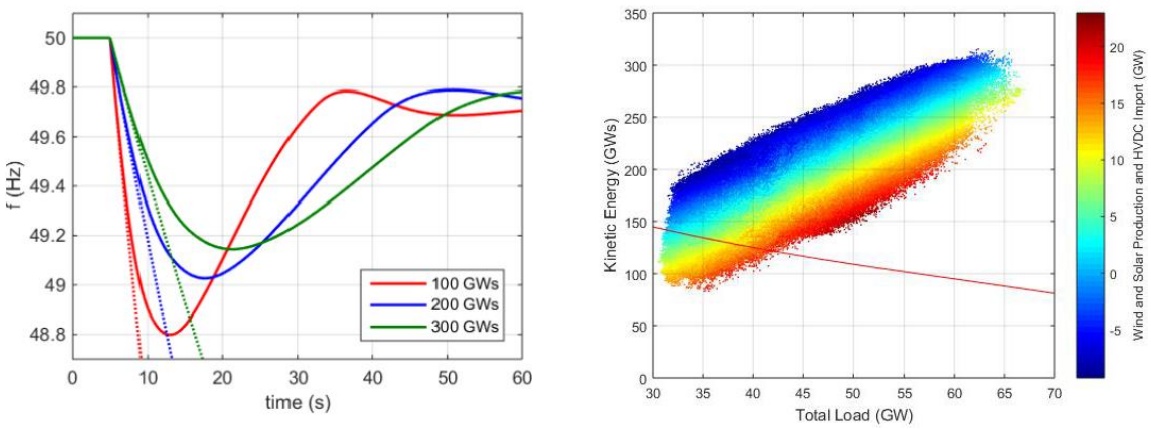

Figure 3-19 On the left, the effect of the amount of kinetic energy (inertia) on the behaviour of frequency after a loss of production with (solid line) and without (dotted line) the Frequency Containment Reserve (FCR).[10] On the right, the estimated kinetic energy in 2025 as a function of total load 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 11.

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

Too little inertia can lead to frequency instability where sudden change in generation and load balance can lead to unacceptable frequency deviation and could further lead to cascading tripping in the system elements, leading to blackouts in the worst-case scenario. 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'.[12]

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. The 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. The maximum output will usually be restored 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 the planned wind power production is located far away 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 the conventional units. For example, in the Nordic countries, wind power from the northern areas need to be transmitted to load centres near the large cities in the southern areas. Similarly, in Germany, the 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.

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

4 REGIONAL RESULTS

This chapter shows and explains the results of the regional studies and is divided into four sections. Subchapter 4.1 provides future capacity needs identified during the Identification of System Needs process or in additional (bilateral or external) studies related to capacity needs. Subchapter 4.2 explains the regional market analysis results in detail, and Subchapter 4.3 focuses on the network analysis results. In Subchapter 4.4, the regional sensitivity analysis results are presented.

4.1 Future capacity needs

The energy system of the Baltic Sea region is undergoing a transformation. Over recent years, onshore wind capacity has been developing at an increasing rate. More recently, in parts of the region, offshore wind generation is being developed in significant quantities. This development of renewable generation, alongside the 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, the nuclear generation is undergoing a major restructuring, being decommissioned in Germany, while Sweden continues to discuss the future of its nuclear generation programme.

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 a part of the production system themselves (prosumers).

The potential changes in both generation and consumption are described in the first phase of the TYNDP-2018 process, building new scenarios for 2030 and 2040 and assessing system needs for the long-term horizon of 2040. As part of this work, cross-border capacity increases were identified, which 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. Identified capacity increases inside or at the borders of the Baltic Sea region are shown in the map below. The system needs for the 2040 horizon are being evaluated with respect to (1) market-integration/socio-economic welfare, (2) integration of renewables and (3) security of supply. For the Baltic Sea region the 2040-needs are mainly being described through:

- Stronger integration between Germany and Poland in order to increase market integration and in order to facilitate thermal power plant decommissioning in Poland;
- Further integration between Sweden and Finland in order to increase market integration;
- Further integration between Norway-Denmark due to price differences, RES integration and the weakened Danish security of supply in periods of high demand and low variable RES (wind and solar) periods;
- Further integration between Sweden/Denmark and Germany due to price differences and better optimisation of RES generation (hydro/wind); and
- Further internal integration in the Baltic region, mainly due to security of supply.

In addition to these main increases, the high wind scenario (GCA) assumes a huge growth in wind power in the north of Norway. This scenario will lead to an increased capacity-need in the north-south direction towards Finland, Sweden and southern Norway. The scenario is not based on a total economy review (grid+production-investments). A complete socio-economic evaluation is needed before settling on the 2040 capacities.

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 the TYNDP 2018. For some of the corridors, there is a gap between the 2040-needs and the projects being assessed in TYNDP 2018.

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However, as shown in Figure 4.1, projects for the Baltics, between Sweden-Finland, between Sweden and Germany and between Norway and the UK/continental cover some of the needs described above, and by doing so plug some of the gaps.

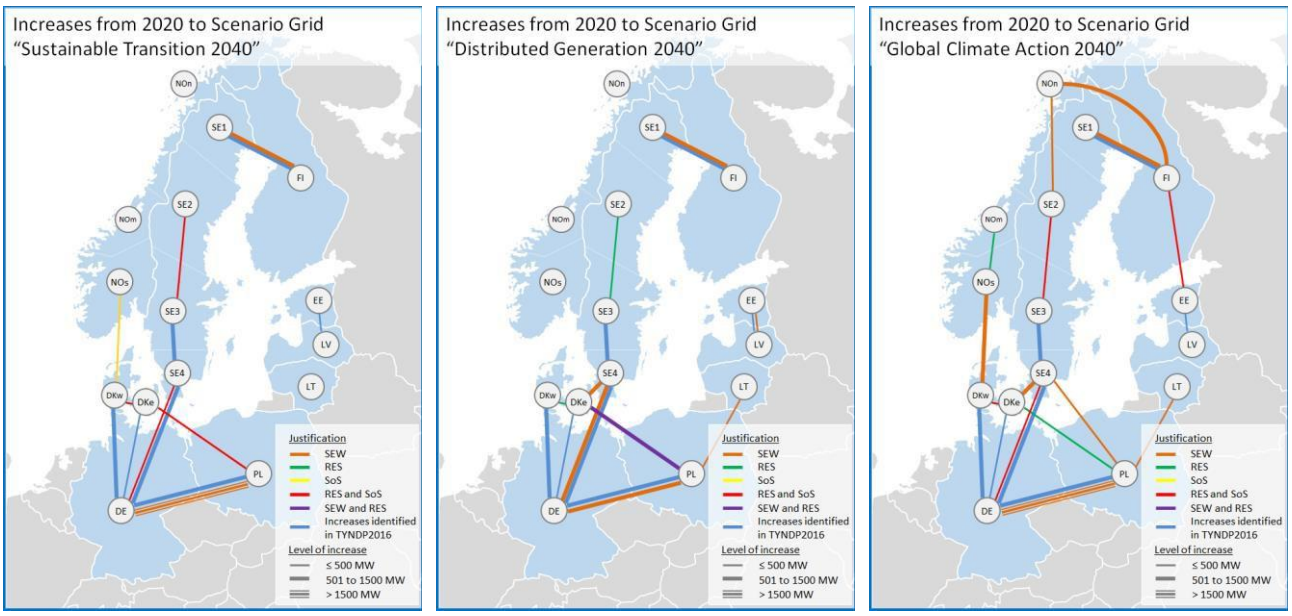

Figure 4-1: Identified capacity increase needs in the three studied 2040 scenarios in the BS region.[13]

Figure 4-1 shows the need for cross-border capacity increases beyond the expected 2020 grid for each of the 2040 scenarios. While mature projects from earlier TYNDP's have been added directly, other increases are shown along with the needs they fulfil according to the 'Identification of System Needs' methodology – needs triggered by market integration in first place and afterwards and in case not solved previously by security of supply and/or renewable integration requirements.

Some of the needs shown above are based on simulations including standard cost estimates for every border investigated (ratio between costs and benefit can be decisive for choosing among potential reinforcements). An overview of these standard costs can be found in Appendix 8.1.4.

The table below shows cross-border capacities including increases identified during the TYNDP2018 process. The first columns show the expected 2020 capacities. The next columns show the capacities relevant for the CBA, which will be carried out on the time horizons of 2025 and 2030. These columns show the capacities of the reference grid for CBA and the capacities if all projects per border are added together. The last three (double) columns show the proper capacities for each of the three 2040 scenarios. These capacities have been identified during the 'Identification of System Needs' phase and are dependent on the particular scenario.

[13] Increases identified in TYNDP2016 refer to the reference capacities of TYNDP 2016 for 2030, for which some borders had been adjusted for TYNDP18. Projects commissioned in 2020 are not included as capacity increases.

	NTC 2020		CBA Capacities		Scenario Capacities					
			NTC 2027 (reference grid)		NTC ST2040		NTC DG2040		NTC GCA2040	
Border	=>	<=	=>	<=	=>	<=	=>	<=	=>	<=
DE-DEkf	400	400	400	400	400	400	400	400	400	400
DE-DKe	600	585	600	585	600	600	600	600	600	600
DE-DKw	1500	1780	3000	3000	3000	3000	3000	3000	3000	3000
DEkf-DKkf	400	400	400	400	400	400	400	400	400	400
DE-NOs	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
DE-PLE	0	2500	0	3000	0	3000	0	3000	0	3000
DE-PLI	500	0	2000	0	4500	0	3500	0	4500	0
DE-SE4	615	615	1315	1300	1815	1815	2315	2315	2315	2315
DKe-DKkf	400	600	600	600	400	600	400	600	400	600
DKe-DKw	600	590	600	600	1100	1090	1100	1090	1100	1090
DKe-PL	0	0	0	0	500	500	1500	1500	500	500
DKe-SE4	1700	1300	1700	1300	1700	1300	2700	2300	2700	2300
DKw-NOs	1640	1640	1700	1640	2140	2140	1640	1640	2640	2640
DKw-SE3	740	680	740	680	740	680	740	680	740	680
EE-FI	1016	1000	1016	1016	1016	1000	1016	1000	1516	1500
EE-LV	900	900	1379	1379	1350	1250	1850	1750	1350	1250
FI-NOn	0	0	0	0	0	0	0	0	1000	1000
FI-SE1	1100	1200	2000	2000	2500	2500	2500	2500	2500	2500
FI-SE2	0	0	0	0	800	800	800	800	800	800
FI-SE3	1200	1200	1200	1200	800	800	800	800	800	800
LT-LV	1200	1500	1200	1500	1200	1500	1200	1500	1200	1500
LT-PL	500	500	1000	1000	500	500	1000	1000	1000	1000
LT-SE4	700	700	700	700	700	700	700	700	700	700
NL-NOs	700	700	700	700	1700	1700	1700	1700	1700	1700
NOm-NOn	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
NOm-NOs	1400	1400	1400	1400	1400	1400	1400	1400	1900	1900
NOm-SE2	600	1000	600	1000	600	1000	600	1000	600	1000
NOn-SE1	700	600	700	600	700	600	700	600	700	600
NOn-SE2	250	300	250	300	250	300	250	300	750	800
NOs-SE3	2145	2095	2145	2095	2145	2095	2145	2095	2145	2095
PL-SE4	600	600	600	600	600	600	600	600	1100	1100
SE1-SE2	3300	3300	3300	3300	3300	3300	3300	3300	3300	3300
SE2-SE3	7800	7800	7800	7800	8300	8300	8300	8300	8300	8300
SE3-SE4	6500	3200	7200	3600	7200	3600	7200	3600	7200	3600

Table 4-1: Cross-border capacities expected for 2020, for the reference grid and identified during the Identification of the System Needs phase

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4.2 Market results

Table 4-1 shows the average results of the pan-European market studies of all three 2040 scenarios using the 2040 scenario grids. Market simulations have been carried out by several pan-European market models, and the results give the average values of all the market models. 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 the energy not served. These figures are available in full for each scenario in Appendix 8.1.2.

Capacity increases improving the security of supply

The amount of unserved energy decreases dramatically in both Germany and Poland with the 2040 grid compared to the simulations with the 2020 grid. This result is expected since the grid capacity to and from both Germany and Poland increases significantly with the 2040 grid. 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 Germany and Poland. The level of unserved energy is very small. Based on these small numbers, unserved energy is not considered to be a very important indicator of the need for more interconnector capacity. There are cheaper solutions for solving the unserved energy issue, such as investing in more production capacity, batteries or storage, demand response or load management.

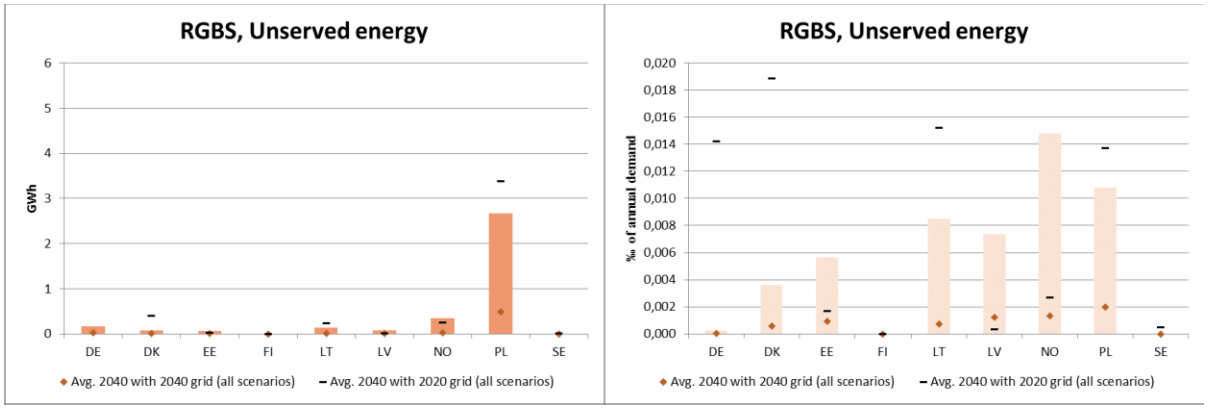

Figure 4-2: Average of unserved energy with and without identified capacity increases and range of unserved energy (all scenarios and all studied weather years) with identified capacity increases in Baltic Sea region in the three 2040 scenarios studied.

In all other countries, the unserved energy is already very small in the 2020 grid simulations. This is due to the large amount of flexible hydropower capacity as well as an already large degree of interconnection between countries compared to other regions. Results with both the 2020 and 2040 grids indicate some unserved energy in Norway, which is unlikely to be due to the abundance of flexible hydropower. This is due to the fact that not all models that were used to produce the pan-European results have a good representation of hydropower, which leads to poor results in some of the hydropower dominated countries.

Improved utilisation of RES generation

The amount of curtailed energy decreases substantially with the 2040 grid compared to the 2020 grid. The amount of curtailment is roughly halved in Germany, Denmark and Sweden. The new capacity in the 2040 grid 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.

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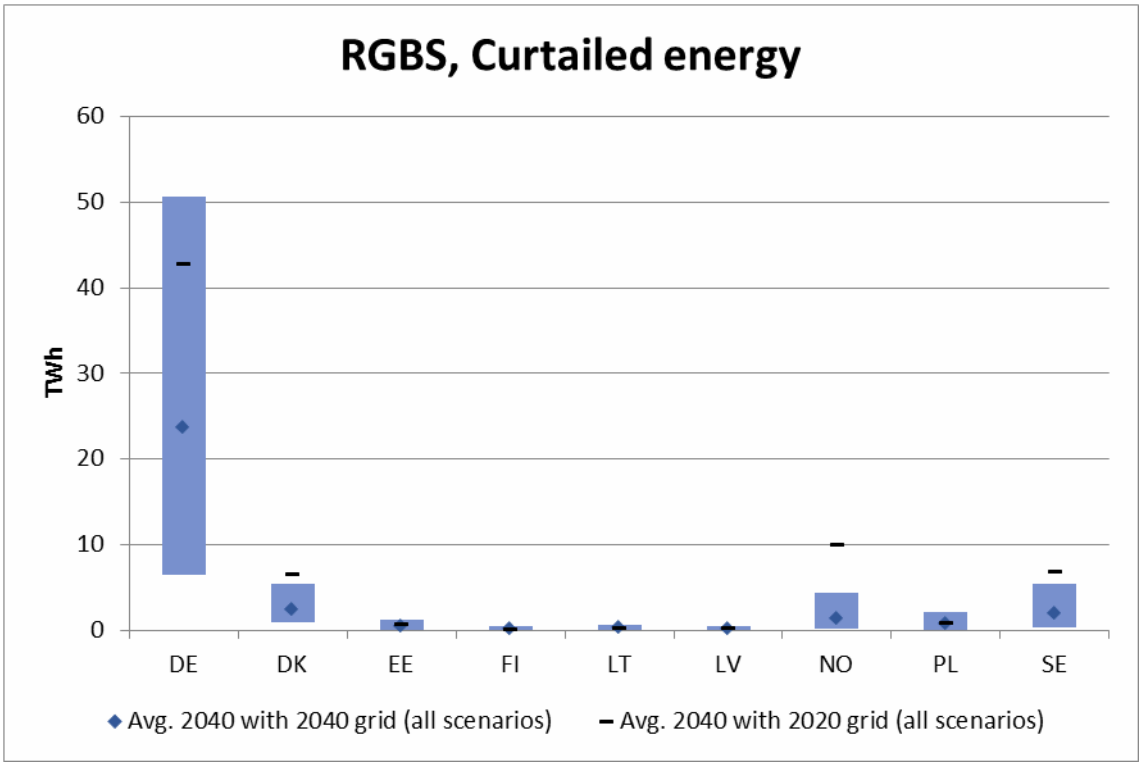

Figure 4-3: Average curtailed energy in the Baltic Sea region with and without identified capacity increases in the three studied 2040 scenarios; and the range of curtailed energy (all 2040 scenarios and all studied weather years) with identified capacity increases.

The results indicate that there would still be relatively large amounts of energy curtailment with the 2040 grid. 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, which means that the same amount of energy can be produced by turbines with lower generation capacity. In addition, curtailment results for Norway are likely to be too high because of the same reasons mentioned above.

Even if the results might be slightly exaggerated, the message is still clear: grid investments are needed to avoid a large amount of wasted renewable energy in the region and even more capacity than the 2040 grid might be needed, particularly in scenarios with a lot of intermittent renewable generation. However, in a future power system with a very large amount of intermittent generation, some curtailment needs to be accepted as avoiding curtailment completely will be too expensive.

Decreased CO_2 emissions

A higher interconnector capacity will also have an effect on CO_2 emissions. This is due to a better integration of zero-emission renewables, as well as increased use of gas instead 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 CO_2 emissions than interconnectors.

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Figure 4-4 shows that the level of CO_2 emissions is neither particularly high nor particularly significant for the Baltic States and the Nordic countries and that both regions are emitting very low level of CO_2 emissions. As the level of CO_2 emissions is moving towards zero in both regions, they are on course to meet their EU target of CO_2 emissions reductions. In contrast, both Germany (62, 000 ktons) and Poland (40 000 ktons) have very high levels of CO_2 emissions and the level of CO_2 emissions vary widely depending on the scenario. The reason for these high CO_2 emissions is the production of fossil fuels (lignite, coal and gas). Additional cross-border capacity increases from Germany to the Nordic countries could reduce the level of CO_2 emissions. Comparing both graphs the CO_2 emissions level in 2040 with 2020 NTCs, and the CO_2 emissions level in 2040 with 2040 NTCs, it can be seen that, on average, CO_2 emission levels will decrease by 7,000 ktons in Germany and by 10,000 ktons in Poland. For the other countries, the CO_2 emissions levels are moderate in 2020. Therefore, additional capacity increases will not significantly reduce the level of CO_2 emissions.

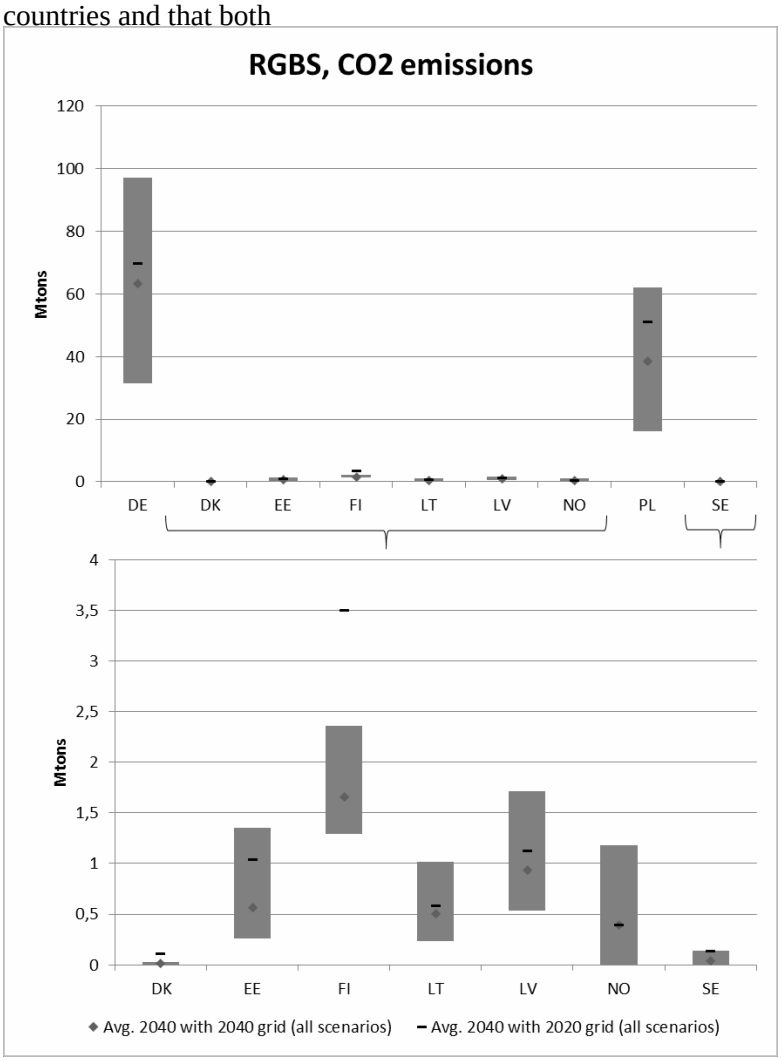

Figure 4-4: Average CO_2 emissions in the Baltic Sea region in the three studied 2040 scenarios with and without identified capacity increases, and range of CO_2 emissions (all 2040 scenarios and all studied weather years) with identified capacity increases.

Improved market integration and decreased average prices

As shown in Figure 4-5, the average price difference decreases when the 2040 grid is implemented.

More interconnector capacity between countries will reduce price differences and will develop a more effective and integrated market. Hence, 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 the price variations between wetter and drier years will be lower.

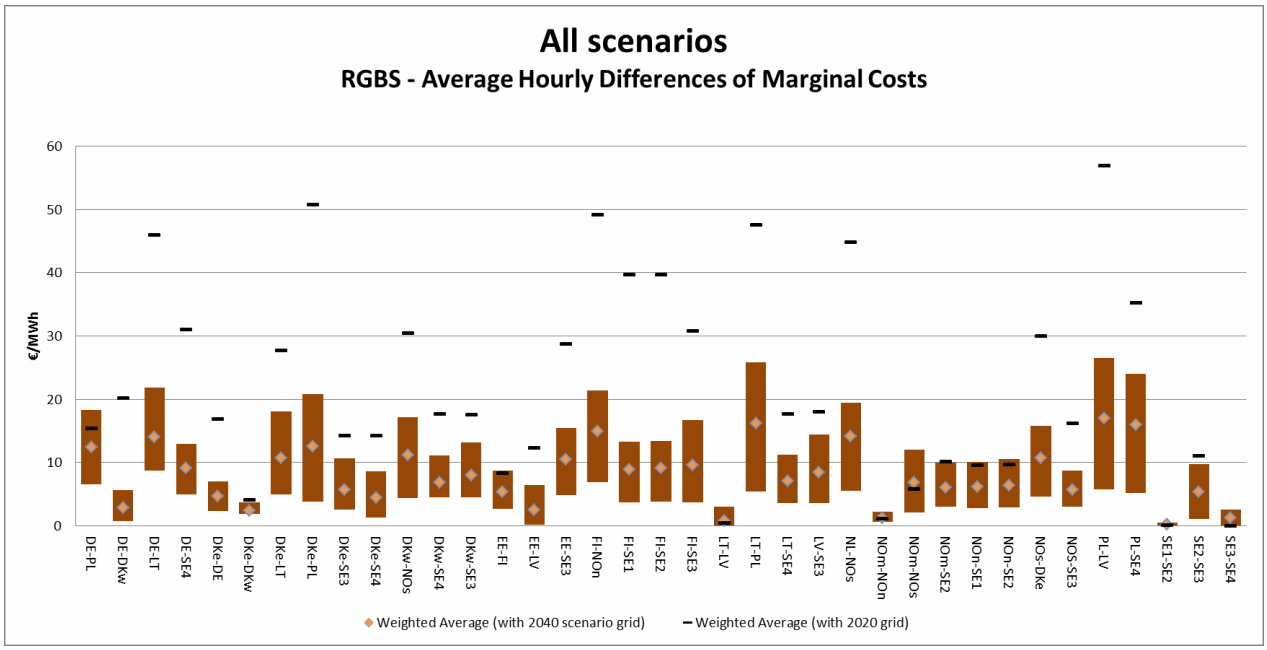

Figure 4-5: Average hourly price differences with and without identified capacity increases in the BS region in the three studied 2040 scenarios, and the range of average hourly price differences (all 2040 scenarios and all studied weather years) with identified capacity increases.

