Regional Investment Plan 2017

North Sea

Final version after public consultation
and ACER opinion – October 2019

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Contents

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1 EXECUTIVE SUMMARY

1.1 Regional investment plans as foundation for the TYNDP 2018

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

The TYNDP is a biennial report published every even year by ENTSO-E. It acts as an essential basis to derive the Projects of Common Interest (PCI) list. Presently the TYNDP 2018 is under preparation.

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.

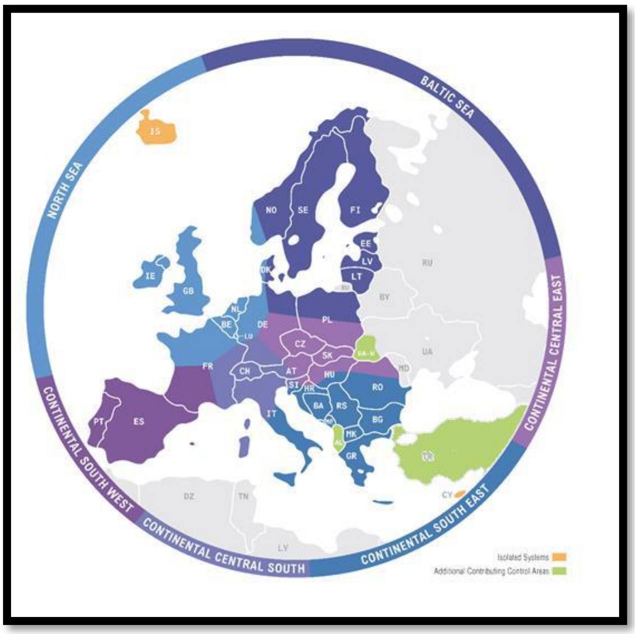

Figure 1-1 ENTSO-E System Development Regions

The six Regional Investment Plans (RegIPs) are part of the TYNDP 2018 package. They are supported by regional and pan-European analyses and take into account feedback received from institutions and stakeholder associations.

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

Beside showing the 2040 challenges and proper scenario grid capacities to solve many of these challenges, the RegIP also shows 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.

Available regional sensitivities and other available studies are included in the RegIP to illustrate circumstances especially relevant for the region. The operational functioning of the regional system and future challenges regarding this are also assessed and described in the reports.

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 changes and updates compared to earlier publications. Since

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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 for ENTSO-E: to establish the most efficient and collaborative way to reach all defined targets of a working Internal Energy Market and a sustainable and secure electricity system for all European consumers.

1.2 Key messages of the region

The North Sea Region faces major challenges over the coming decades. The large increase in renewable generation across the region needed to meet European targets, coupled with the requirement to integrate