On average, the price levels in the countries in the Baltic Sea region are fairly close to each other in the 2040 scenarios with the 2040 grid, with Norway and Sweden slightly below the other countries, while Poland is slightly above. The average marginal cost level is around 60 EUR/MWh. However, it should be noted that the absolute level is very sensitive to assumptions made regarding fuel and CO_2 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.

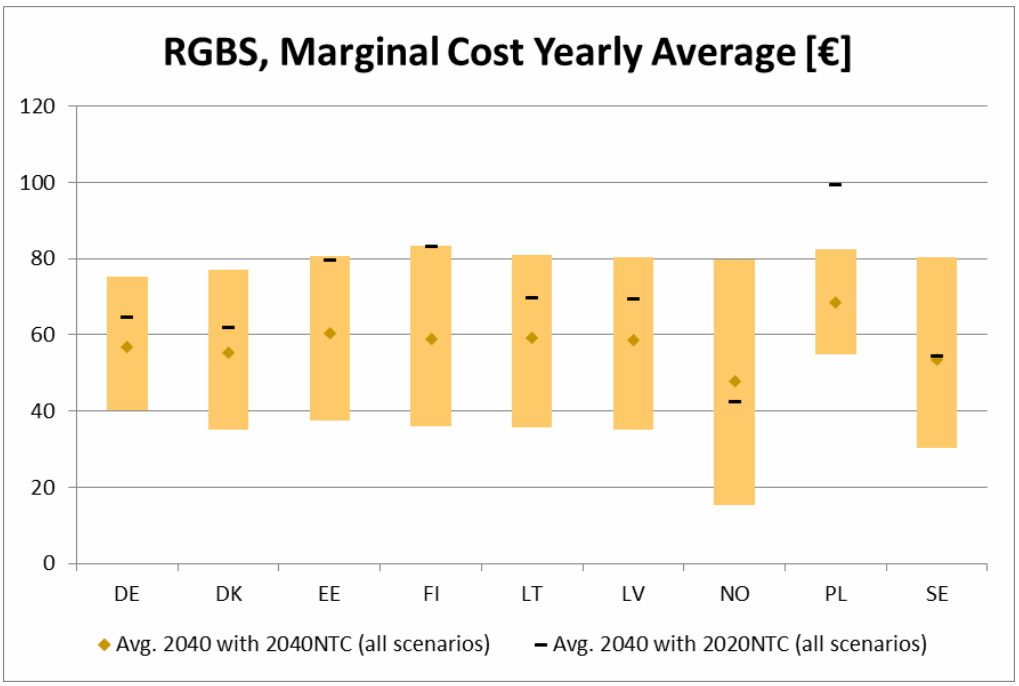

Figure 4-6: Yearly average of marginal cost (€/MWh) with and without identified capacity increases in the BS region in the three studied 2040, and the range of average marginal cost (all 2040 scenarios and all studied weather years) with identified capacity increases.

The yearly average marginal cost for the Baltic Sea region varies from 41 Euro/MWh in Norway to 100 Euro/MWh in Poland in the case of NTC2020. The yearly price variation in Norway is due to the variations in inflow between the wet and dry years. Greater interconnector capacity will lift the Nordic price level in wet years and reduce prices in dry years. Overall, the price level in all Baltic Sea region countries will decrease, except for in Norway where it will increase slightly because the hydro system is more integrated than the thermal-based system, and the Nordic countries will export more electricity to the rest of Europe.

Surplus in the western part of the region and deficit in the eastern part

The net annual country balance shows that main electricity producers in the Baltic Sea region are Germany, Norway and Sweden. The annual country balance varies widely depending on the scenario, the weather year (wet or dry) and the assumptions set for the study. Production in all these countries is based on wind and solar energy, hydropower and hydro storage as well as biomass generation.

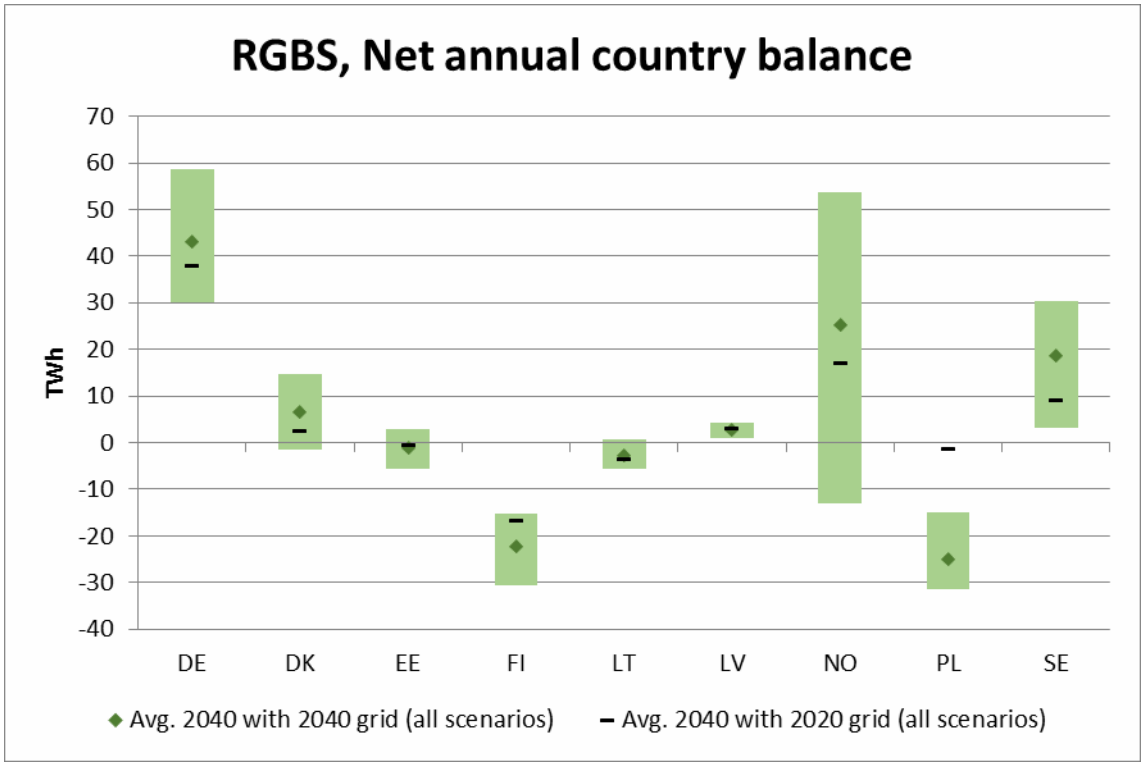

Figure 4-7: Net annual country balance with and without identified capacity in the BS region in the three 2040 scenarios with identified capacity increases, and the range of country balances (all 2040 scenarios and all studied weather years) with identified capacity increases.

The difference between net balances in different scenarios is estimated to be highest for Norway, and its generation depends greatly on the type of weather year. 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 Estonia, Lithuania and Latvia. The annual balance for these countries is very close to zero because they have relatively small power systems compared with Germany, Norway and Sweden. In addition, Estonia and Latvia are focused on become self-sufficient for energy by 2040. A large amount of imported electricity is expected for Finland and Poland in most of the 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 a growth in demand as well as the decommissioning of existing nuclear and CHP generation by 2040. The annual balance in hydro-based system are affected by inflow. The inflow to a hydro reservoir will not increase, with more interconnector capacity. More capacity give the opportunity to import or export a larger amount of energy in a shorter period. However, the inflow and weather values will be the same.

4.3 Network results

Network studies were conducted to analyse the adequacy of the grid and the necessary grid reinforcements in each scenario. Network analysis was first conducted in order to check the amount of necessary grid reinforcements to prepare the grid for different generation portfolios and different generation patterns conducive to each scenario (ST2040, DG2040 and GCA2040). The need to strengthen the grids inside market areas was discussed in Section 3.3.2 as challenges that needed to be met. Secondly, the grid reinforcements needed to increase the NTCs between market areas to the levels identified and shown in Section 4.1 were studied. As an example, the flows on the borders on which the capacities were increased in sustainable transition 2040 scenario are shown below.

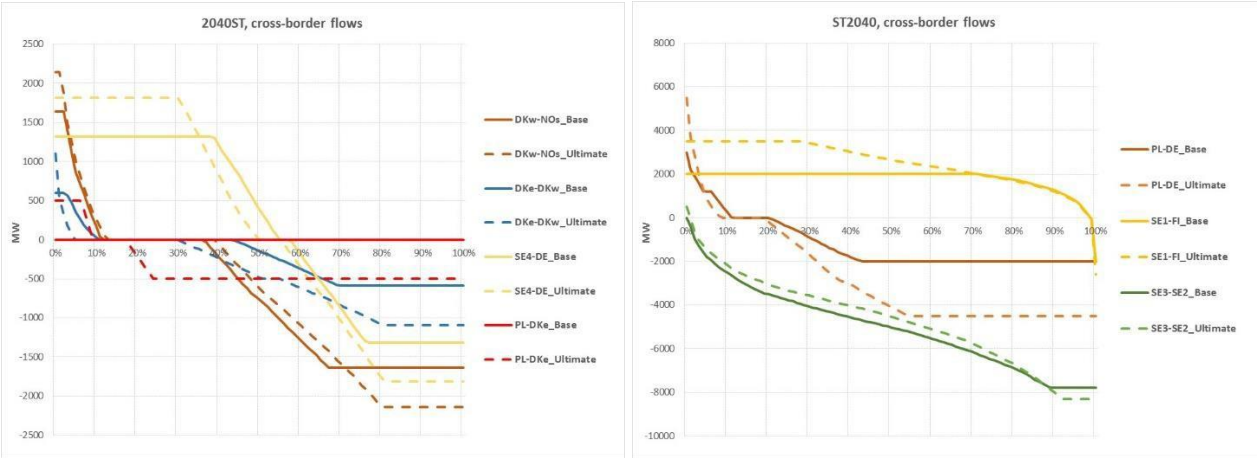

Figure 4-8: ST2040 scenario duration curves of flows on borders where capacity increases were identified based on the SEW loop of Identification of System Needs in the RGBS region. 'Base' values are those without increased capacities and 'Ultimate' values are those with identified increases.

As seen from Figures 4-8 and 4-9, the increased capacities on the borders are utilised by the market in the 2040 simulations. The increased flows can also increase the need for additional internal grid reinforcements. Even with a grid which includes projects between 2020 and 2030, as assessed in TYNDP2016, the new TYNDP2018 scenarios for 2040 will cause internal bottlenecks. The maps below show the need for additional internal grid reinforcements for all three 2040 scenarios when combined with the identified 2040 cross-border capacity needs.

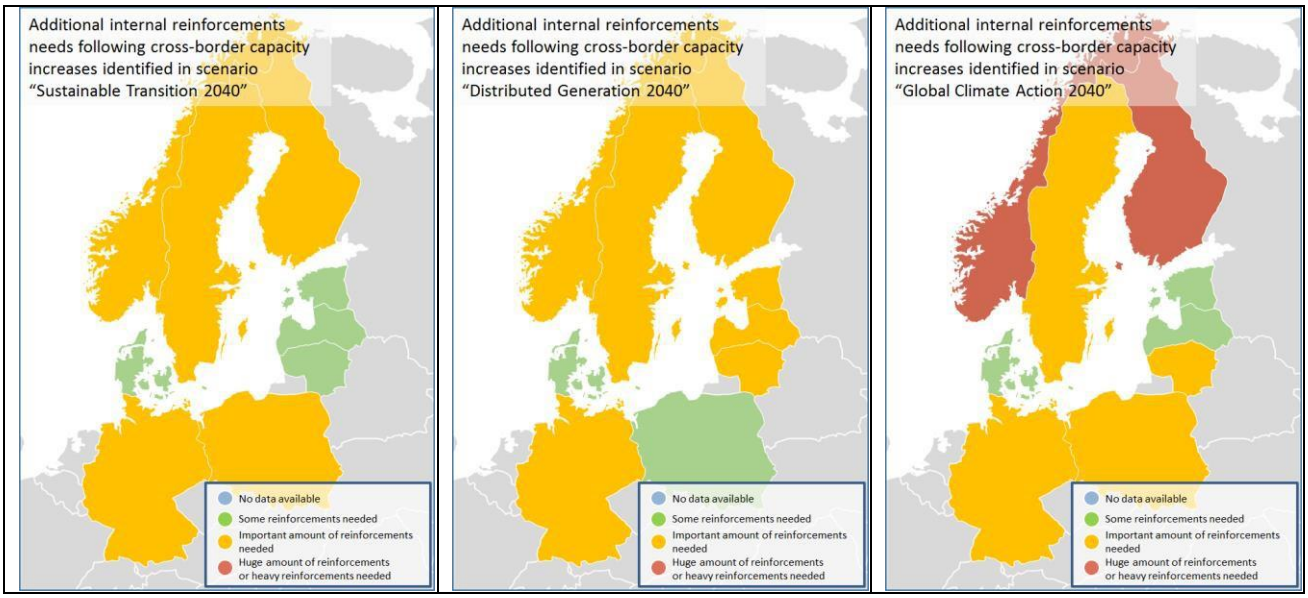

Figure 4-9: Impact of identified capacity increases on internal grid reinforcement needs in the three studied 2040 scenarios.

The ST 2040 scenario needs the least number of reinforcements in the Baltic Sea region, while a considerable amount of grid reinforcements is needed in Finland, Germany, Norway, Poland and Sweden. In Sweden, the screening indicates the internal reinforcements necessary between 2020 and 2040. Within that time period, several internal transmission lines will be replaced due to ageing, which will result in more internal capacity. Due to the high amount of renewable installed capacity expected to be installed by 2030 and 2040, internal reinforcements in the German transmission grid are necessary. To evaluate which reinforcements need to be implemented, the German TSOs (50Hertz, Amprion, TenneT DE and TransnetBW) are working together on the German National Development Plan, German: *Netzentwicklungsplan*, NEP), which has to be published, by law, every two years. In order to allow all stakeholders to participate in this process, two consultation phases are included. After publishing the NEP, the German regulator, the *Bundesnetzagentur*, decides which projects will go ahead. As the German NDP published in 2017 focuses on 2030 and 2035, some additional reinforcements, which are not yet identified, may be required until 2040. All internal German bottlenecks will be resolved by this process. The NDP also considers the results of the latest TYNDP in order to ensure that the German grid is prepared to provide the capacities needed for the TYNDP projects. For example, there is an ongoing discussion regarding additional DC links in the North/South axis for 2035 in order to integrate the RES generation capacity.

The DG 2040 scenario contains more production from renewable sources as well as additional cross-border increases between Lithuania and Poland being identified, which will increase the flow through the Baltic countries. The increased cross-border flow requires additional internal reinforcements in all Baltic countries.

The GCA 2040 scenario also contains a lot of production from renewable sources, and the highest level of increased cross-border capacity needs were identified for this scenario in the Baltic Sea region. The cross-border capacity needs to and from Finland are 3,000 MW in this scenario, which requires a lot more internal north-south capacity in the country. In addition, heavy reinforcement needs are necessary in order to cope with the additional cross-border capacities in Norway.

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4.4 Regional sensitivities

Regional sensitivities were based upon a regional bottom-up scenario. The regional scenarios as well as the sensitivities were described in Chapter 3.2.3. The regional sensitivities were simulated with the EMPS market model[14] using a set of 33 weather years (1980–2012) to include the effect of variation in hydrological inflow, wind and temperature. In the regional sensitivity study, there is no CBA assessment of project candidates. Instead, the potential benefit of new capacity on a border is approximated by the average hourly price difference on each border. The hourly price difference indicates the magnitude of possible increased SEW if more capacity would be added to that border. Results were extracted for all borders with existing connections in the region. However, if the price difference is lower between two market areas the result for an existing border could be used to approximate for a potential new one.

4.4.1 Regional Base case – high impact of wet and dry years

In the regional base case, the average price level in Sweden, Norway and Denmark is close to the price level on the continent, whereas Finland and the Baltic countries have slightly higher prices. The Scandinavian countries (Denmark, Norway and Sweden) have surpluses, whereas Finland and the Baltic countries have deficits. This is on a general level and is in line with the pan-European results. The main difference is that in the pan-European results, thermal generation is higher in the Baltics and lower in Denmark. This is due to the fact that the thermal generation in Denmark in the regional case is modelled with more details, with must-run constraints yielding more generation. This is in line with what can be observed in the market today. Average balances (generation minus demand) are presented in Figure 4.10. The results are shown as an average of all the 33 simulated weather years and a dry and a wet year to indicate the variation between weather conditions, which is significant in the region. The main source of variation is hydrological inflow. However, both demand and wind production also vary between different weather years (see Section 3.2.3).

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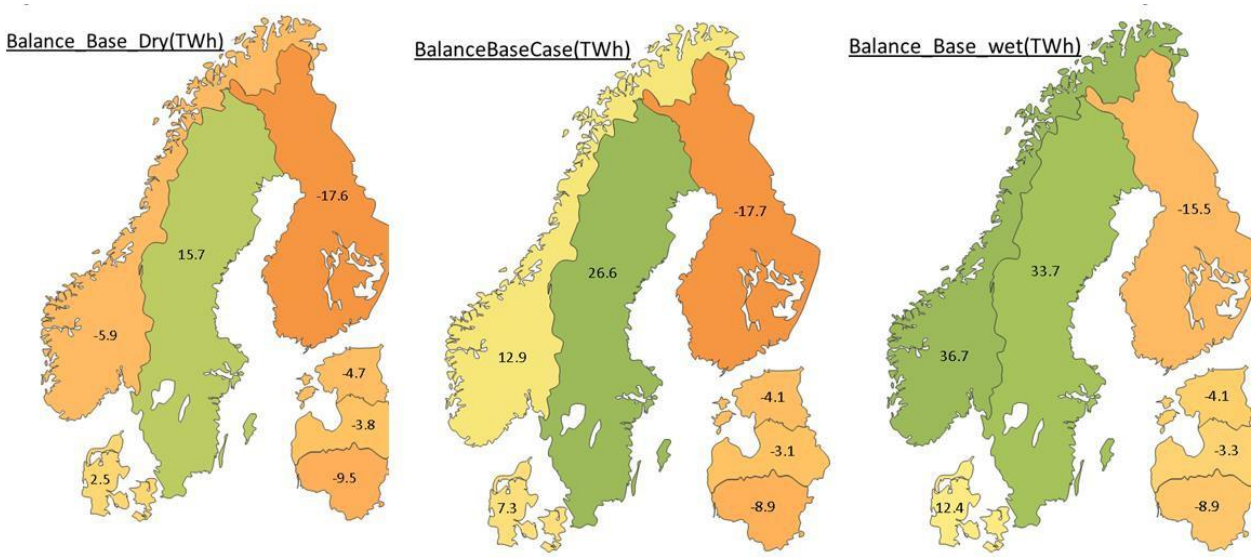

Figure 4-10: Balance in the regional base case scenario for dry, average and wet years (2030).

[14] EMPS (EFI's Multi-area Power-market Simulator) is a tool for forecasting and planning in electricity markets. It has been developed for optimisation and simulation of hydrothermal power systems with a considerable share of hydropower. It takes into account transmission constraints and hydrological differences between major areas or regional subsystems. https://www.sintef.no/en/software/emps-multi-area-power-market-simulator/

The variation in weather conditions also has an effect on the price levels, which are higher than the continental average in dry years and lower in wet years (see Figure 4-11). These results underline the importance of using a large dataset of weather conditions when analysing the need for interconnectors within this region, since just using one average weather year would yield lower price differences than would the average over a large number of weather years.

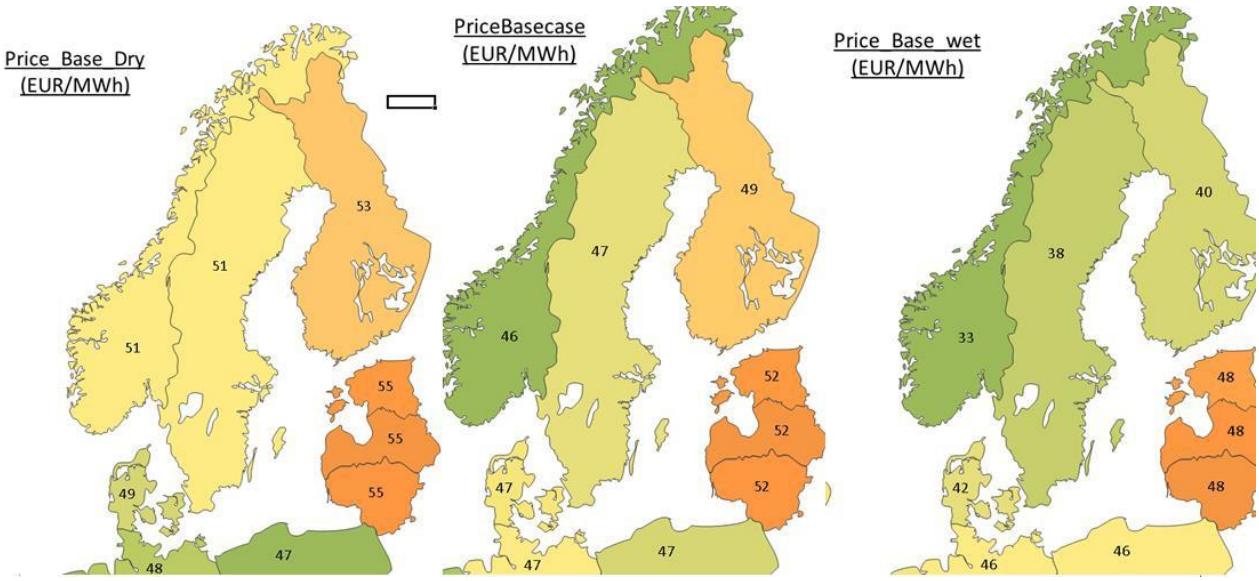

Figure 4-11: Price in the regional base case for dry, average and wet years.

The resulting average hourly price difference between the base case and the spread for all sensitivities is shown in Figure 4-12. The highest price differences are between the synchronous areas, which are in line with the pan-EU simulation results. However, there are some significant price differences between some areas within the Nordic system. The Nordic TSOs will analyse the need for additional capacity between the Nordic areas in the Nordic Grid Development Plan, which is due for publication in 2019.

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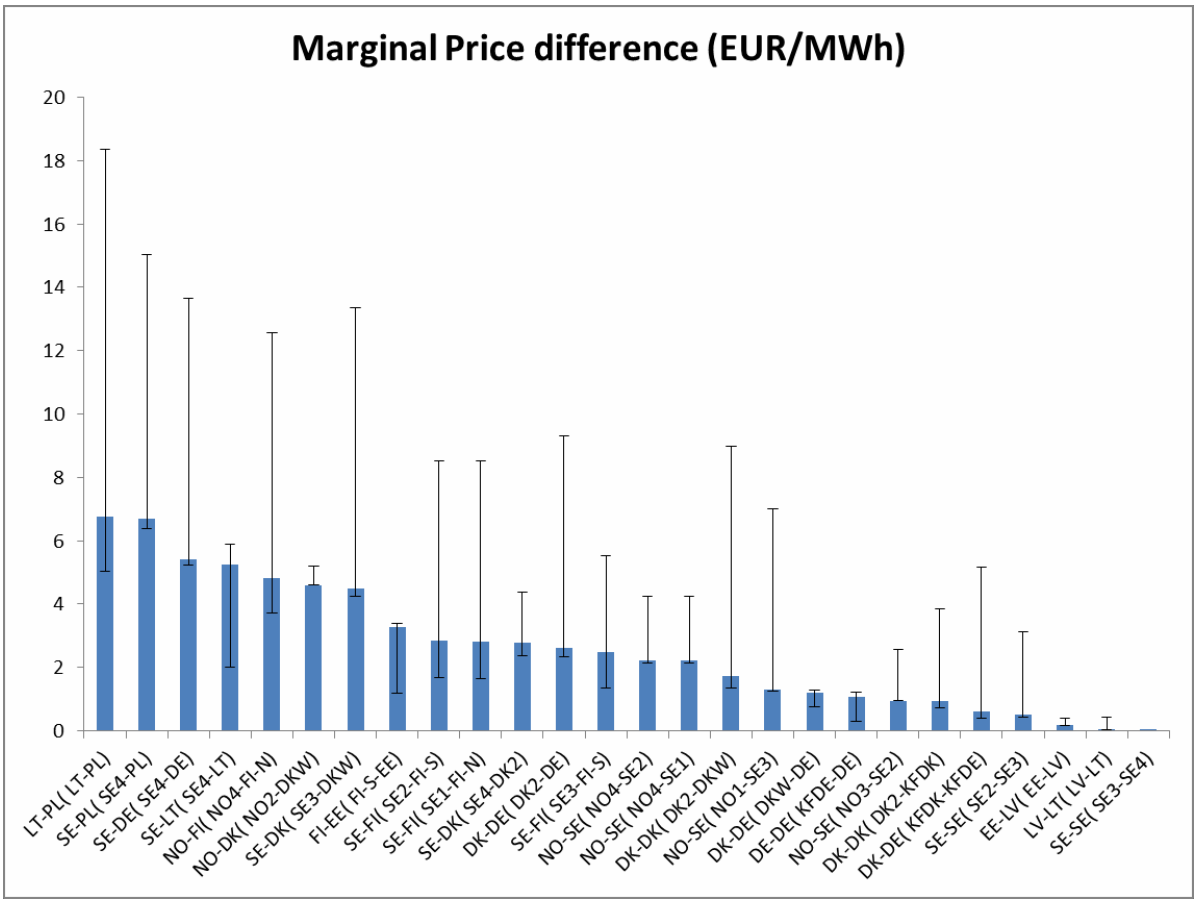

Figure 4-12: Average marginal price differences over all weather years between areas in the region (existing interconnectors) for the base case and the spread between the sensitivities (see Chapters 4.4.2–4.4.5).

The sensitivity results focus on the effect on price differences between the areas, and the resulting average prices and balances are presented in the Appendix, Section 8.1.5.

4.4.2 Low nuclear capacity – Challenging the Nordic adequacy

In the sensitivities with less nuclear capacity (see Section 3.2.3), the Nordic price level increases and becomes higher than continental prices in both cases where additional production is added, and where nuclear units are decommissioned without being replaced. In the extreme cases, where all nuclear capacity is removed without replacement, the price difference increases significantly, particularly with interconnectors to the continental system (Figure 4.13). In this extreme case, the Nordic adequacy is also challenged, as shown by the results in Section 4.4.6.

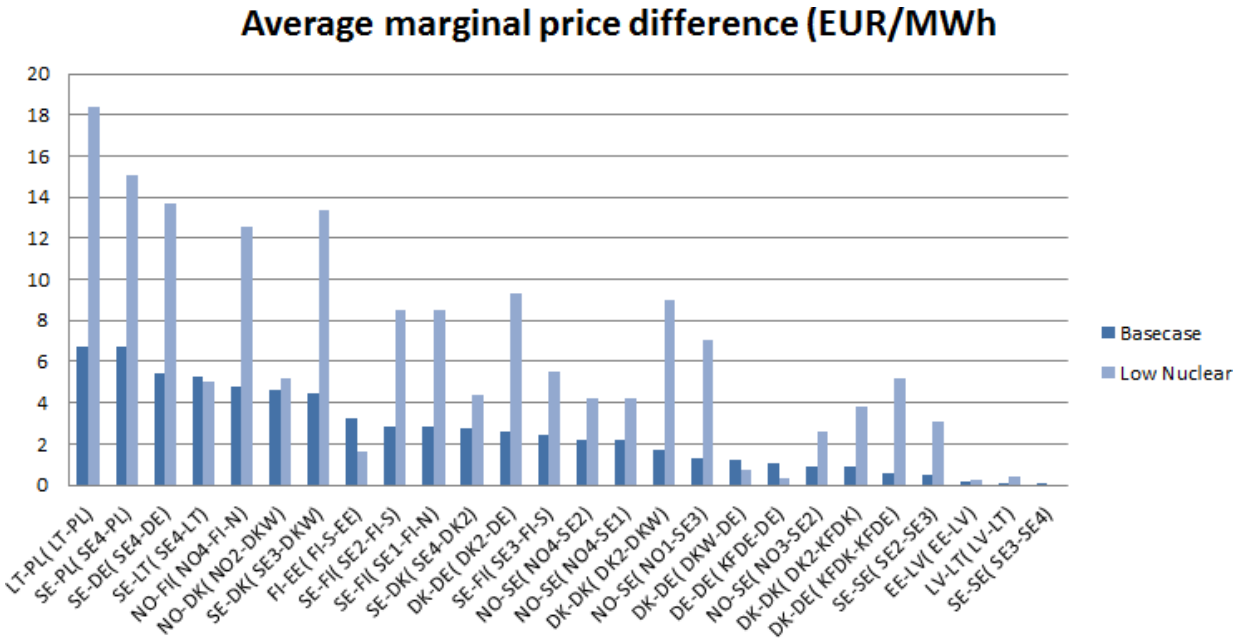

Figure 4-13: Average marginal price difference in the sensitivity of low nuclear capacity compared to the base case (no replacement of nuclear power plants).

In the more market-based case, when nuclear capacity is replaced with more wind power (due to the higher prices) the price difference also increases. As the surplus of energy in Sweden decreases, the price difference between the Nordics and Baltics decrease significantly as well as the price difference between Sweden and Finland.

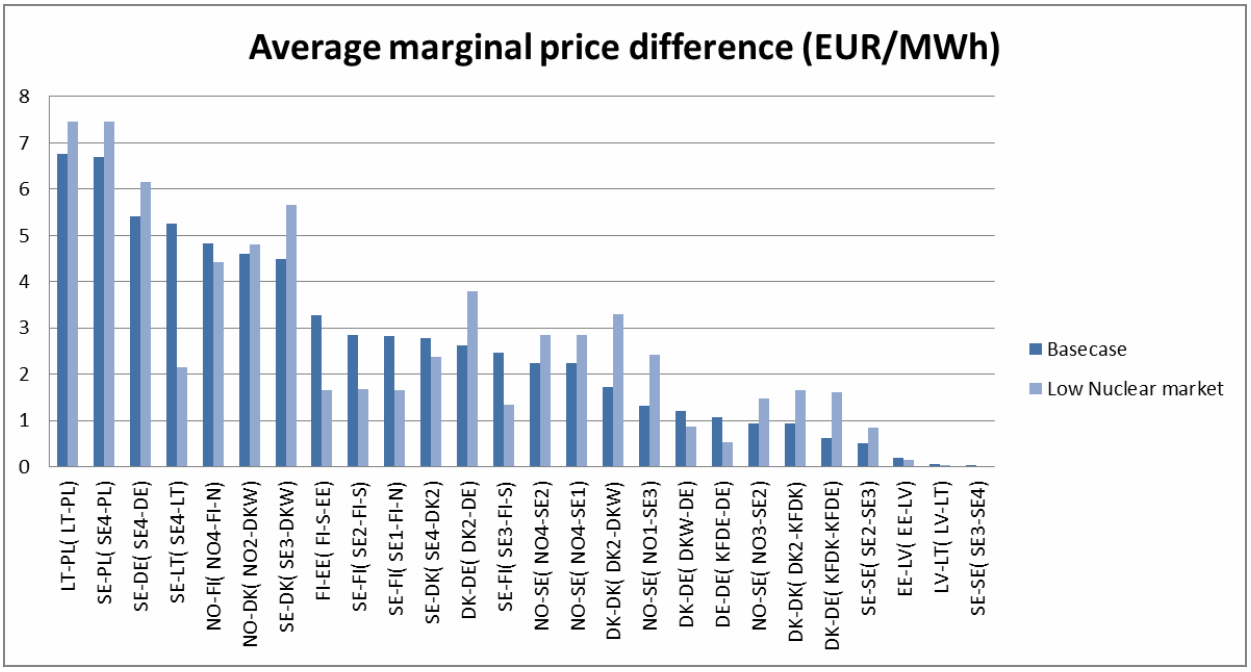

Figure 4-14: Average marginal price difference in the sensitivity of a low nuclear market compared to the base case (replacement of nuclear with wind power).

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4.4.3 Low fuel price – Significant coal-fired generation still present in 2030

In the 'Low Price' sensitivity (see Chapter 3.2.3), the price difference on the borders with Poland will increase since Poland has a significantly lower price in this sensitivity. This is because coal generation is very cheap compared to gas and there will still be assumed to be significant coal generation in Poland by 2030. The price difference between the Nordics and the continent will also increase slightly. This is caused by the more volatile Nordic price caused by the decommissioning of CHP/nuclear plants. On the other hand, the price difference between the Nordics and the Baltics will decrease since fossil fuel generation is cheaper, which drives the Baltic price down more than the Nordic price. The decommissioning of CHP and nuclear power in the Nordics also entails a reduction in the Nordic energy surplus. This means that the price difference between the Nordic and Baltic countries will become smaller.

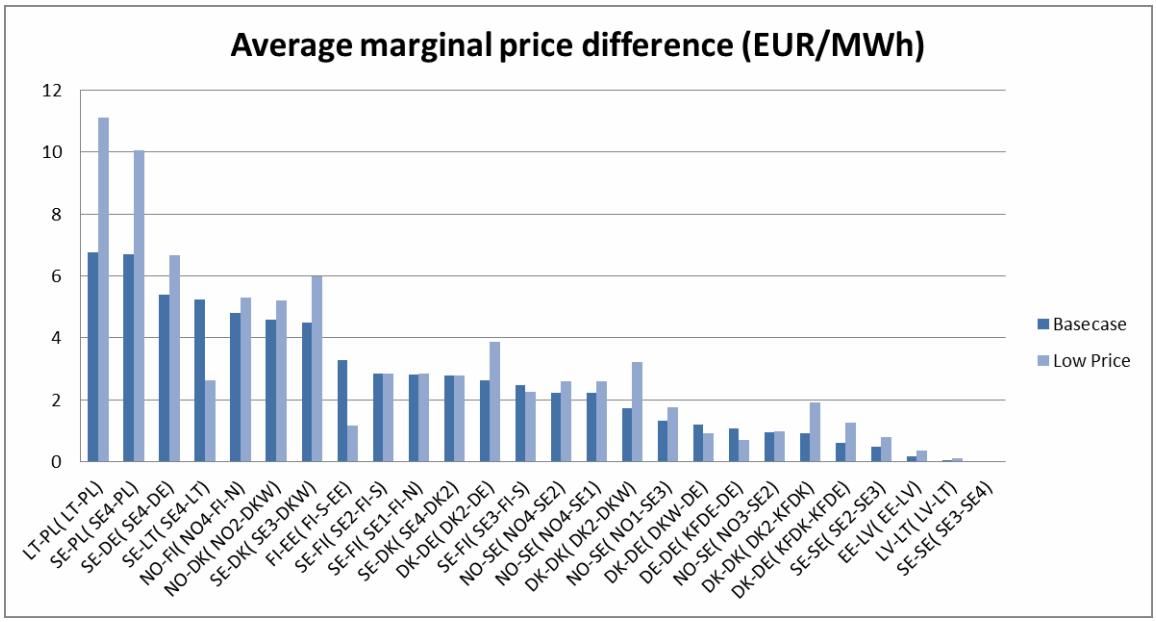

Figure 4-15: Average marginal price difference in the low-price sensitivity compared to the regional scenario base case.

4.4.4 More wind power in the Baltics – Decreasing imports to the Baltics

In the sensitivity with more wind in the Baltics, the price levels will be similar to the base case. The reason for price levels remaining steady is that in this sensitivity, the possibility for trade (import) with non-ENTSO-E countries was removed. This shows that in the market point of view, imports could be replaced by approximately 2 GW of wind power with the average price level being maintained. There were no radical changes to price differences in this sensitivity, only some smaller increase on interconnectors to the Baltic system as well as a small amount of congestion on the Estonian-Latvian border.

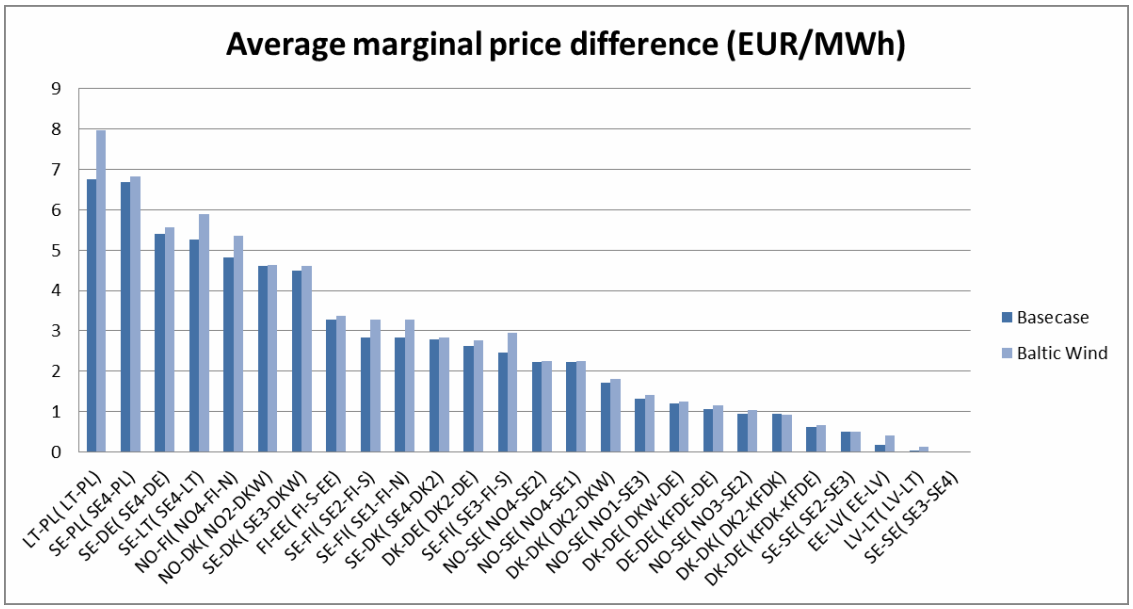

Figure 4-16: Average marginal price differences in the sensitivity with more wind power in the Baltics compared to the regional scenario base case.

Grid studies were done to check the impact of big offshore wind farms that could be built in the Baltic Sea near Lithuania and Estonia. Hourly simulations using the BID market tool and the PSS/E network tool were carried out to evaluate typical load flow durations and how they would impact the 330kV network in the Baltics. It was evaluated connection of offshore wind farms of up to 1000 MW capacity in Lithuania, up to 1,500 MW capacity in Estonia and up to 165 MW in Latvia.

After checking the hourly load flows using the network analysis tool PSS/E, overloaded 330 kV AC lines in Baltics 330 kV network during different worst n-0 and n-1 situations were identified. A total of eight different 330 kV OHL in the Baltic region were in danger of overloading because of high load flows caused by surplus power generation in the offshore wind farms, but the severity of situations when line overloads more than 100% was identified not more than 9% time per year. This issue should be studied further in future research in the Baltic region if the offshore plans are further investigated.

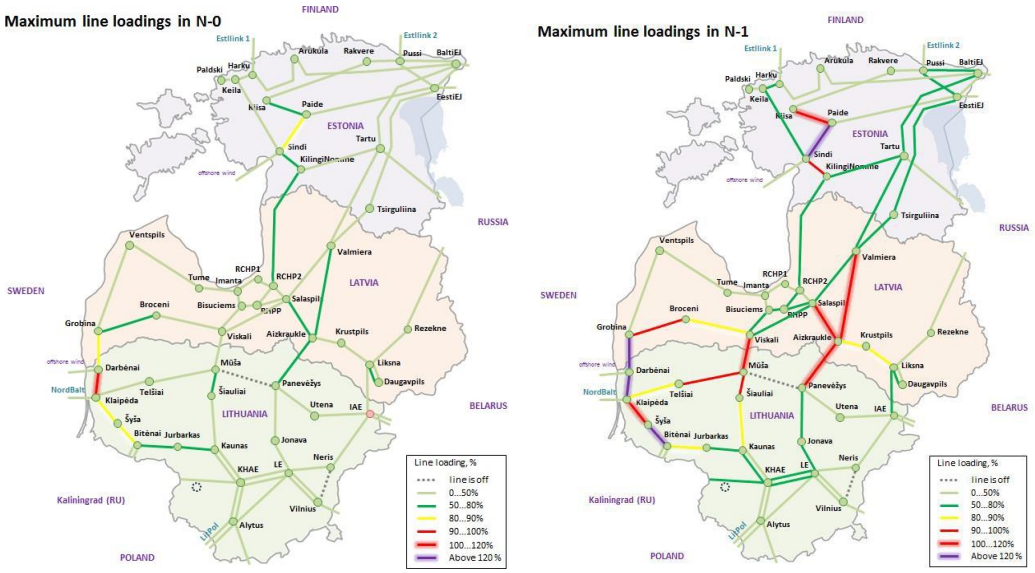

Figure 4-17: Bottlenecks in the Baltic 330 kV grid in N-0 and N-1 after connecting offshore wind farms.

4.4.5 New nuclear plant in Lithuania – Price decreases in the Baltic countries

When a nuclear plant in Lithuania is added, the price drops significantly in all the Baltic countries as well as the price difference in between Baltic, Nordic and Continental systems, which in turn reduces the benefits of new transmission capacity between all of the systems. Even if some price differences occur between Latvia and Lithuania there will still be very little difference in prices between the Baltic countries, despite the large increase in baseload production capacity.

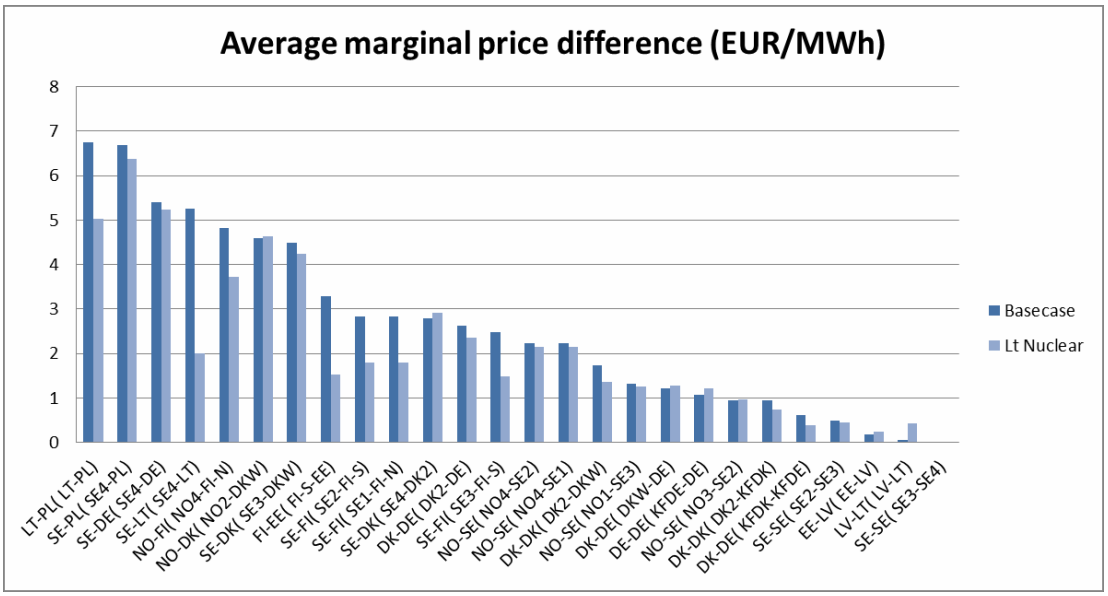

Figure 4-18: Average marginal price difference in the sensitivity with new nuclear power in Lithuania compared to the regional scenario base case.

4.4.6 Adequacy in the studied sensitivities

There was no probabilistic analysis for assessing the generation adequacy in this study. In the market model results, there was no loss of load as extreme situations are not fully captured when average profiles are used for availability of interconnectors as well as for generation units. However, an indicator or proxy for adequacy could be the number of hours where prices were high. For this purpose, prices higher than 200 EUR/MWh have been chosen as an indicator of very strained situations in the system. In the base case, this varied between two and ten hours per year on average, with the highest number of hours in Finland and the Baltics. The low nuclear case obviously increases this. In the sensitivity where nuclear is not replaced, there are, on average, up to 180 hours per year that have high prices. However, the effects are less extreme in the case where nuclear capacity is replaced. The figure for the worst-performing country (Finland) is approximately 50 hours per year on average.

In the ‘low fuel price sensitivity’, the number of high price hours is significantly increased compared to the base case. This is due that even if the average price level is lower due to lower fuel prices the number of hours with very strained generation adequacy is increased because of the decommissioning of CHP and nuclear plants.

When new nuclear capacity was added in Lithuania the number of hours with high prices dropped to zero since this unit would cover a large share of the peak load in the Baltics. In the case with more wind and no trade with non-ENTSO-E countries, the number of hours with high prices went up and remained higher compared to the base case but was still not higher than the ‘low fuel price’ sensitivity.

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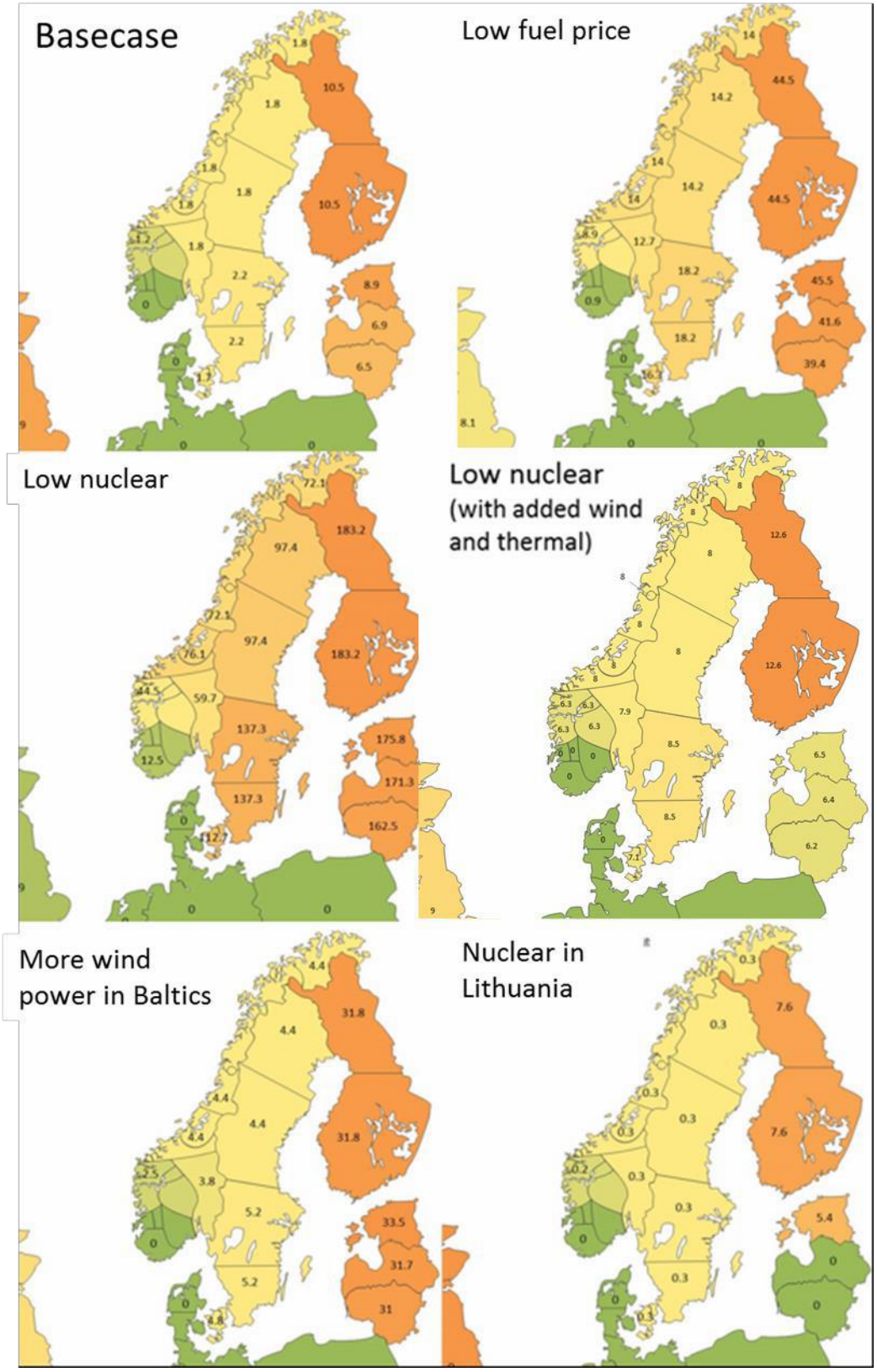

Figure 4-19: Number of hours per year with prices above 200 EUR/MWh for the regional scenario base case and for each sensitivity. The figures are an average for all 33 weather years.

5 Additional Regional Studies

This chapter introduces the most interesting regional studies performed outside the ENTSO-E RGBS cooperation. Important background and the main outcomes of the studies will also be discussed.

5.1.1 Baltic synchronisation

For historical reasons, the Baltic States currently operate in synchronicity 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. Additional to the objectives mentioned above, the Baltic States have to continue developing competitive and fully integrated electricity markets, along with a sufficiently developed energy infrastructure to connect the distributed RES (wind, biomass and biogas, solar etc.), possible high capacity power plants and meet a Barcelona criterion (10%) on interconnectors of capacity for cross-sections. Subsequently, the Baltic States have politically endorsed the synchronisation of the Baltic States' power systems with CEN as a common strategic goal. In December 2014, the three Baltic TSOs proposed a roadmap for de-synchronisation from the IPS/UPS and synchronisation with the CEN directly through current interconnection link between Lithuania and Poland.

Following a request by the EC, an initial assessment carried out by ENTSO-E in 2015 concluded that synchronisation with CEN would be technically feasible, although at a cost of €970 million. However, it was not thought to be economically profitable (based only on traditional cost/benefit evaluations and without considering geopolitical aspects, among them SoS in a high-level strategic perspective).

On 9th June 2015, the EC and the involved Member States of the Baltic Sea Region concluded a Memorandum of Understanding on the reinforced Baltic Energy Market Interconnection Plan (BEMIP). At the same time, based on lack of progress on the continental interconnection alternative, the Baltic States and the EC asked for a wider investigation, which would consider a Nordic interconnection alternative as well as a project alternative whereby the power systems of the Baltic countries operate as a self-sufficient region.

With this background at the end of 2015, the EC – 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: A cost-benefit and geopolitical energy security analysis'. 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 power systems of Baltic countries into the interconnected networks of CE – three Baltic TSOs in cooperation with Tractebel, a consulting company, has performed the multi-disciplinary study of isolated operation of the Baltic power system. In this study, the technical, economic, legal and organisational aspects of isolated operation of power systems of Baltic countries were investigated in preparation for a real-life isolated test operation of power systems of Baltic countries, which is scheduled to take place in 2019. Such real-life tests will be one of several technical testing procedures that the Baltic power systems will have to undergo prior to real interconnection to the networks of the CE, preliminarily scheduled to take place in 2025. The study has provided very valuable insight into both the financial and technical requirements that the new mode of synchronous operation will put on the Baltic power systems, as well as helping to clarify the possible implementation schedules of such serious and in many ways unprecedented undertakings.

Currently, two of the most serious challenges standing in the way of the synchronisation project development are the unclear solutions regarding the operation and status of the Kaliningrad electrical enclave (part of the Russian power system), located on the Lithuania-Poland border, and the very narrow geographical corridor of the border between the Baltic countries and the CE (Lithuania-Poland), preventing the development of the electrical interconnection between the Baltic and the CE power systems

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towards much safer levels of NTC. Both of these issues will require a lot of political willpower and might influence the technical outcomes and schedule of the synchronisation process.

In the meantime, new interconnection development targets and triggering thresholds, currently being developed by electricity interconnection target expert group within EC (with an NTC of 30%– 60% from peak load and a maximum 2 EUR/MWh price differential in adjacent market areas) will definitely prove helpful in providing much stronger economic justification for the Baltic synchronisation project, previously found to be rather lacking when based on old Barcelona criteria and SEW analysis.

5.1.2 Challenges and opportunities for the Nordic power system

The challenges and opportunities of the Nordic power system report summarises the shared view of the four Nordic TSOs, Svenska Kraftnät, Statnett, Fingrid and Energinet.dk, regarding the key challenges and opportunities affecting the Nordic power system in the period leading up to 2025.

The Nordic power system is changing. The main drivers of the changes are climate policy – which in turn stimulates the development of more RES – technological developments and a common European framework for markets, operation and planning. While the system transformation has already begun, the changes will be much more visible by 2025.

The main challenges foreseen by the Nordic TSOs in the period leading up to 2025 include meeting the demand for flexibility, ensuring adequate transmission and generation capacity to guarantee security of supply and to meet the demand of the market, maintaining a good frequency quality, and sufficient inertia in the system to ensure operational security.

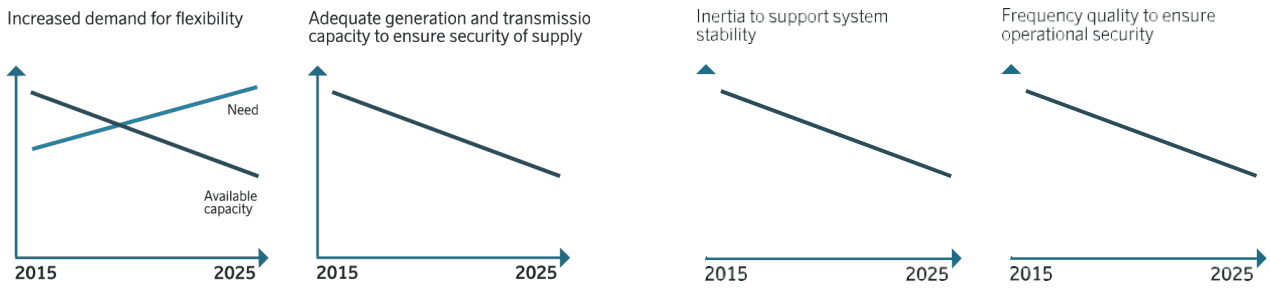

Figure 5-1 Figures from "Challenges and Opportunities for Nordic Power System" report.

Link to the report:
http://www.fingrid.fi/fi/ajankohtaista/Ajankohtaista%20liitteet/Ajankohtaisten%20liitteet/2016/Report%20Challenges%20and%20Opportunities%20for%20the%20Nordic%20Power%20System.pdf

5.1.3 Nordic Grid Development Plan 2017

(link to Nordic Grid Development Plan 2017:
https://energinet.dk/Om-nyheder/Nyheder/2017/08/01/Nordisk-netudviklingsplan-og-vurdering-af-produktionstilstraekkelighed)

The Nordic Grid Development Plan 2017 describes the ongoing and future investments in the grid of the Nordic countries (Norway, Sweden, Finland and Denmark).

The most important messages of the Nordic plan summarised below.

- Many transmission projects are being built and commissioned. The main drivers are the integration of an increasing number of renewables, security of supply and market integration with entailed socio-economic welfare gains.
- There is an historically high level of investment in the Nordic region (see Figure 5-2). The Nordic TSOs expect to invest more than €15 billion in the period until 2025.
- Identification of transmission corridors need to be analysed for possible reinforcement. This will be done in the next Nordic Grid Development Plan to be issued in 2019 (see Figure 5-3).

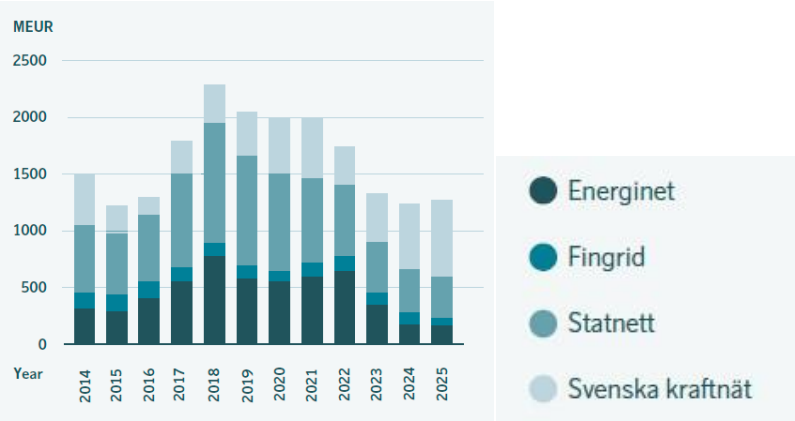

Figure 5-2 Nordic TSO investments in transmission until 2025

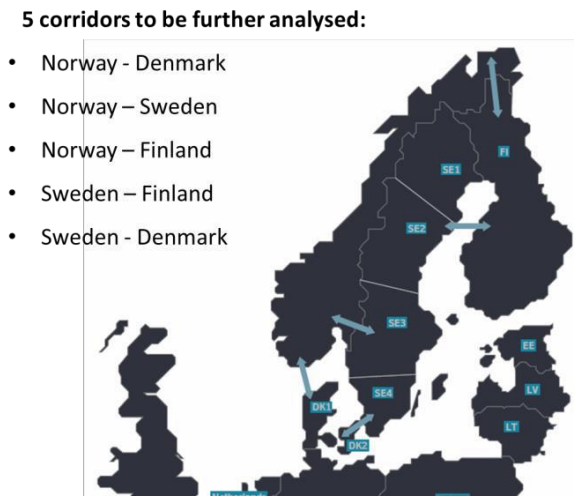

Figure 5-3 Nordic corridors that will be further analysed in the 2019 Nordic Grid Development Plan.

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6 Links to National Development Plans

Table 6-1: ENTSO-E Regional Group Baltic Sea national development plans

Country	Company/TSO
Denmark	https://www.energinet.dk/-/media/Energinet/Projekter-KTR-HFV/Dokumenter/Netplanlaegning/Reinvesterings---Udbygnings--og-Saneringsplan-2016.pdf?la=da
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-2017-2027.pdf
Germany	https://www.netzentwicklungsplan.de/
Latvia	http://www.ast.lv/files/ast_files/gadaparskzinoj/Attistibasplans20182027.pdf
Lithuania	http://www.leea.lt/wp-content/uploads/2015/05/Network-development-plan-2015.pdf
Norway	http://www.statnett.no/Global/Dokumenter/NUP%202017-endelig/Nettutviklingsplan%202017.pdf
Poland	https://www.pse.pl/documents/31287/c1eca7ac-5ec1-4f7a-a7cb-a487cdf5cf9f?safeargs=646f776e6c6f61643d74727565
Sweden	https://www.svk.se/siteassets/om-oss/rapporter/2017/svenska-kraftnats-systemutvecklingsplan-2018-2027.pdf

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7 PROJECTS

The following projects were collected during the project calls. They 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 TYNDP 2018[15]. The chapter is divided into pan-European and additional regional projects.

7.1 pan-European projects

The map below shows all project applicants, submitted by project promoters during the TYNDP2018 call for projects. In the final version of this document (after the consultation phase), the map will be updated showing the approved projects. Projects have different statuses, which are described in the CBA-guidelines as:

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

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

Figure 7-1 TYNDP 2018 Project: Regional Group Baltic Sea.

15 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

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7.2 Regional projects

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

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

The table below lists the projects of regional and national significance in the Baltic Sea region.

Country	Project Name	Investment		Expected Commiss-ioning year	Description	Main Drivers	Included in RegIP 2015?
		From	To				
Finland	Lieto-Forssa	Lieto (FI)	Forssa (FI)	2018	New 400 kV AC single circuit OHL of 67 km between substations Lieto and Forssa.	Security of supply	No
Finland	Hikiä-Orimattila	Hikiä (FI)	Orimattila (FI)	2019	New 400 kV AC single circuit OHL of 70 km between substations Hikiä and Orimattila.	Security of supply	No
Finland	Fennovoima NPP connection	Valkeus (FI)	Lumijärvi (FI)	2024	This project involves a new double-circuit 400 kV 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 when the construction permit is given to build the Hanhikivi NPP.	Connection of new NPP	No
Norway	Voltage upgrades through north and central Norway				Will potentially increase the capacity in the north-south direction. Detailed information given in Statnett's Grid Development Plan 2017.	Increase of capacity and RES integration	No
Norway	Fosen			2019	New 420-kV lines in central Norway (Fosen) in order to facilitate new wind production. Detailed information given in Statnett's Grid Development Plan 2017	RES integration	No
Norway	Ofoten–Balsfjord–Skillemoen-Skaidi			2016-2021	A new 420-kV line (ca. 450 km) 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	No

					is under consideration; however, no decision has yet been taken.		
Norway	Western corridor			2021	Voltage upgrades in the southwestern 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	Increase of capacity and utilisation of interconnectors	No
Sweden	Southwest Link			2017/2018	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, Security of supply	No
Sweden	Ekhyddan – Nybro -Hemsjö			2023	This is currently a PCI project included in the 3rd PCI list. The project consists of a new 400 kV AC single circuit OHL of 70 km between Ekhyddan and Nybro and a new 400 kV AC single circuit OHL of 85 km 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 integration	No
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 400 kV 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	No
Sweden	Skogssäter - Stenkullen Swedish West Coast			2021	A new 400 kV 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 integration, RES integration	No
Denmark	Endrup-Idomlund Revsing-Landerupgaard Idomlund-Tjele Bjæverskov-			2019-2021	All projects are 400 kV 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	No

	Hovegaard						
Germany		Pulgar (DE)	Vieselbach (DE)	2024	Construction of a new 380 kV double-circuit OHL in an existing corridor Pulgar-Vieselbach (104 km). Detailed information given in Germany's Grid Development Plan.	RES integration / Security of supply	Yes
Germany		Hamburg/Nord (DE)	Hamburg/Ost (DE)	2024	Reinforcement of existing 380 kV OHL Hamburg/Nord - Hamburg/Ost and Installation of Phase Shifting Transformers in Hamburg/Ost. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany		Krümmel (DE)	Hamburg/Nord (DE)	2030	New 380 kV OHL in the existing corridor Krümmel-Hamburg/Ost. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany		Control area 50Hertz (DE)		2024	Construction of new substations, Var-compensation and extension of existing substations for integration of newly build power plants and RES in 50HzT control area.	RES integration	Yes
Germany		Elsfleht/West (DE)	Ganderkesee (DE)	2021	new 380 kV OHL in the existing corridor for RES integration between Elsfleth/West, Niedervieland and Ganderkesee	RES integration	Yes
Germany		Irsching (DE)	Ottenhofen (DE)	2030	new 380-kV-OHL in the existing corridor between Irsching and Ottenhofen	RES integration	Yes
Germany		Dollern (DE)	Alfstedt (DE)	2024	new 380-kV-OHL in the existing corridor in Northern Lower Saxony for RES integration	RES integration	Yes
Germany		Unterweser (DE)	Elsfleth/West (DE)	2024	new 380-kV-OHL in the existing corridor for RES integration in Lower Saxony	RES integration	Yes
Germany		Conneforde (DE)	Unterweser (DE)	2024	new 380-kV-OHL in the existing corridor for RES integration in Lower Saxony	RES integration	Yes
Germany		Klostermansfeld (DE)	Querfurt (DE)	2025	New 380 kV OHL in an existing corridor between Klostermansfeld and Querfurt. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany		Niederrhein (DE)	Utfort (DE)	2030	New lines and installation of additional circuits, extension of existing and erection of several 380/110 kV-substations.	RES integration/Security of supply	Yes
Germany		Landesbergen (DE)	Wehrendorf (DE)	2023	Installation of an additional 380-kV circuit between Landesbergen and Wehrendorf	RES integration/Security of supply	Yes
Germany		Point Kriftel (DE)	Farbwerke Höchst-Süd (DE)	2022	The 220-kV substation Farbwerke Höchst-Süd will be upgraded to 380 kV and integrated into the existing grid.	RES integration/Security of supply	Yes
Germany		Several		2019	This investment includes new 380/220 kV transformers in Walsum, Sechtem, Siegburg, Mettmann and Brauweiler. Some of them are already installed, while others are under construction.	RES integration/Security of supply	Yes
Germany		Lippe (DE)	Mengede (DE)	2030	Reconductoring of an existing 380 kV line between Lippe and Mengede.	RES integration/Security of supply	Yes

Germany		Several		2019	This investment includes several new 380/110 kV transformers in order to integrate RES in Erbach, Gusenburg, Kottigerhook, Niederstedem, Öchtel, Prüm and Wadern. In addition, a new 380 kV substation and transformers in Krefeld Uerdingen are included.	RES integration / Security of supply	Yes
Germany		Büttel (DE)	Wilster (DE)	2021	A new 380-kV line in an existing corridor in Schleswig-Holstein for integration of RES especially wind on- and offshore	RES integration	Yes
Germany		Junction Mehrum (DE)	Mehrum (DE)	2019	A new 380-kV line junction Mehrum (line Wahle - Grohnde) - Mehrum including a 380/220-kV-transformer in Mehrum	RES integration	Yes
Germany		Borken (DE)	Mecklar (DE)	2021	A new 380-kV line Borken-Mecklar in an existing corridor for RES integration	RES integration	Yes
Germany		Borken (DE)	Gießen (DE)	2022	A new 380-kV line Borken - Gießen in an existing corridor for RES integration	RES integration	Yes
Germany		Borken (DE)	Twistetal (DE)	2021	A new 380-kV line Borken - Twistetal in an existing corridor for RES integration	RES integration	Yes
Germany		Wahle (DE)	Klein Ilsede (DE)	2018	A new 380-kV line Wahle - Klein Ilsede in an existing corridor for RES integration	RES integration	Yes
Germany		Hoheneck (DE)	Engstlatt (DE)	2022	A new 380 kV OHL Pulverdingen-Oberjettingen (45 km), a new 380kV OHL Oberjettingen-Engstlatt (34 km) and a new 380 kV OHL Hoheneck-Pulverdingen (13 km).	Security of supply	Yes
Germany		Birkenfeld (DE)	Ötisheim (DE)	2019	A new 380 kV OHL Birkenfeld-Ötisheim (Mast 115A). Length: 11 km.	Security of supply	Yes
Germany		Hamm/Uentrop (DE)	Kruckel (DE)	2018	Extension of existing line to a 400-kV single circuit OHL Hamm/Uentrop - Kruckel and extension of existing substations.	RES integration/Security of supply	Yes
Germany		Bürstadt (DE)	BASF (DE)	2021	New line and extension of existing line to 400 kV double-circuit OHL Bürstadt - BASF including extension of existing substations.	RES integration/Security of supply	Yes
Germany		Pkt. Metternich (DE)	Niederstedem (DE)	2021	Construction of new 380 kV double-circuit OHLs, decommissioning of existing old 220 kV double-circuit OHLs, extension of existing and erection of several 380/110 kV-substations. Length: 108 km.	RES integration/Security of supply	Yes
Germany		Area of West Germany (DE)		2018	Installation of reactive power compensation (e.g., MSCDN, SVC, phase shifter). Devices are planned in Kusenhorst, Büscherhof, Weißenthurm and Kriftel. Additional reactive power devices will be evaluated.	RES integration/Security of supply	Yes
Germany		Neuenhagen (DE)	Vierraden (DE)	2020	A new 380 kV double-circuit OHL Neuenhagen-Vierraden-Bertikow with 125 km length as prerequisite for the planned upgrading of the existing 220 kV double-circuit interconnection Krajnik (PL) – Vierraden (DE Hertz Transmission). Detailed information given in Germany's Grid Development.	RES integration/Security of supply	Yes
Germany		Neuenhagen (DE)	Wustermark (DE)	2018	Construction of a new 380 kV double-circuit OHL between the substations Wustermark and Neuenhagen with 75 km length. Support of RES and conventional generation integration, maintaining security of supply and support of market development. Detailed information given in Germany's Grid Development Plan.	RES integration/Security of supply	Yes
Germany		Pasewalk (DE)	Bertikow (DE)	2021	Construction of a new 380 kV double-circuit OHL in the north-eastern part of the 50HzT control area and the decommissioning of an existing 220 kV double-circuit OHLs, incl. 380-kV line Bertikow-Pasewalk (30 km). Support of RES and conventional generation integration in Northern Germany, maintaining of security of supply and support of market development. Detailed information given in Germany's Grid Development.	RES integration/Security of supply	Yes
Germany		Röhrsdorf (DE)	Remptendorf (DE)	2025	Construction of new double-circuit 380 kV OHL in existing corridor Röhrsdorf-	Security of supply	Yes

					Remptendorf (103 km)		
Germany		Wolmirstedt (DE)	Wahle (DE)	2022	Reinforcement of existing OHL 380 kV. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany		Vieselbach (DE)	Mecklar (DE)	2023	A new double-circuit OHL 380 kV line in an existing OHL corridor. Detailed information given in Germany's Grid Development Plan.	RES integration	Yes
Germany		Conneforde (DE)	Unterweser (DE)	2029	A new double-circuit OHL 400 kV line in an existing OHL corridor (33 km)	RES integration	TYNDP 2016
Germany		Area of Altenfeld (DE)	Area of Grafenrheinfeld (DE)	2027	A new double-circuit OHL 380 kV in an existing corridor (27 km) and a new double-circuit OHL 380 kV (81 km). Detailed information given in Germany's Grid Development Plan.	RES integration	TYNDP 2016
Germany		Gießen/Nord (DE)	Karben (DE)	2025	A new 380-kV line Gießen/Nord - Karben in an existing corridor for RES integration		Yes
Germany	P205	Schwörstadt (DE)		2025	Upgrade of the Schwörstadt station from 220 kV to 380 kV including two transformers 380/110 KV, supply via an Eichstetten-Kühmoos 380 kV circuit	Security of supply	No
Germany	P206	Herbertingen/Area of Constance/Beuren (DE)	Gurtweil/Tiengen (DE)	2025	Upgrade of the existing grid in two circuits between Gurtweil/Tiengen and Herbertingen. New substation in the Area of Constance	Security of supply	No
Germany		Querfurt (DE)	Wolkramshausen (DE)	2024	A new 380 kV OHL in an existing corridor between Querfurt and Wolkramshausen. Detailed information given in Germany's Grid Development Plan.	RES integration	No
Germany		Marzahn (DE)	Teufelsbruch (DE)	2030	AC Grid Reinforcement between Marzahn and Teufelsbruch (380-kV-Kabeldiagonale Berlin). Detailed information given in Germany's Grid Development Plan.	Security of supply	No
Germany		Güstrow (DE)	Gemeinden Sanitz/Dettmannsdorf (DE)	2025	A new 380 kV OHL in an existing corridor between Güstrow - Bentwisch - Gemeinden Sanitz/Dettmannsdorf. Detailed information given in Germany's Grid Development Plan.	RES integration	No
Germany		Güstrow (DE)	Pasewalk (DE)	2025–2028	A new 380 kV OHL in an existing corridor between Güstrow –Siedenbrünzow – Alt Tellin – Iven – Pasewalk. Detailed information given in Germany's Grid Development Plan.	RES integration	No
Germany		Wolkramshausen (DE)	Vieselbach (DE)	2024	A new 380 kV OHL in an existing corridor between Wolkramshausen-Ebeleben-Vieselbach. Detailed information given in Germany's Grid Development Plan.	Security of supply	No
Germany		Thyrow (DE)	Berlin/Südost (DE)	2030	A new 380 kV OHL in an existing corridor between Thyrow and Berlin/Südost. Detailed information given in Germany's Grid Development Plan.	Security of supply	No
Germany		several		2023	Several PSTs in the Amprion Grid to allow a higher utilisation of parallel lines having different impedances	RES integration	No
Germany		Bürstadt (DE)	Kühmoos (DE)	2023	An additional 380 kV OHL will be installed on an existing power pole.	RES integration/Security of supply	No
Germany		Wolmirstedt (DE)	Wahle (DE)	2027–2029	A new 380 kV OHL in an existing corridor. Detailed information given in Germany's Grid Development Plan.	New 380 kV OHL in an existing corridor. Detailed information given in Germany's Grid Development.	No
Germany		Oberbachern (DE)	Ottenhofen (DE)	2025	Upgrade of the existing 380 kV line. Detailed information given in Germany's Grid Development plan	RES integration / Security of supply	No

8 APPENDICES

8.1 Additional figures

8.1.1 Future challenges

Charts showing results of the 2040 market studies when a 2020 grid is applied – on a market node level.

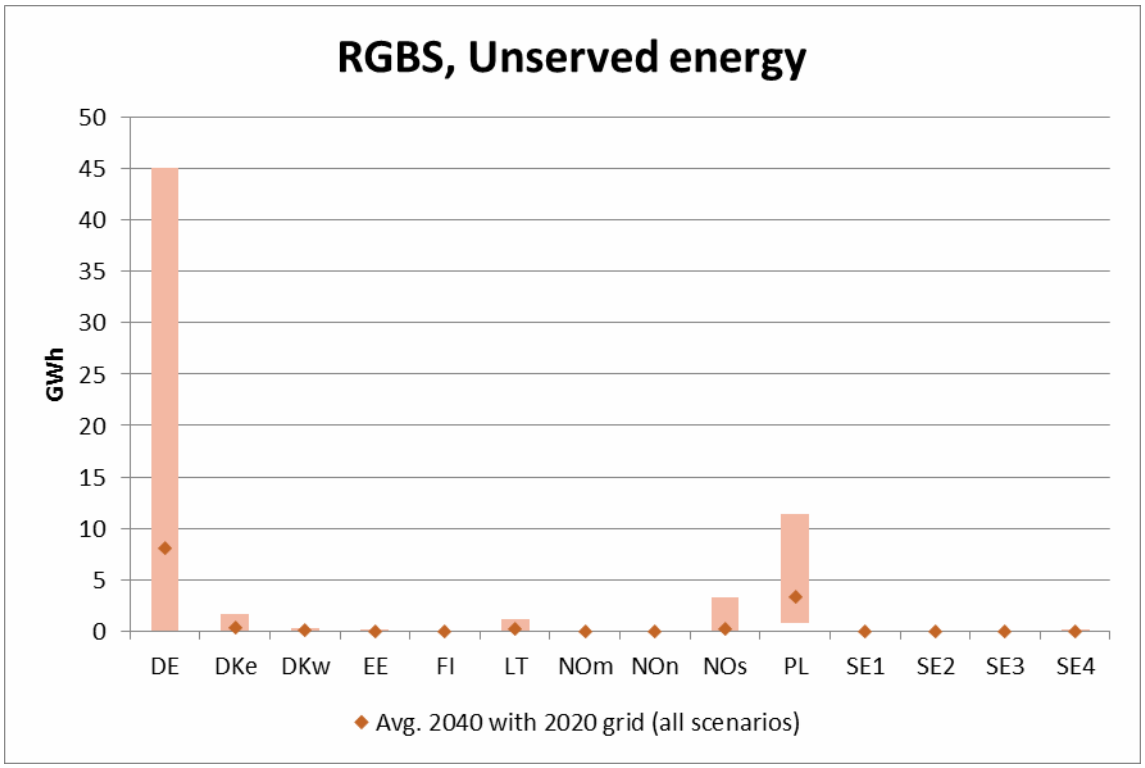

Figure 8-1 Span and average of unserved energy in GWh in RGBS Region in 2040 scenarios with 2020 grid capacities.

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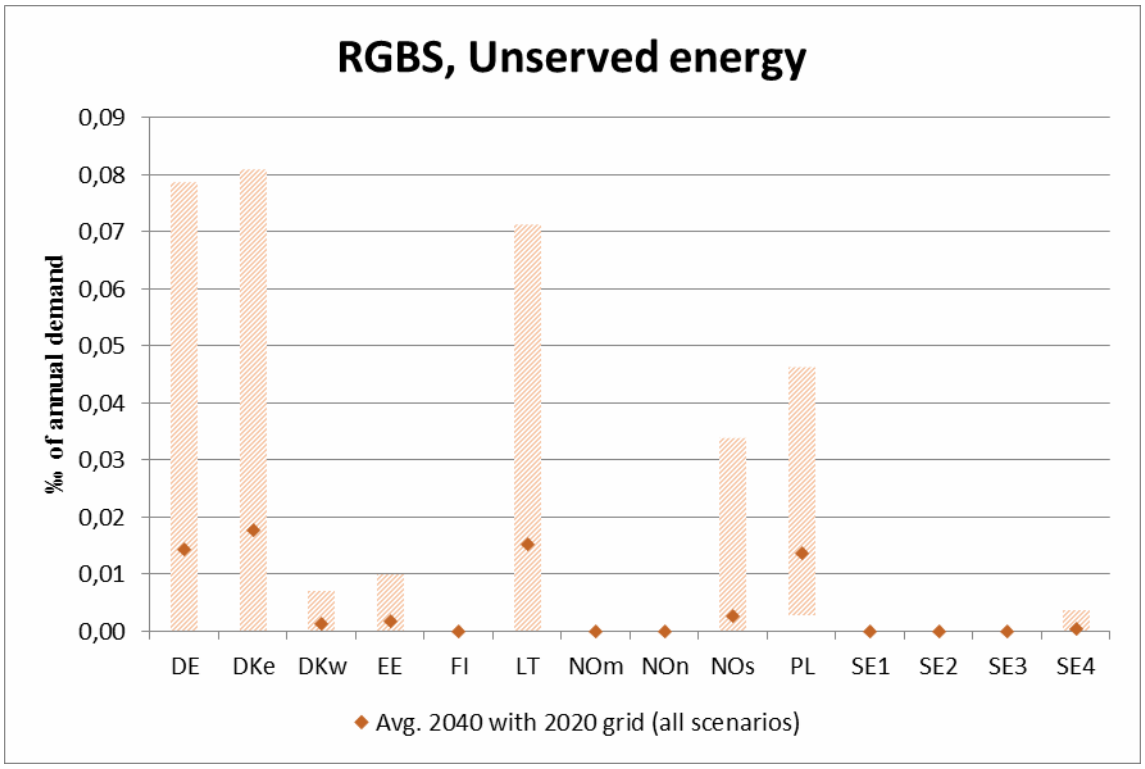

Figure 8-2 Span and average of unserved energy as a percentage of annual demand in the RGBS region in 2040 scenarios with 2020 grid capacities.

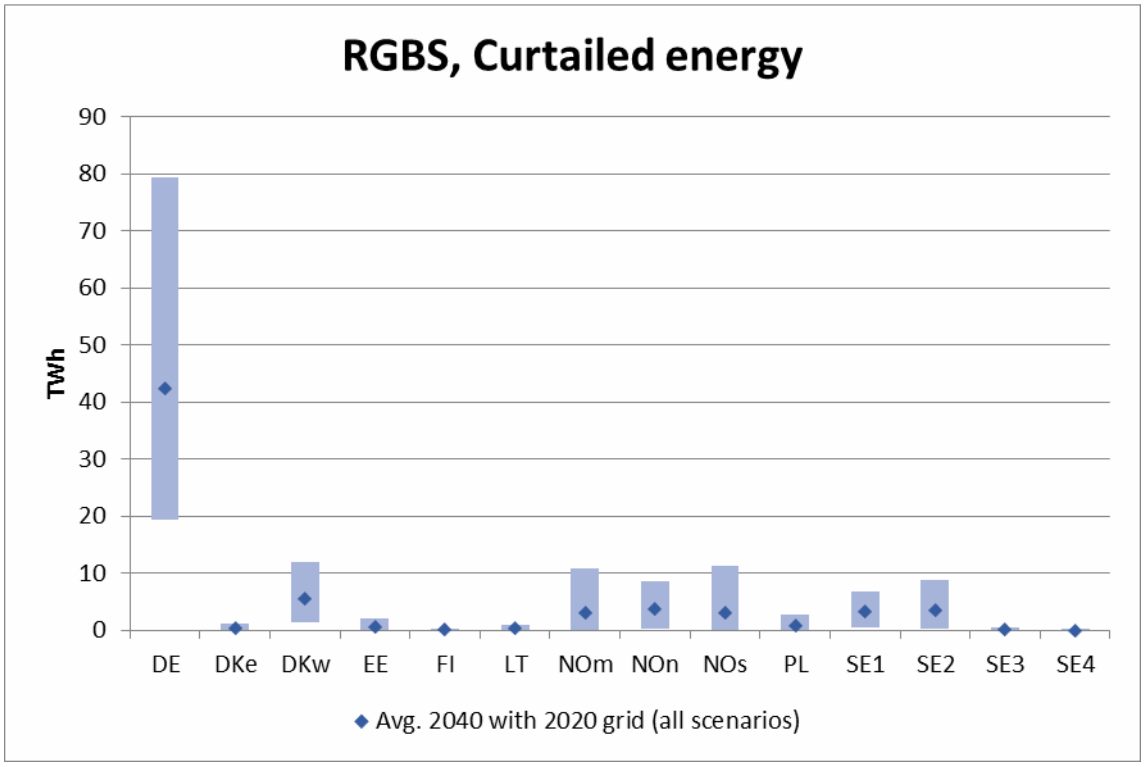

Figure 8-3 Span and average of curtailed energy in TWh in RGBS Region in 2040 scenarios with 2020 grid capacities.

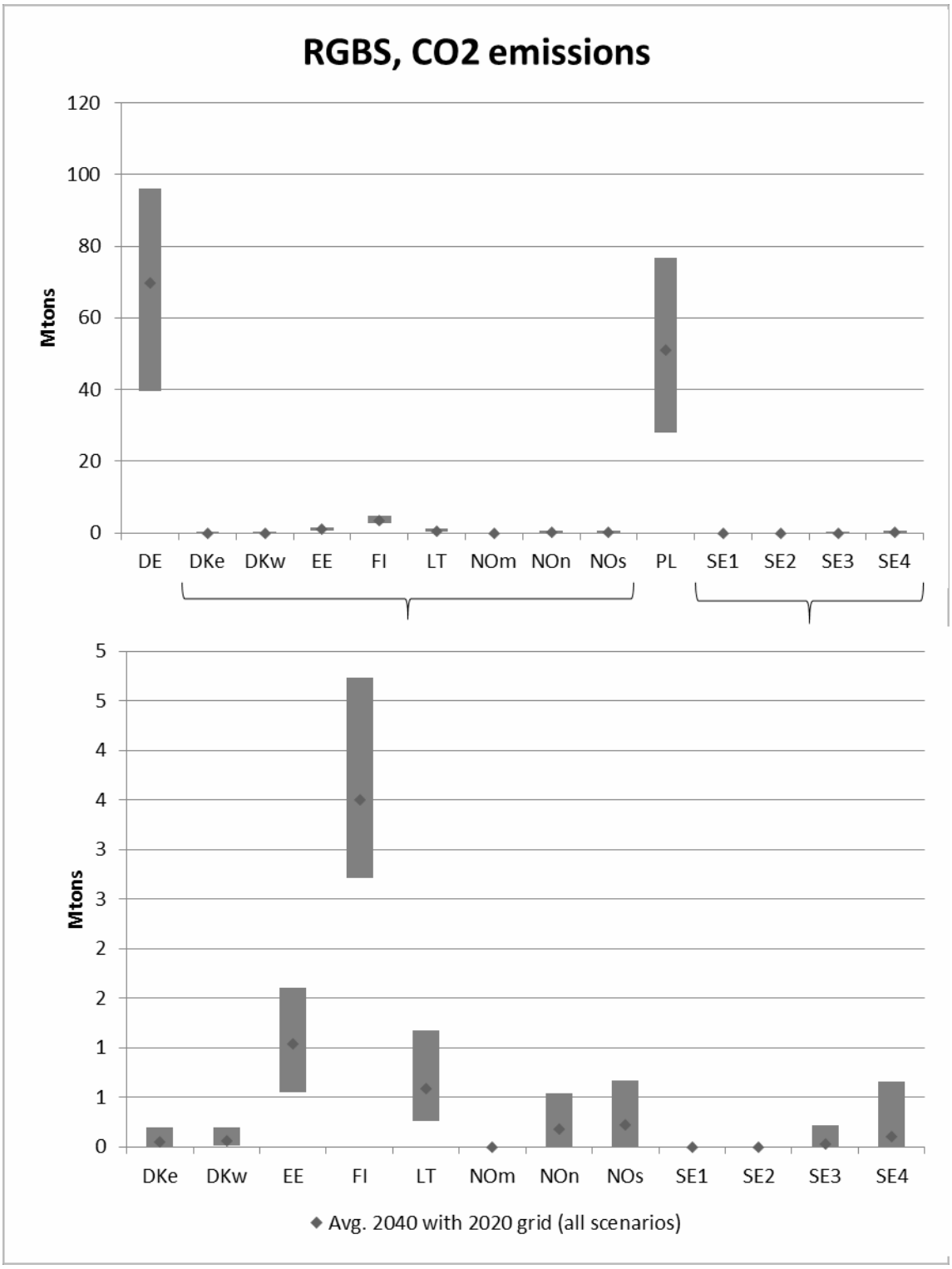

Figure 8-4 Span and average of CO_2 emissions in MT in RGBS Region in 2040 scenarios with 2020 grid capacities.

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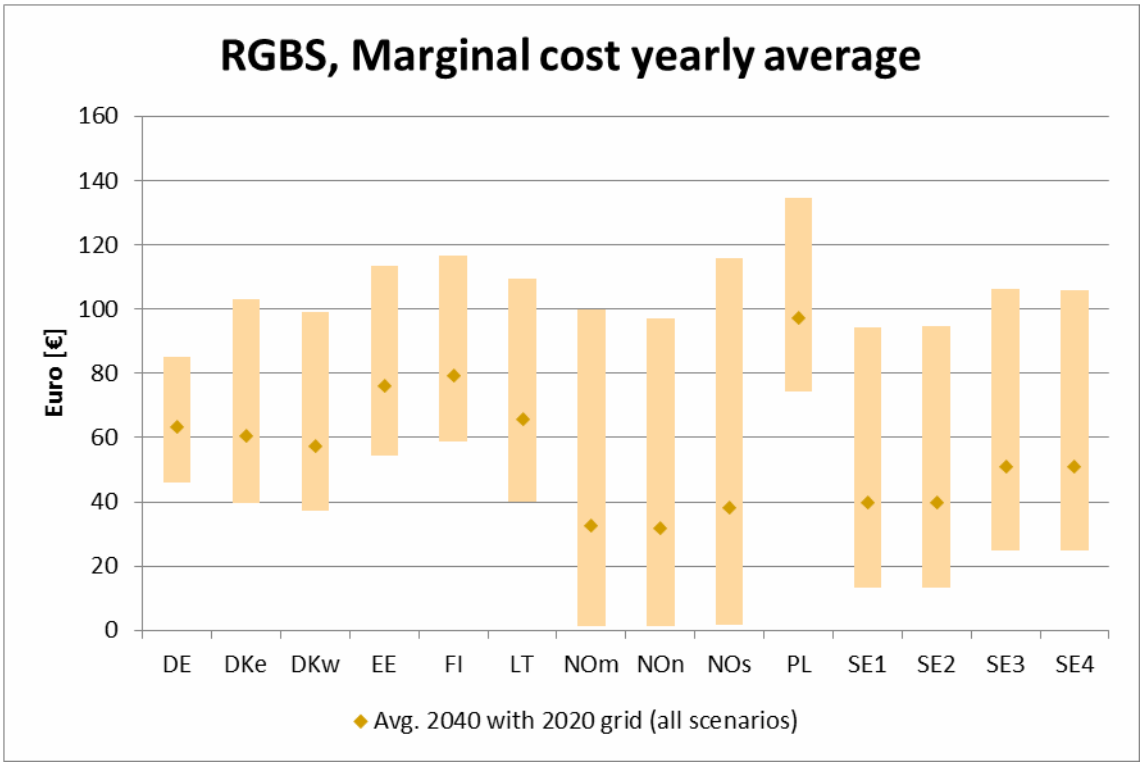

Figure 8-5 Span and yearly average of marginal costs in euros in the RGBS region in 2040 scenarios with 2020 grid capacities.

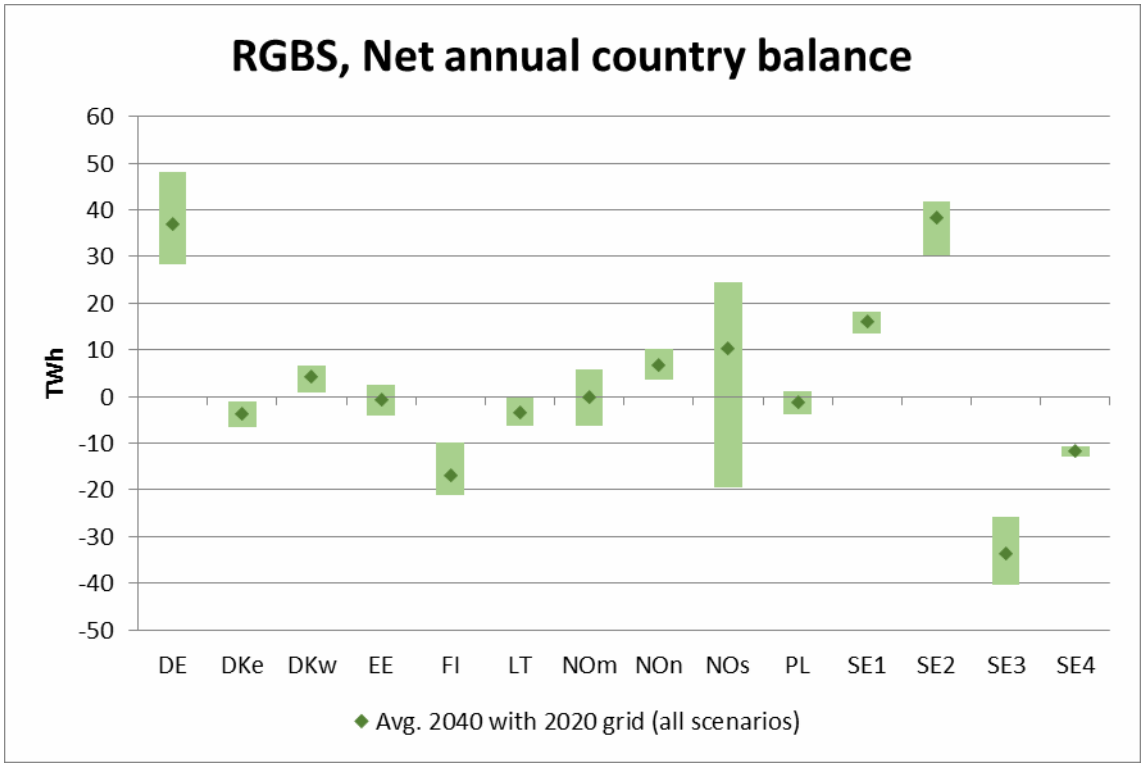

Figure 8-6 Span and average of net annual country balance in TWh in RGBS Region in 2040 scenarios with 2020 grid capacities.

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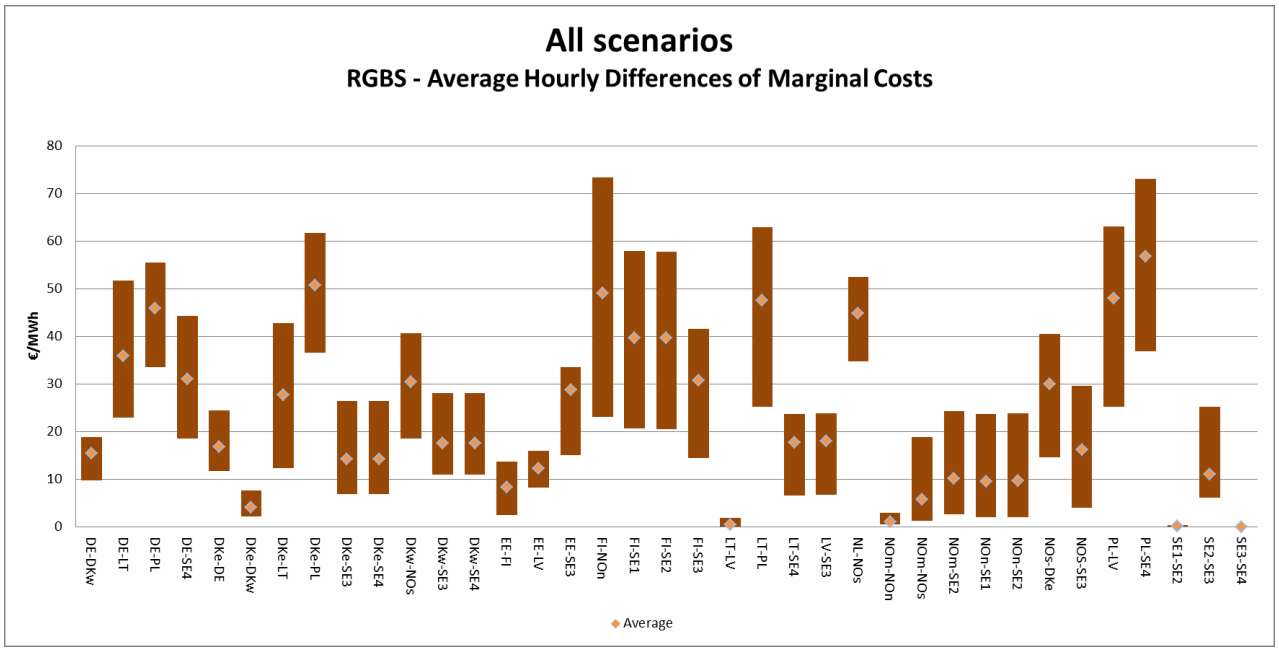

Figure 8-7 Span and average of hourly differences of marginal costs in euros per MWh in RGBS Region in 2040 scenarios with 2020 grid capacities.

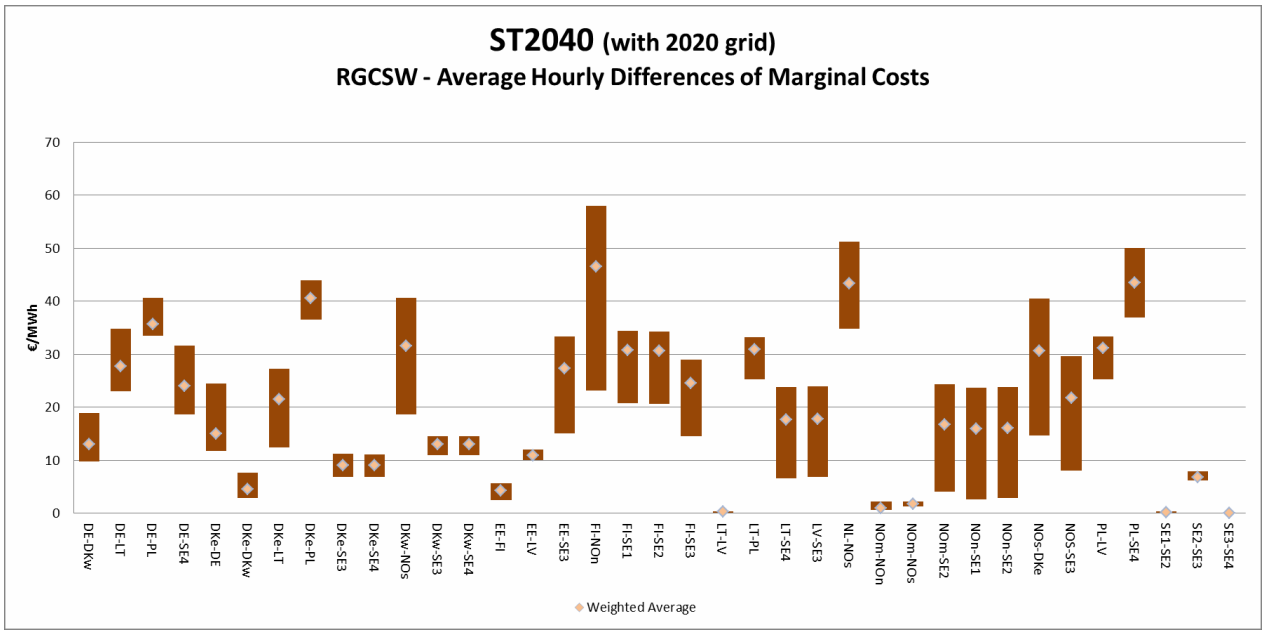

Figure 8-8 Span and average of hourly differences of marginal costs in euros per MWh in the RGBS region in the Sustainable Transition 2040 scenario with 2020 grid capacities.

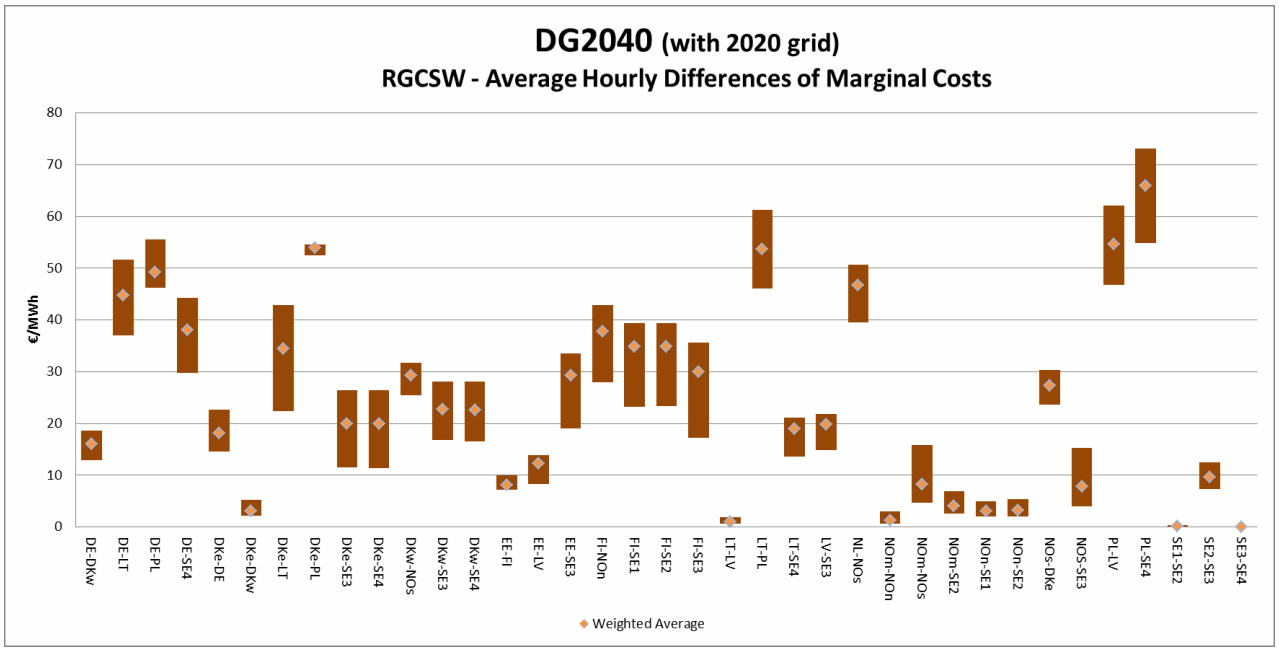

Figure 8-9 Span and average of hourly differences of marginal costs in euros per MWh in RGBS Region in the Distributed Generation 2040 scenario with 2020 grid capacities.

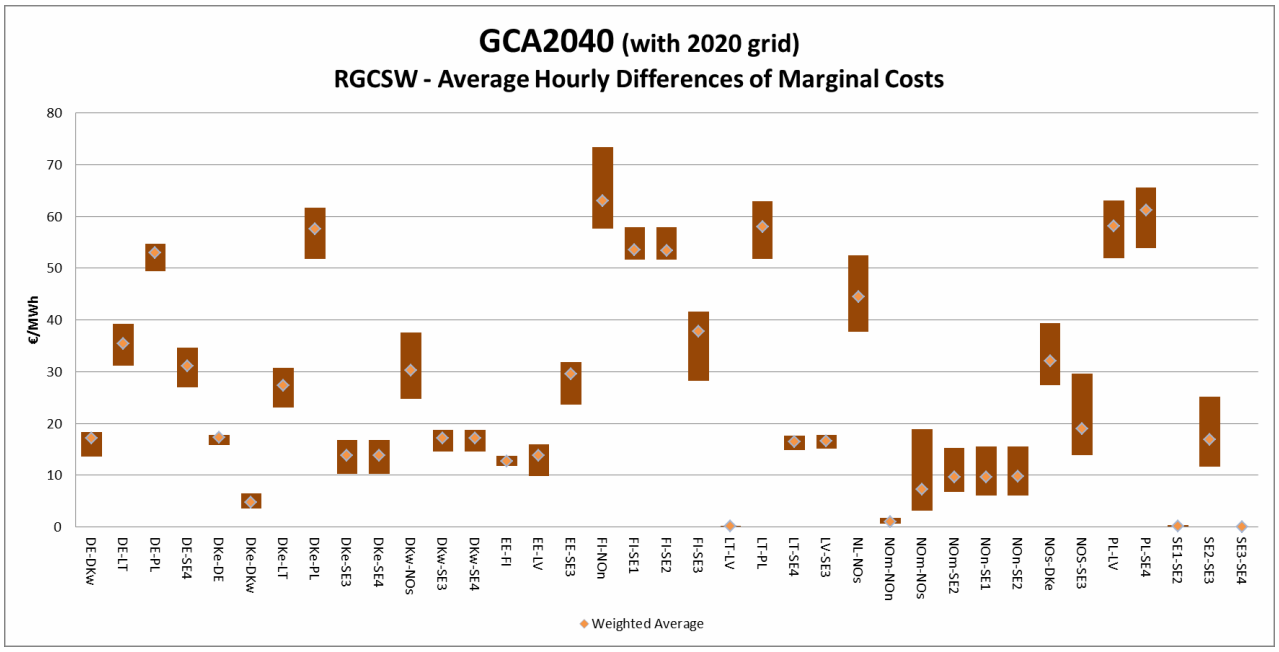

Figure 8-10 Span and average of hourly differences of marginal costs in euros per MWh in RGBS Region in the Global Climate Action 2040 scenario with 2020 grid capacities.

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8.1.2 Market and network study results

Charts showing results of the 2040 market studies when a 2040 grid with identified capacity-need is applied on a market node level. As a reference, the charts also show the average results of the 2040 market studies when a 2020 grid is applied.

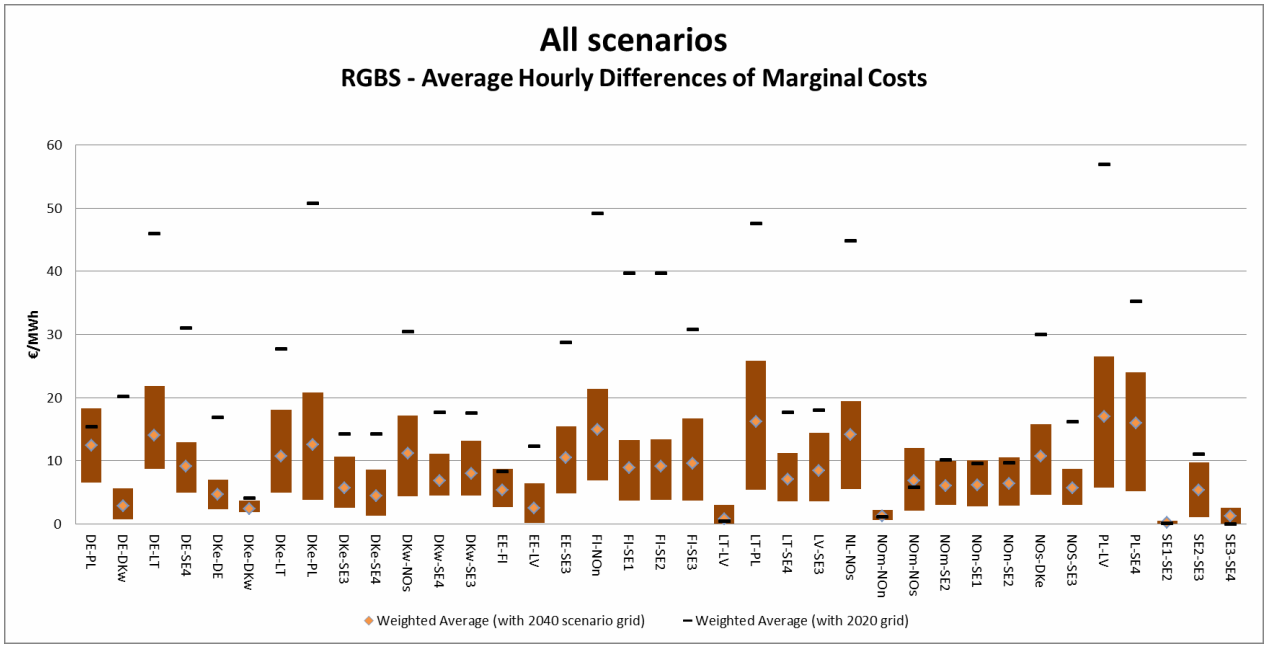

Figure 8-11 Average hourly price differences with and without identified capacity increases in BS region in the three studied 2040 scenarios and the range of average hourly price differences (all 2040 scenarios and all studied weather years) with identified capacity increases.

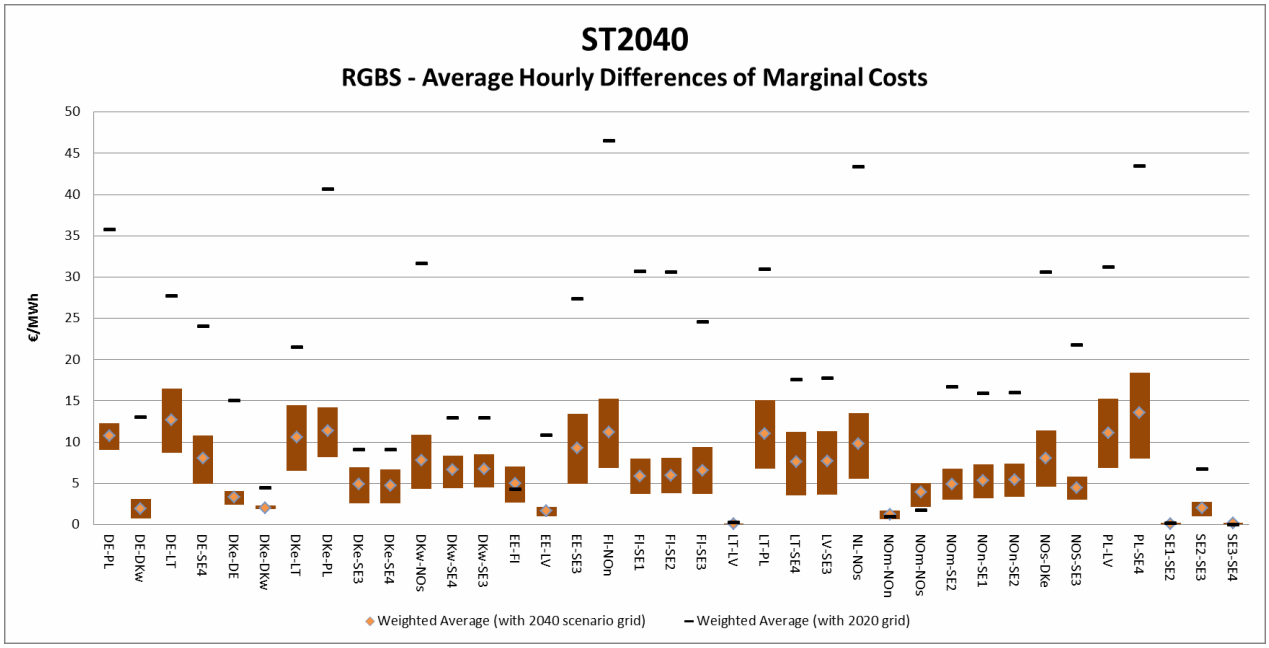

Figure 8-12 Average hourly price differences with and without identified capacity increases in BS region in the Sustainable Transition 2040 scenario, and the range of average hourly price differences (all studied weather years) with identified capacity increases.

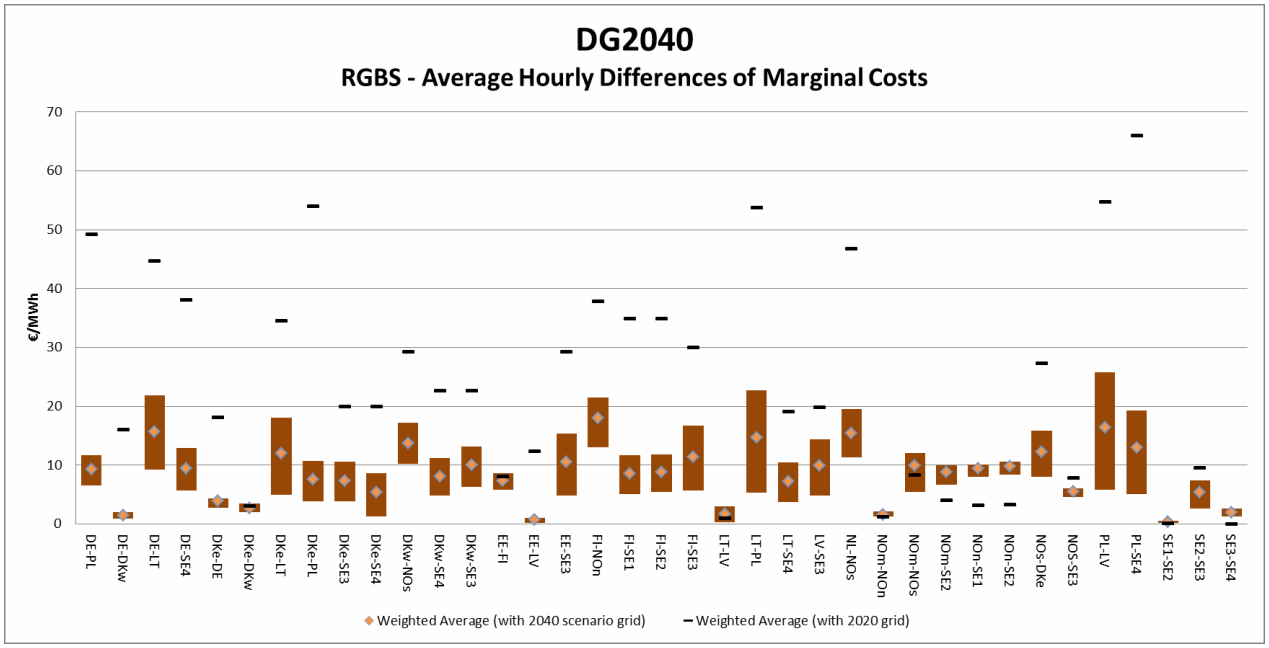

Figure 8-13 Average hourly price differences with and without identified capacity increases in the BS region in the Distributed Generation 2040 scenario, and the range of average hourly price differences (all studied weather years) with identified capacity increases.

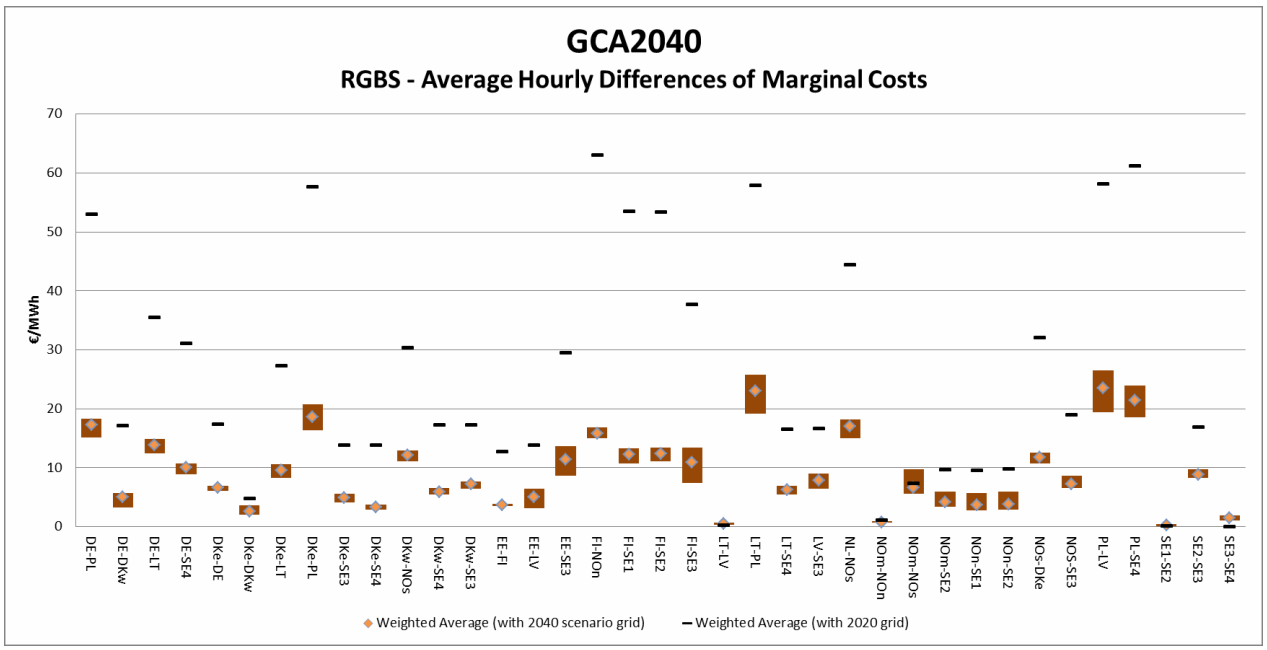

Figure 8-14 Average hourly price differences with and without identified capacity increases in the BS region in the Global Climate Action 2040 scenario, and the range of average hourly price differences (all studied weather years) with identified capacity increases.

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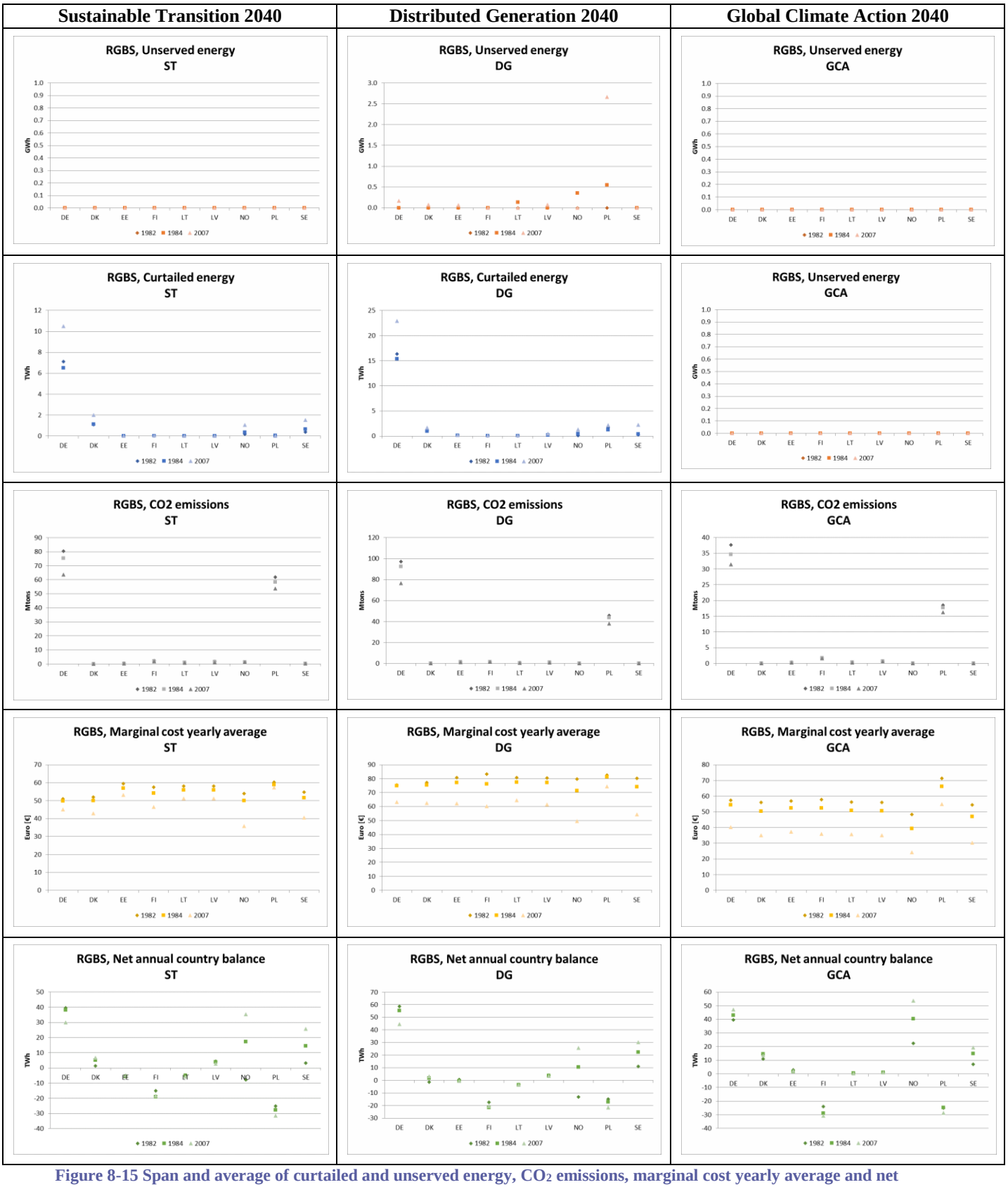

Figure 8-15 Span and average of curtailed and unserved energy, CO_2 emissions, marginal cost yearly average and net annual country balance in RGBS Region in 2040 scenarios with 2020 grid capacities.

8.1.3 Standard cost map

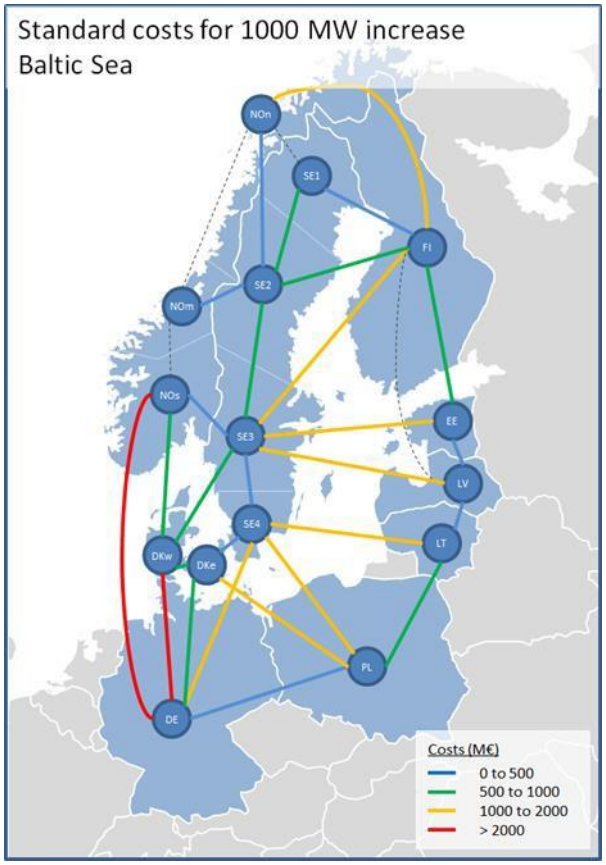

Figure 8-16 The standard costs in M€ for a 1,000 MW interconnector capacity increase in the Baltic Sea region.

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8.1.4 Regional market results

Overall

In the regional base case, the average price level in the Nordics is quite close to the price level on the continent whereas the Baltics have slightly higher prices. The Scandinavian countries (Denmark, Norway and Sweden) have surpluses whereas Finland and the Baltic States have deficits. On a general level, this is in line with the pan-European results. The main difference is that in the pan-European results, thermal generation is higher in the Baltics and lower in Denmark, which is due to the fact that the thermal generation in Denmark is modelled with more details with must-run constraints which yield more generation. This is in line with what can be observed in the market today. The average prices and balances are presented in Figure 8-17.

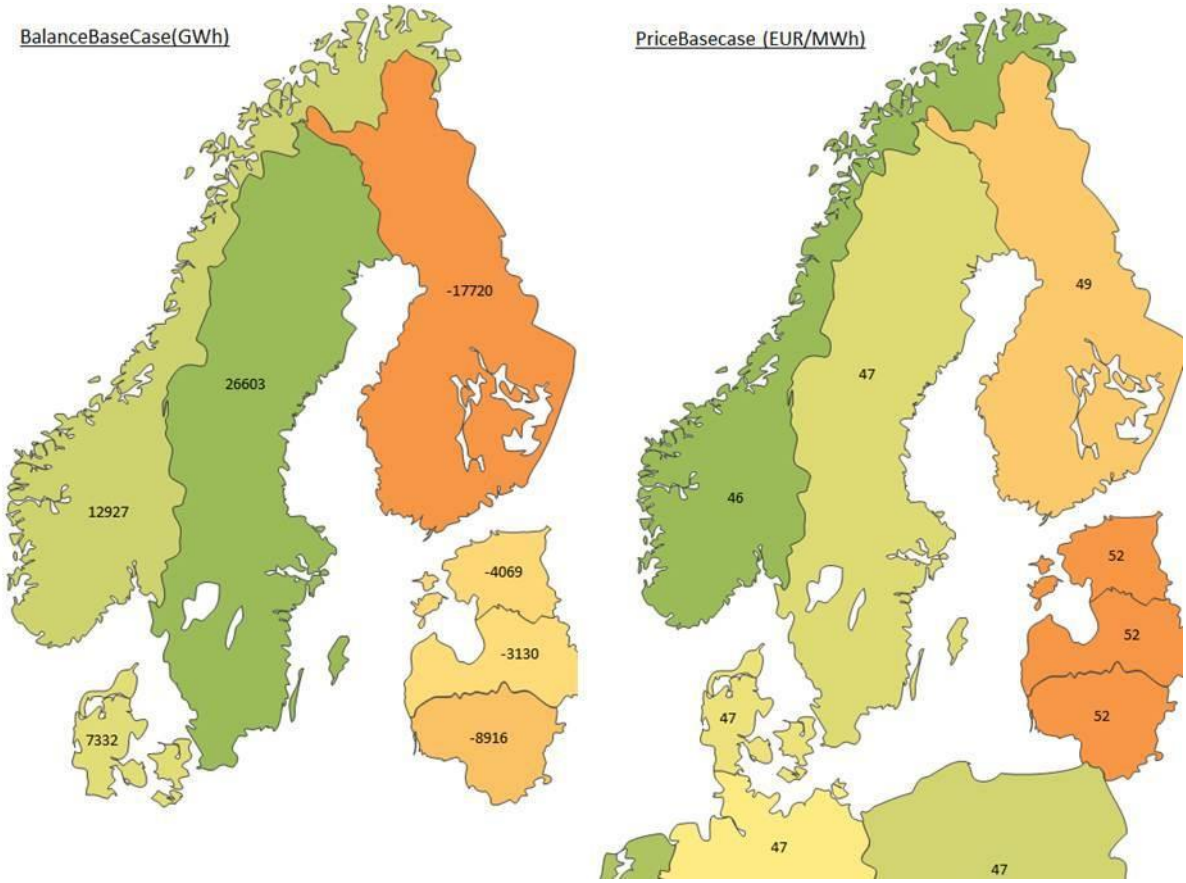

Figure 8-17 Balance in GWh and price in € per MWh in the regional base case scenario for dry, average and wet year (year 2030).

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Weather years

The results presented here are the average results in the scenario when the scenario is using a set of 33 different weather years. When analysing the Nordic system, it is essential to use a sufficient number of weather years. This is due to the fact that hydrological inflow has large variations between different years in contrast to wind and solar, which has larger variations between hours and weeks, but has small variations in annual output. Since the Nordic system has a large amount of hydropower, both prices and balances vary considerably between different weather years, as illustrated by Figure 8-18 and Figure 8-19.

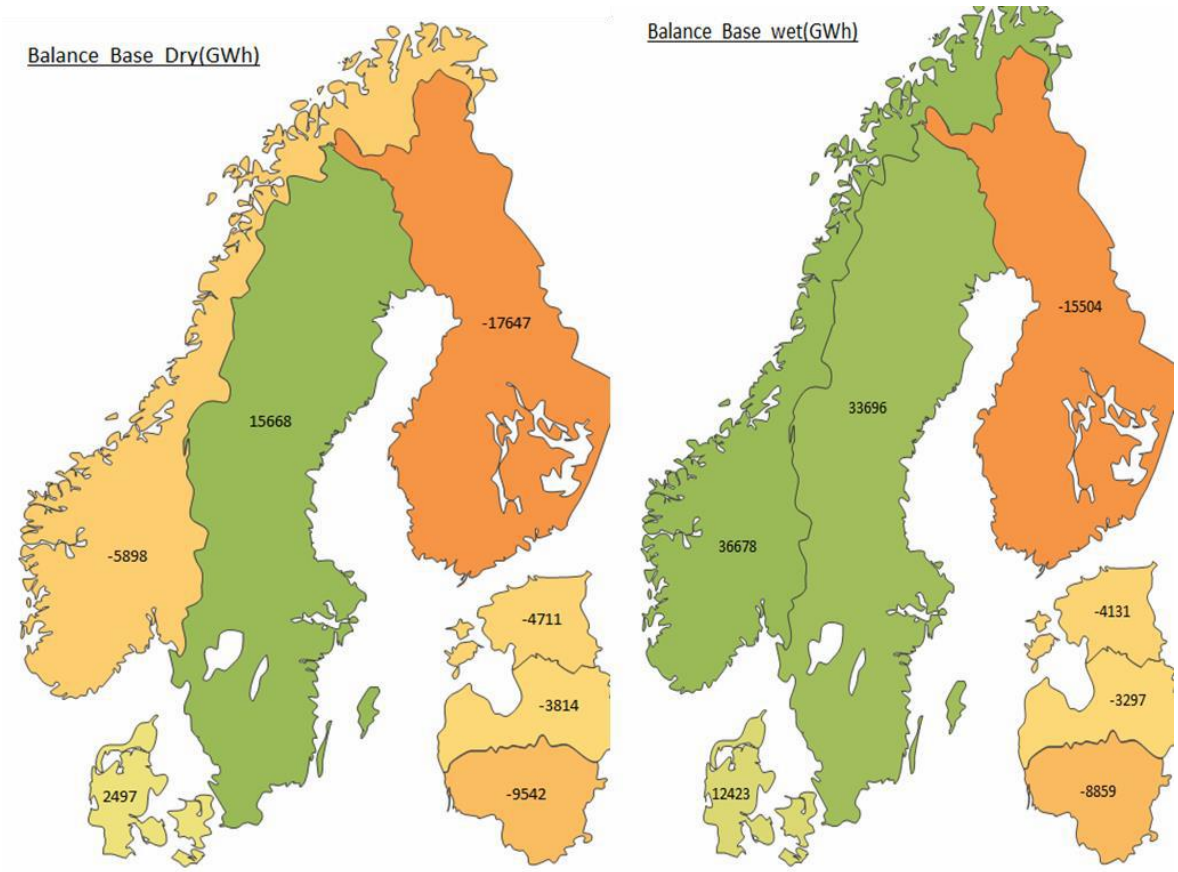

Figure 8-18 Balance in the regional base case scenario for dry and wet years (2030).

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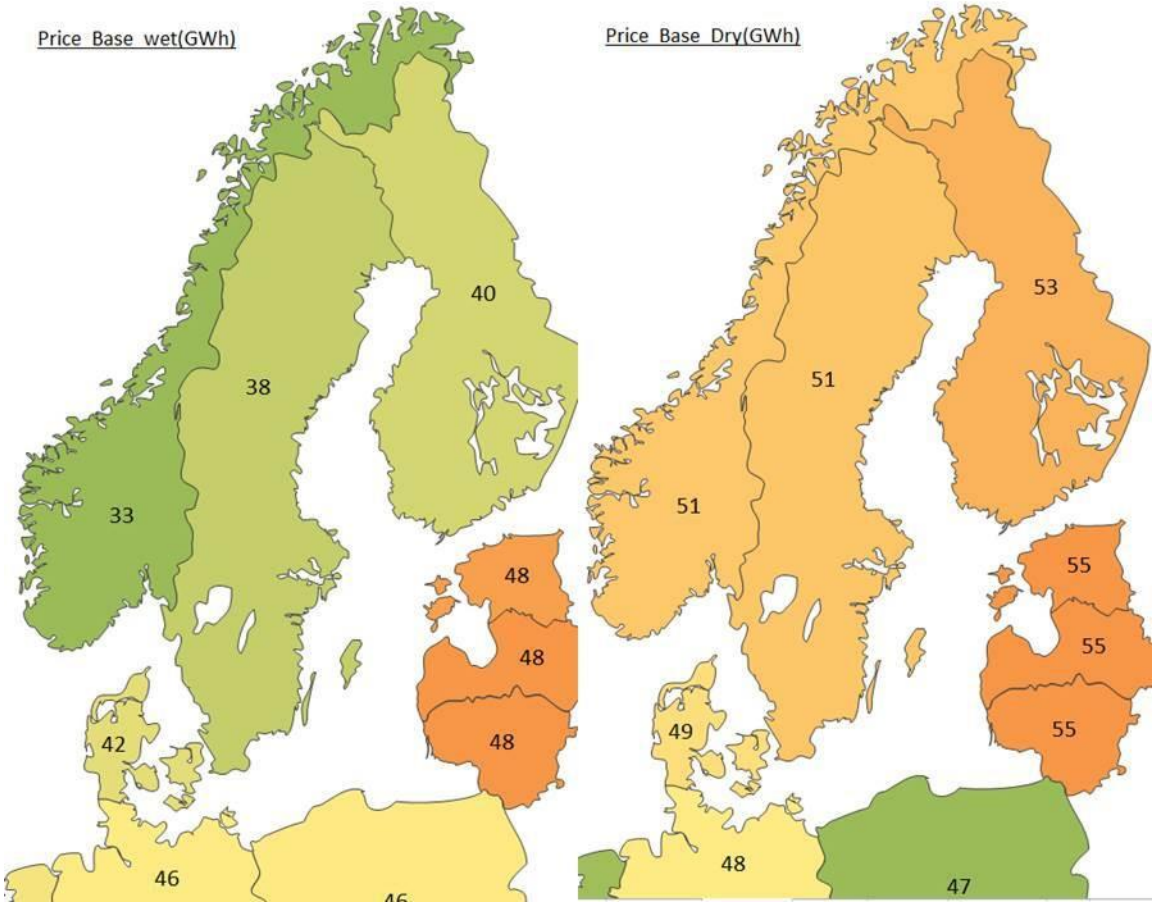

Figure 8-19 Average price in € per MWh region in the regional base case scenario for dry and wet years (2030).

In the sensitivities with less nuclear capacity, the Nordic price level increases and becomes higher than continental prices in both cases where additional production is added and where nuclear power decreases. In the 'LowNukeExt' case, the average price difference between Norway Sweden and Finland increased significantly, whereas in the 'LowNukeMkt' case, these price differences were mostly on the same level as in the base case.

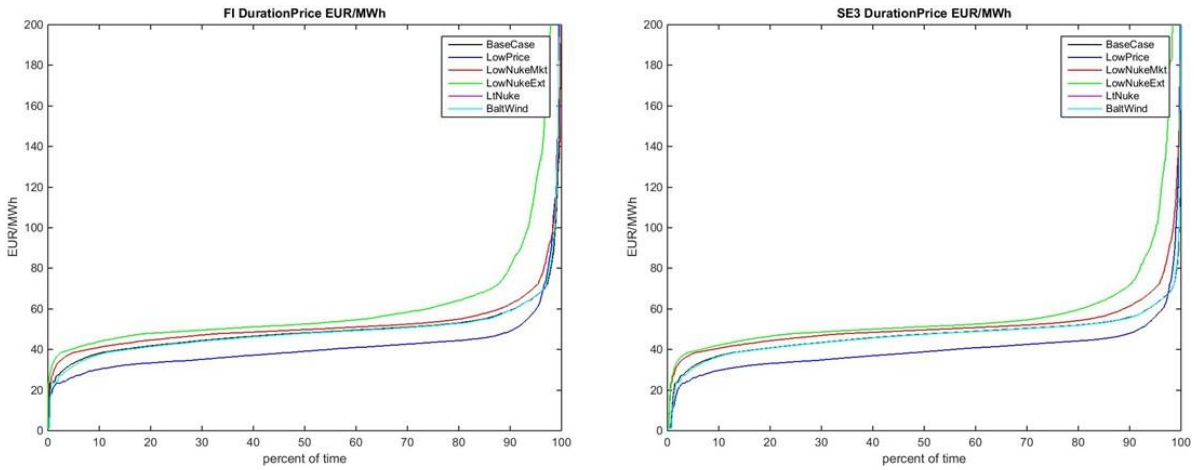

Figure 8-20 Duration of price in € per MWh in price areas Finland and Sweden SE3 in different 2030 sensitivities.

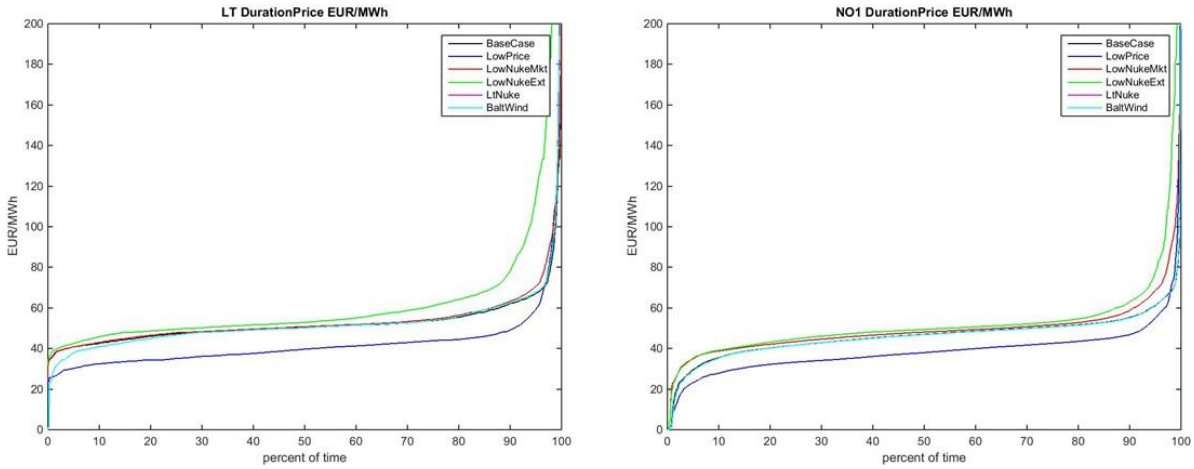

Figure 8-21 Duration of price in € per MWh in price areas Lithuania and Norway NO1 in different 2030 scenarios

When a nuclear plant in Lithuania is built, the price drops significantly in all the Baltic countries as well as reducing the price difference between the Baltic and Nordic countries, which in turn decreases the benefits of the new transmission capacity between the systems. In the sensitivity with more wind in the Baltics, the price levels are similar to the base case. The reason that price levels are not decreasing is that in this sensitivity the possibility for trade with non-ENTSO-E countries was removed. This shows that from the market's point of view, imports could be replaced by approximately 2 GW of wind power while maintaining the average price level.

Transmission needs

In the regional study, there is no CBA assessment of project candidates. Instead, the potential benefits of new capacity on a border is approximated by the average hourly price difference on each border. This method only gives an indication of the benefits of increased capacity. In order to do a full evaluation, a run with an increased capacity would have to be compared with a run without the increase. The hourly price difference does, however, indicate the maximum increase in SEW. So, for example, if the hourly price difference is 5 EUR/MWh then 1 GW of capacity could generate maximum 5 EUR/MWh*8760 h/year * 1 GW=43.8M EUR/year in SEW. The results were extracted for all borders with existing connections in the region.

However, if the price difference is low between two market areas the result for an existing border could be used to approximate for a potential new. For example, the SE4-LT results are comparable with SE3-LV since the price difference between SE3 and SE4 and LT and LV is very low.

The results from the regional best estimate scenario indicate that the main bottlenecks in the region are those between the three synchronous areas i.e., Nordics-Continent, Nordic-Baltic and Baltics-Continent. However, on an annual level, the Nordic and continental prices are on approximately the same level although there are still price differences on hourly and weekly levels due to temporary surpluses and deficits caused by the large share of intermittent power generation.

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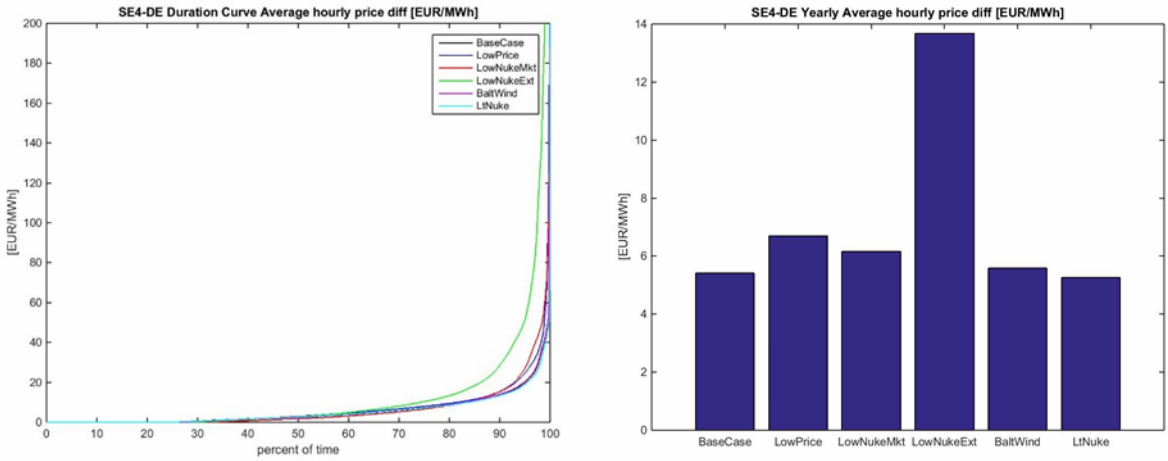

Figure 8-22 Duration curve and average of hourly price differences in € per MWh between the price areas of Sweden SE4 and Germany in different 2030 sensitivities.

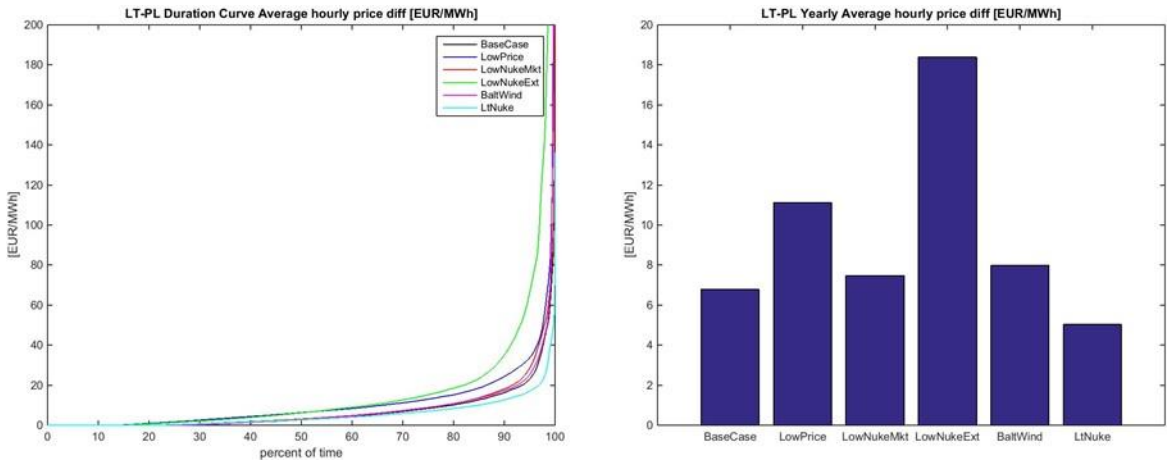

Figure 8-23 Duration curve and average of hourly price differences in € per MWh between the price areas of Lithuania and Poland in different 2030 sensitivities.

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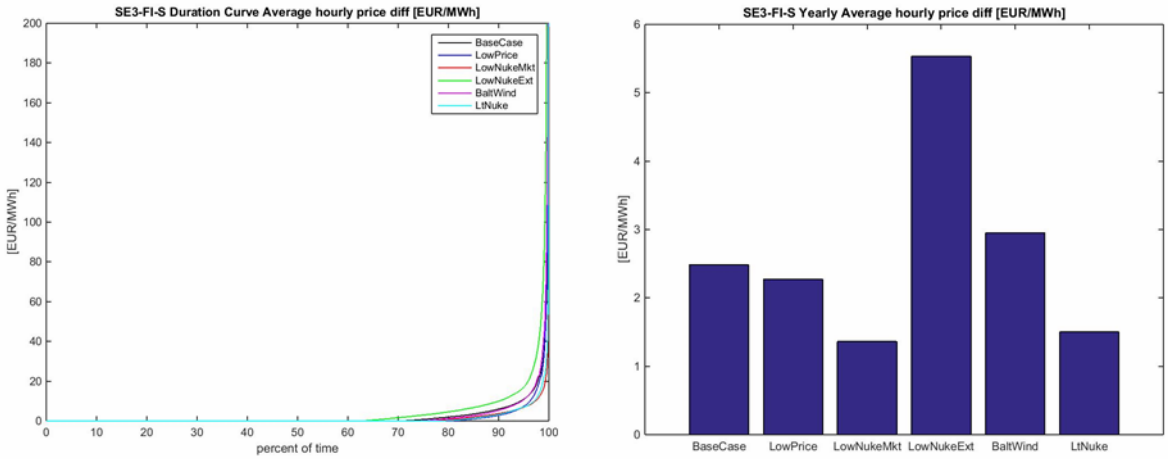

Figure 8-24 Duration curve and average of average hourly price differences in € per MWh between the price areas of Sweden SE3 and Finland in different 2030 sensitivities

In contrast to the pan-European market simulation, there is also a bottleneck in the west-east direction in the Nordic system. One reason for this is that the regional simulations cover 33 different weather years, that can be either dry or wet, whereas the pan-European simulation only covers one year with normal conditions. In the Nordic region, the largest price differences occur in dry and wet conditions. Figure 8-25 displays the average absolute hourly price difference in the base case and the spread between the simulated sensitivities.

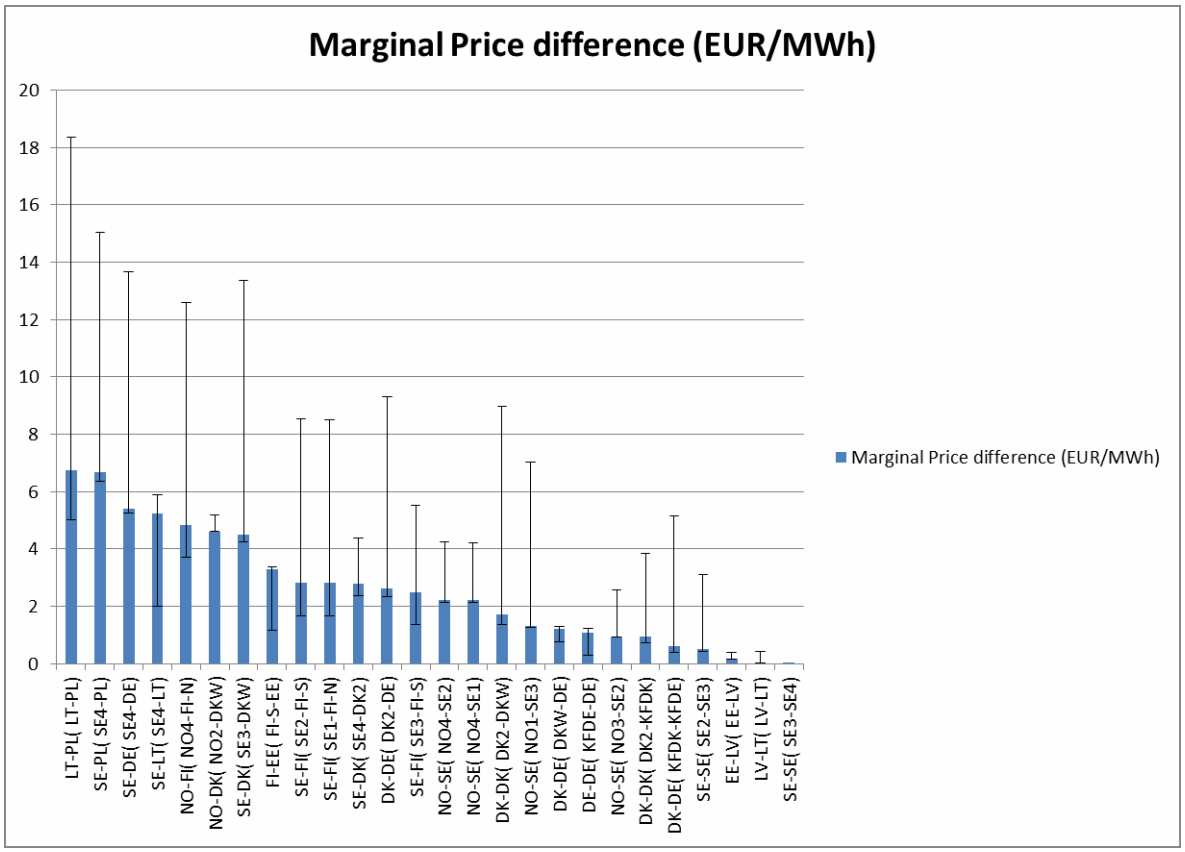

Figure 8-25 The average and span of marginal price difference in € per MWh between price areas in the Baltic Sea region in 2030 scenarios.

In the low nuclear sensitivities, the transmission needs between the Nordic and Baltics to the continental system increase even further since there will be a great need for imports during low production times from renewable and intermittent sources. The need for transmission capacity between the Nordic countries also increases since the need for imports by Sweden and Finland could also be partly satisfied via imports from Norway and Denmark. However, there is no increase in transmission needs from the Nordic to the Baltic region in such a sensitivity due to the fact that the main benefit of those interconnectors is greater exports from the Nordic to the Baltic countries.

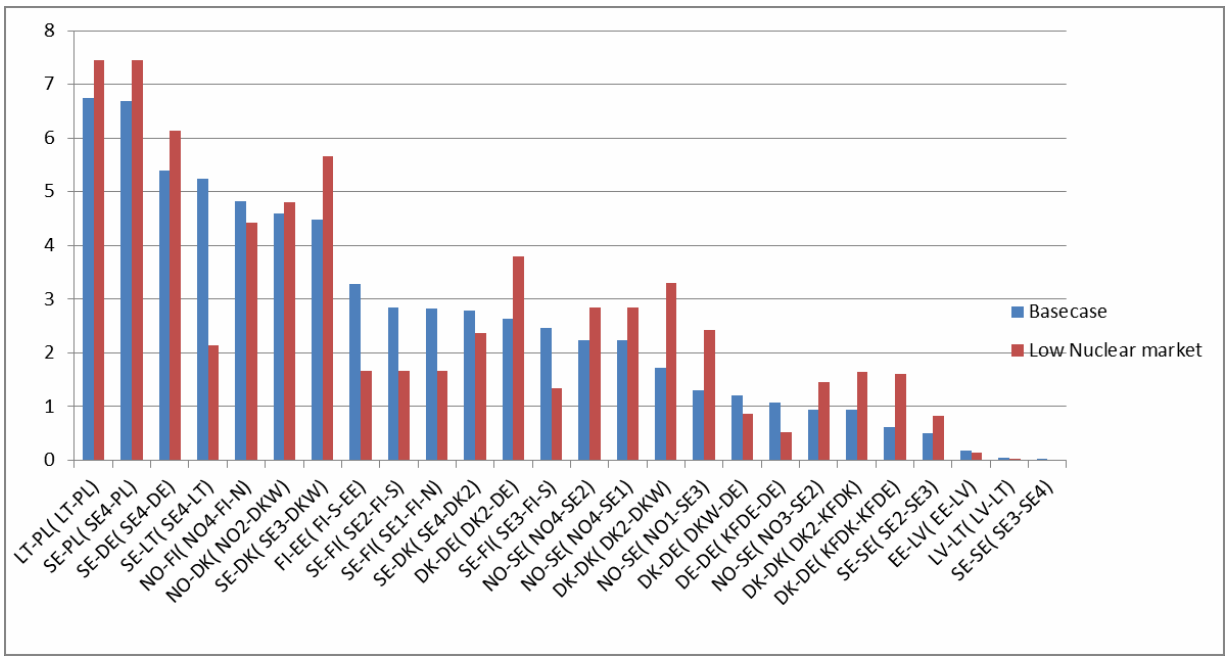

Figure 8-26 Average price differences between the Nordics or Baltics and the continental system in base case and low nuclear sensitivity in 2030.

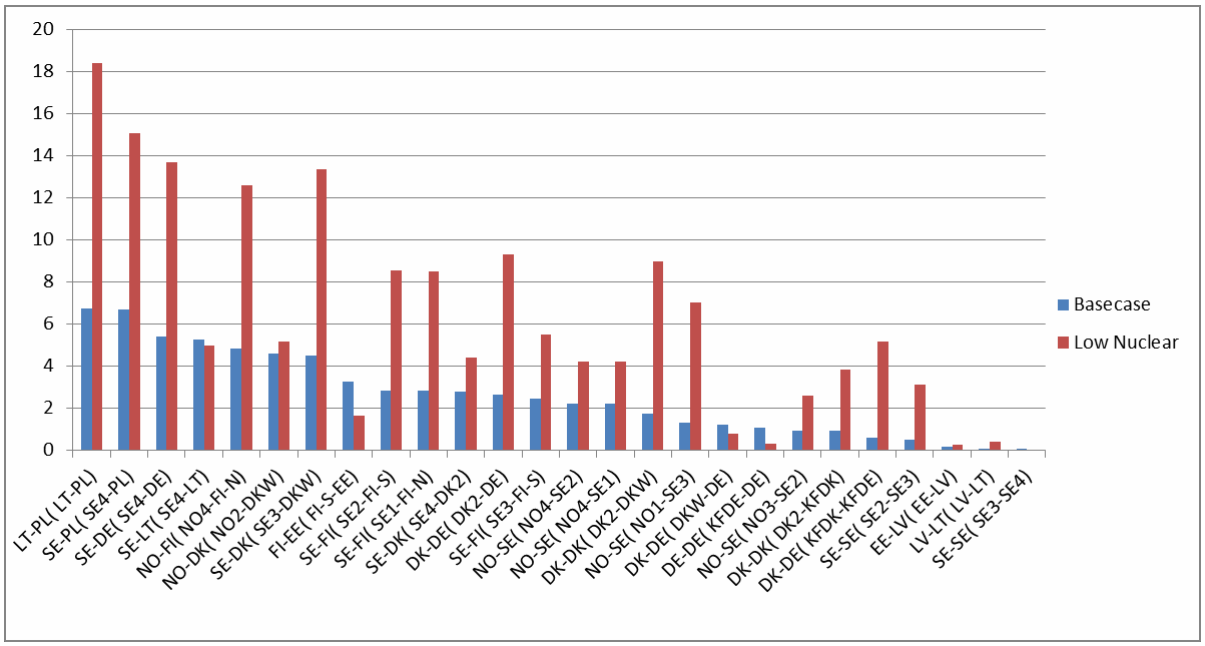

Figure 8-27 Average price differences between the Nordics or Baltics and the continental system in the base case and low nuclear sensitivity in 2030,

In the 'Low Price' sensitivity, the price difference on the borders with Poland increases since Poland has a significantly lower price in this sensitivity. This is because coal generation is very cheap there compared to gas and there is assumed to be a lot of coal generation in Poland in 2030. The price difference between the Nordics and the continent will therefore increase slightly. This is due to the more volatile Nordic price caused by the decommissioning of CHP/nuclear plants. On the other hand, the price difference between the Nordics and the rest of Europe will decrease since fossil fuel generation is cheaper, which drives the Baltic price down more than the Nordic. The decommissioning of CHP and nuclear power plants in the Nordics also decreases the Nordic surplus. This means that the price difference between the Nordics and Baltics becomes smaller.

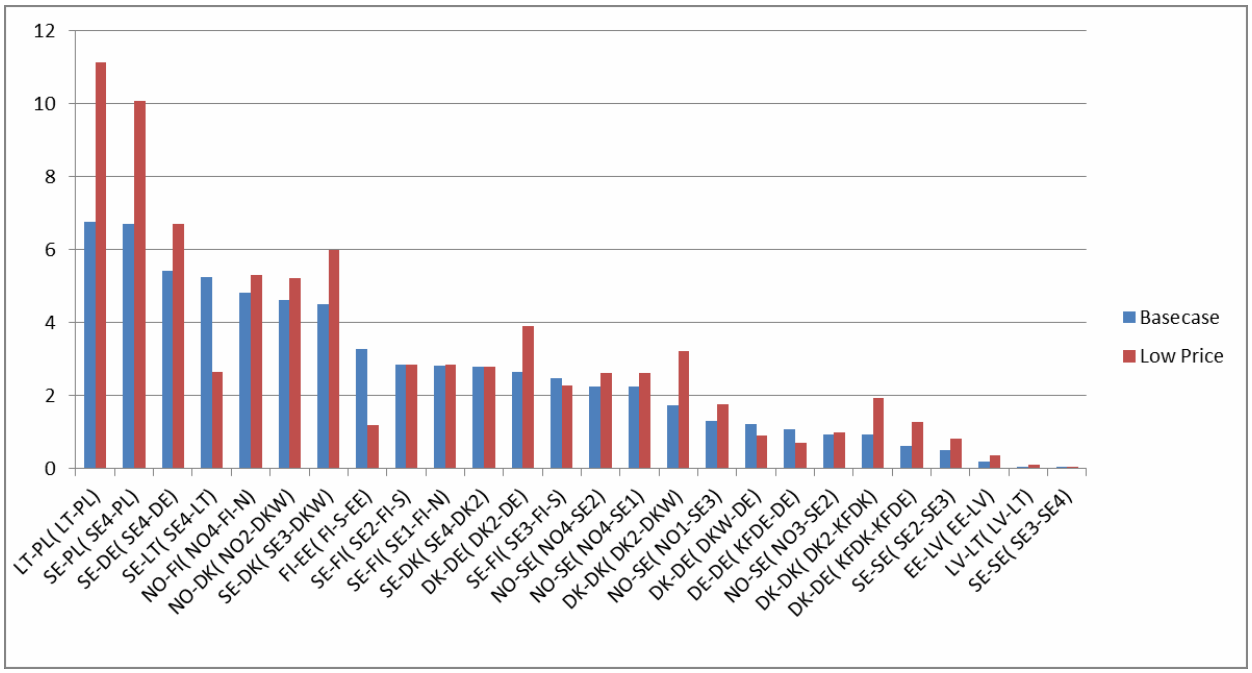

Figure 8-27 Average price differences between the Nordics or Baltics and the continental system in base case and low-price sensitivity in 2030.

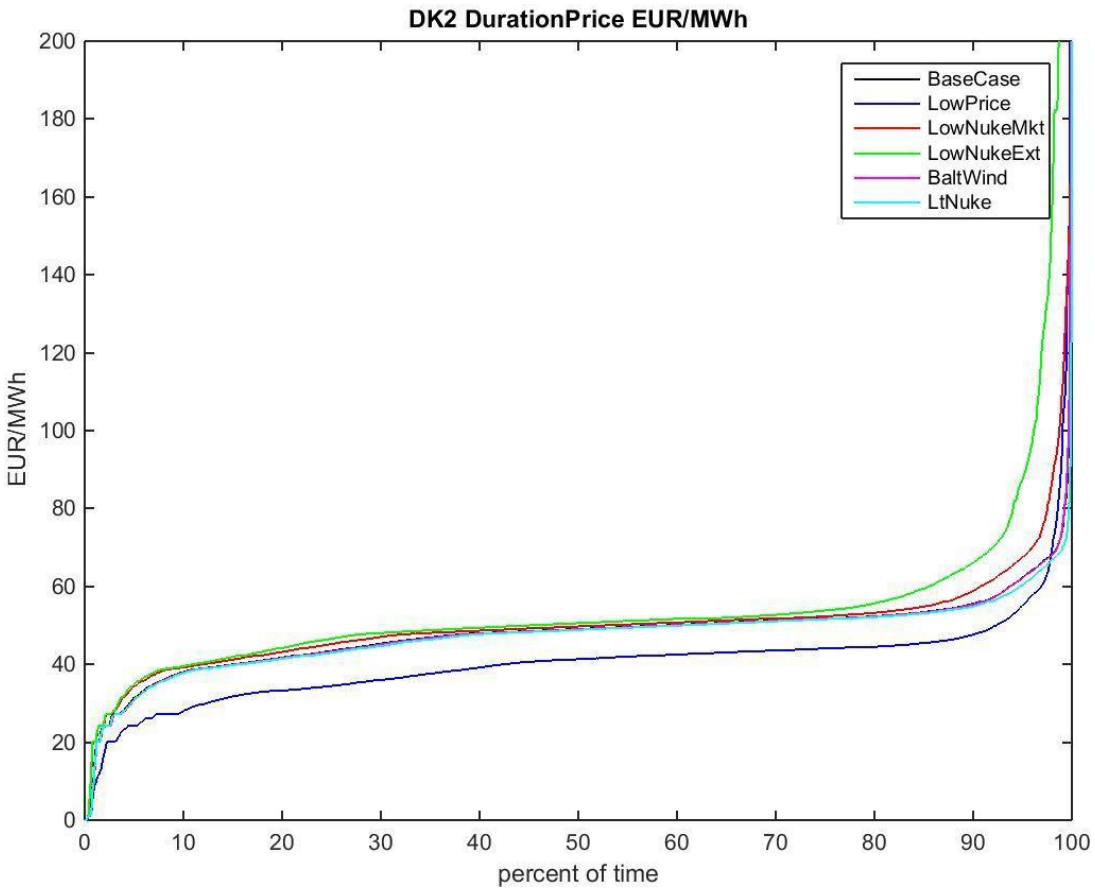

Figure 8-28 Duration curve of price in € per MWh in the price area Denmark DK2 in different sensitivities in 2030.

In the 'Baltic Wind' sensitivity, the price difference increases slightly on most borders, particularly on those to the Baltic countries as increased RES production in combination with the removal of trade with non-ENTSO-E countries creates a more volatile price. In the 'Lt Nuke' case, the price differences decrease significantly on all borders with the Baltic States and Finland, since this would remove a lot of the price volatility.

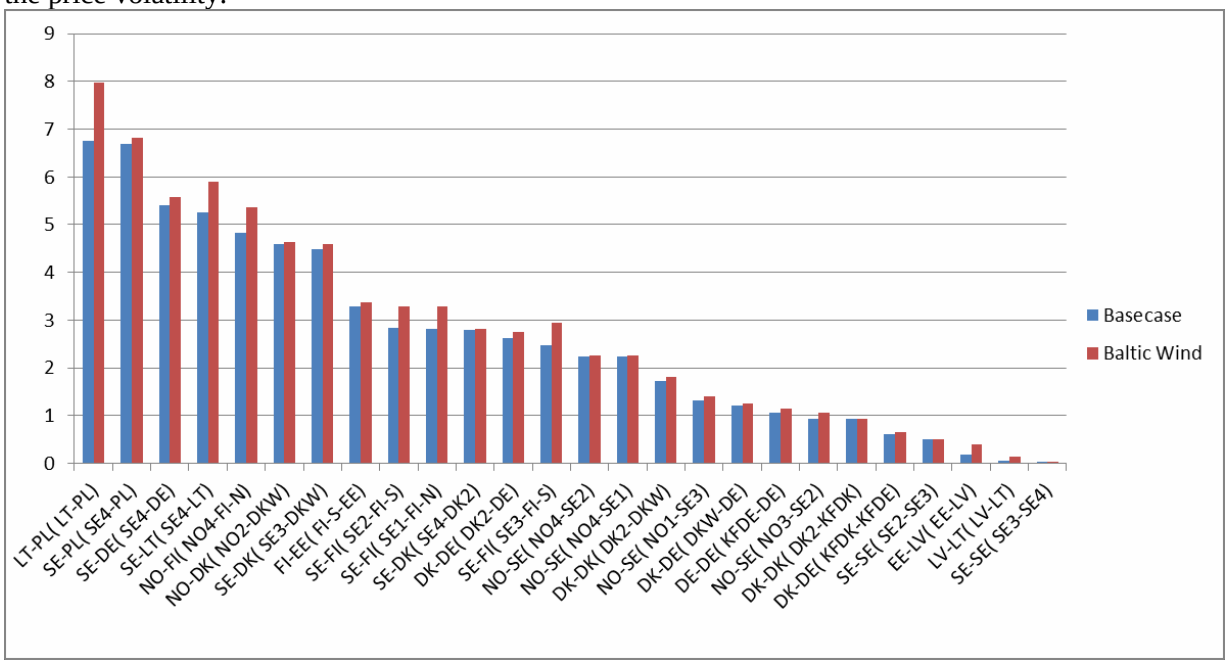

Figure 8-29 Average price differences between the Nordics or Baltics and the continental system in base case and the Baltic Wind sensitivity in 2030.

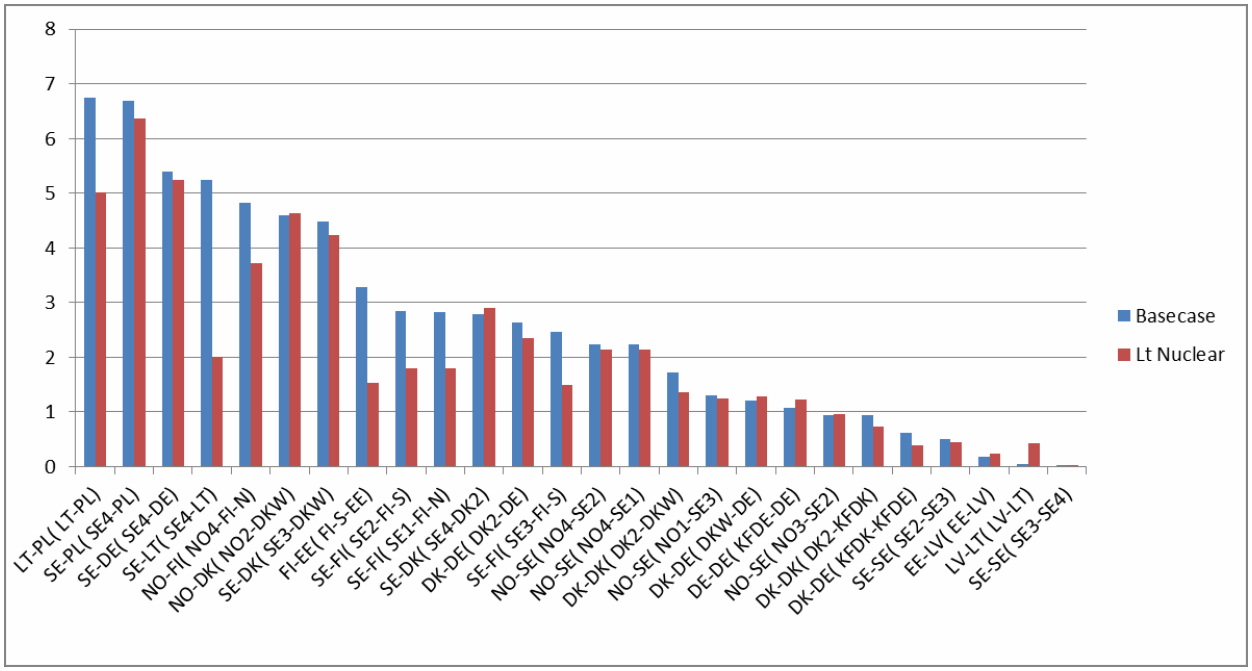

Figure 8-30 Average price differences between the Nordics or Baltics and the continental system in base case and the Lithuanian Nuclear sensitivity in 2030.

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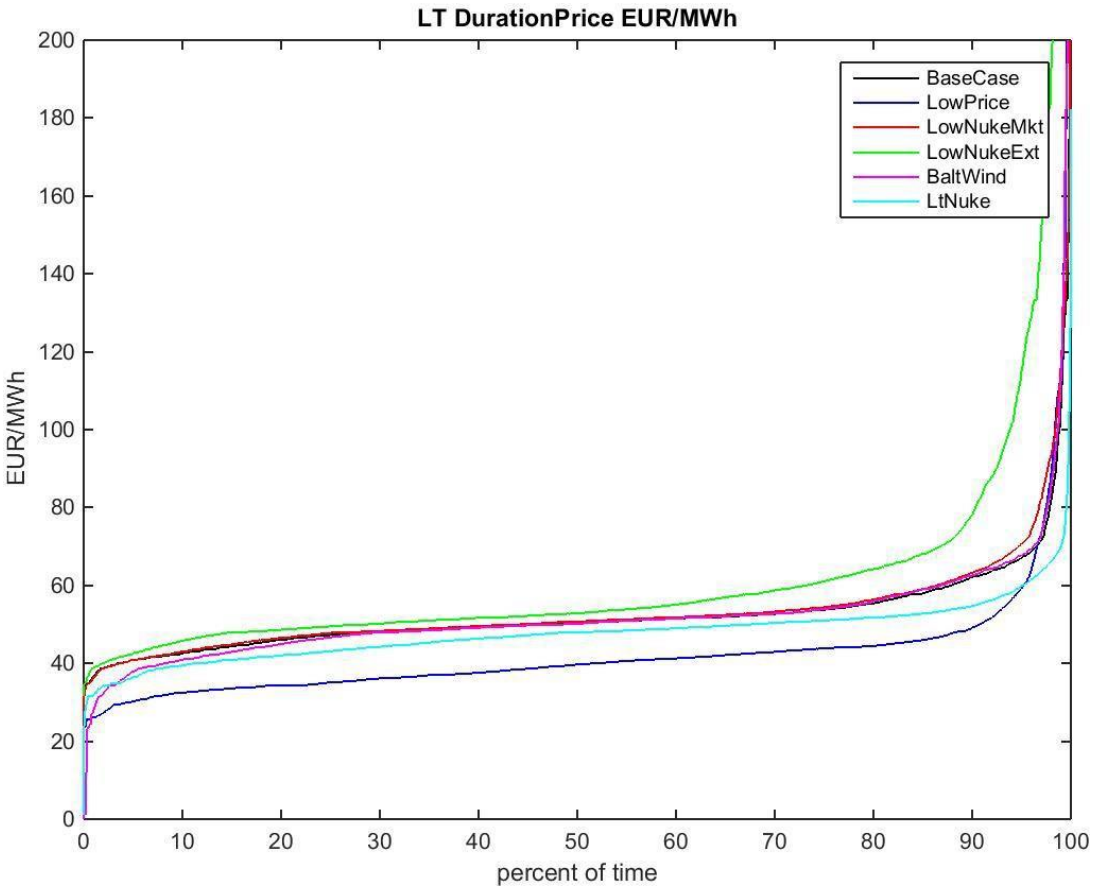

Figure 8-31 Duration curve of price in € per MWh in Lithuania in different sensitivities in 2030.

Adequacy

There was no probabilistic analysis to assess the adequacy of generation in this study. In the market model results, there is no loss of load since extreme situations are not fully captured when average profiles are used for availability of interconnectors as well as generation units. However, the number of hours with prices higher than 200 EUR/MWh which indicates the frequency of very strained situations in the system, were used instead. In the base case, the number of hours varied between two and ten hours per year on average and was worse in Finland and the Baltics. The low nuclear case obviously increases this. In the sensitivity 'Low Nuke Ext', with only reduced nuclear capacity, there is an average of up to 180 hours of high prices. The effects are, however, less extreme in the more realistic 'Low Nuke Mkt' case, where this figure was around 50 hours in the worst-performing country (Finland). In the low-price sensitivity, the number of high price hours is significantly increased compared to the base case. This is due to the fact that even if the average price level is lower due to lower fuel prices, the number of hours with very tight balance is increased because of the decommissioning of CHP and nuclear plants.

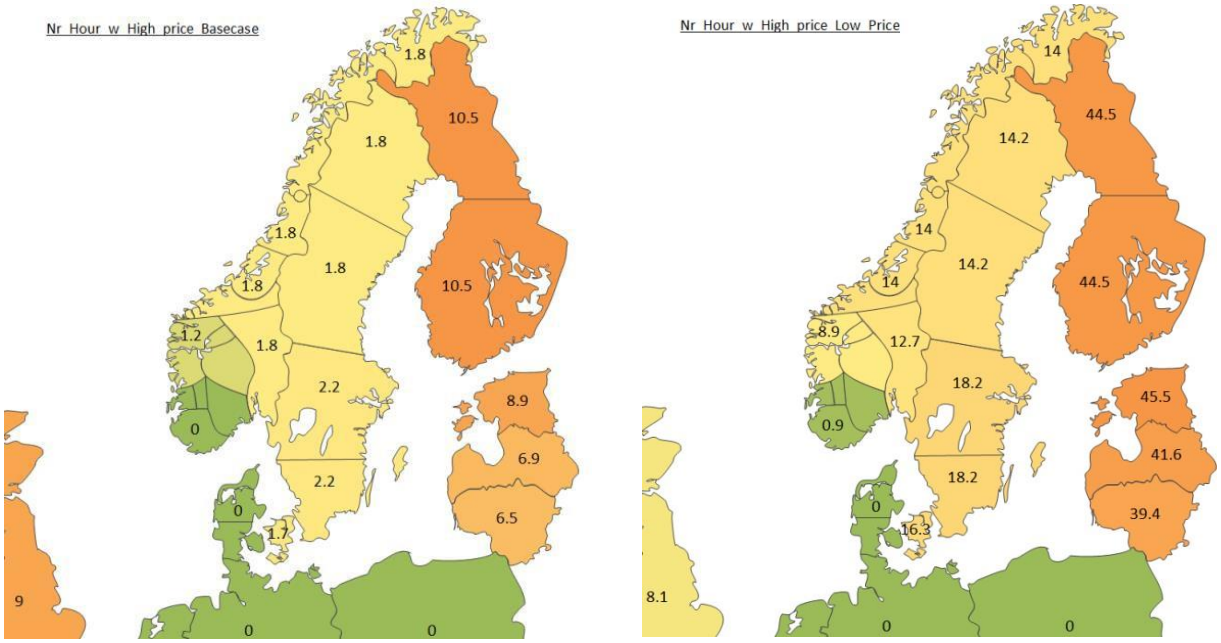

Figure 8-32 Average number of hours with prices higher than 200 EUR/MWh in the Baltic Sea region in the base case and the low-price sensitivity in 2030.

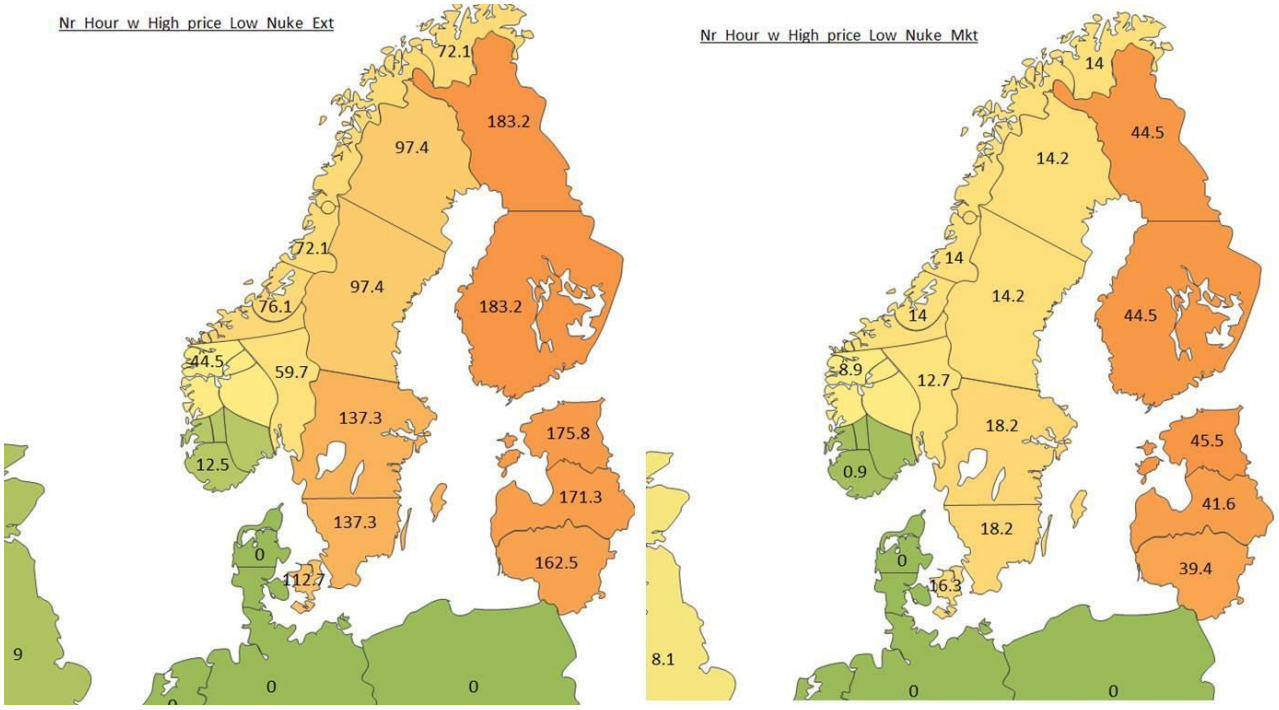

Figure 8-33 Average number of hours with prices higher than 200 EUR/MWh in the Baltic Sea region in the Low Nuclear Ext and Low Nuclear Mkt sensitivities in 2030.

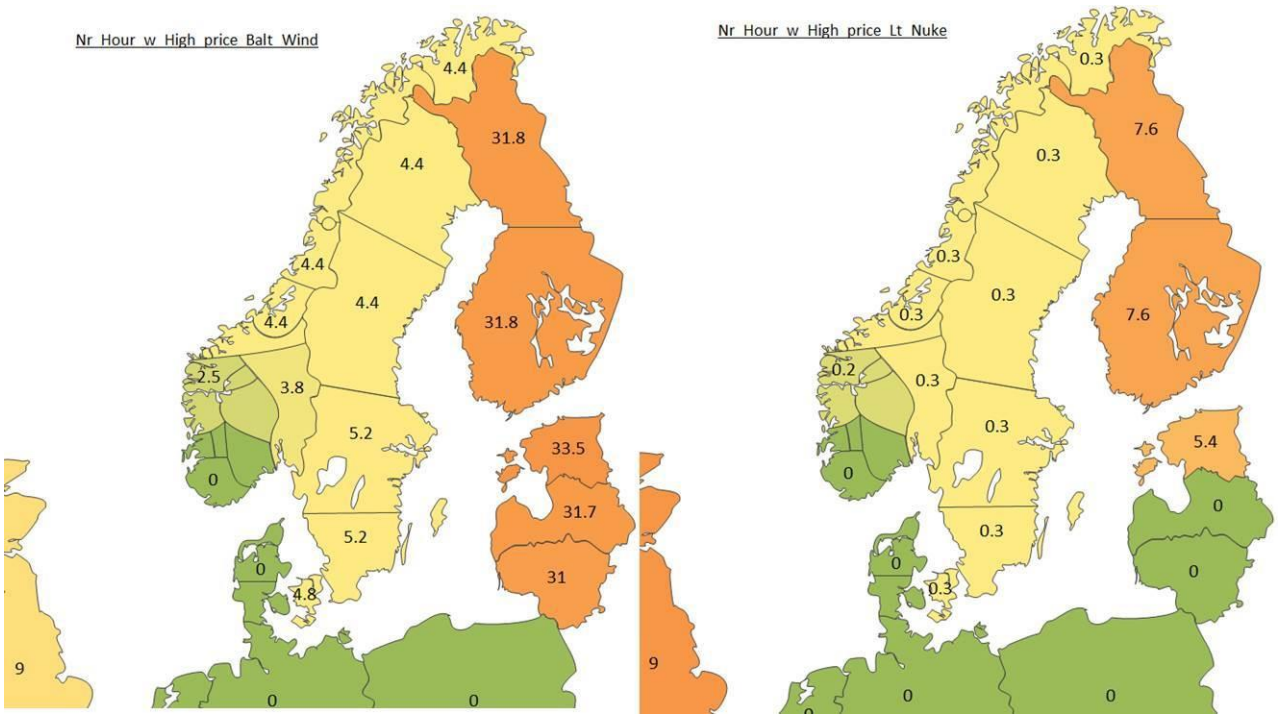

Figure 8-34 Average number of hours with prices higher than 200 EUR/MWh in the Baltic Sea region in the Baltic Wind and Lithuanian Nuclear sensitivities in 2030.

8.2 Abbreviations

The following list shows abbreviations used in the Regional Investment Plans 2017.

- 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
- 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

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- 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
- 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

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8.3 Terminology

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

Congestion Revenue/Congestion Rent – The revenue derived by interconnector owners from the sale of the interconnector capacity through auctions. In general, the value of the congestion rent is equal to the price differential between the two connected markets, multiplied by the capacity of the interconnector.

Congestion – A situation in which an interconnection linking national transmission networks cannot accommodate all physical flows resulting from international trade requested by market participants, because of a lack of capacity of the interconnectors and/or the national transmission systems concerned.]

Cost-Benefit-Analysis (CBA) – Analysis carried out to define to what extent a project is worthwhile from a social perspective.

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.

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.

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.

Investment – An individual equipment or facility, such as a transmission line, a cable or a substation.

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 CO_2 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 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.

Project – 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 – A project which meets the general and at least one of the specific criteria defined in Art. 4 of the TEN-E Regulation and which has been granted the label of PCI Project according to the provisions of the TEN-E Regulation.

Put IN one at a Time (PINT) – A 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 Network – 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 gas demand and gas supply, gas infrastructures, fuel prices and global context occur.

Transmission capacity/Total Transfer Capacity – 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.

Take Out One at a Time (TOOT) – A 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 – The union-wide report carried out by ENTSO-E every other year as (TYNDP) part of its regulatory obligation as defined under Article 8 para 10 of Regulation (EC) 714 / 2009

Total transfer capacity (TTC) – See Transmission capacity above.

Vision – Plausible future states selected as possible wide-ranging alternatives.

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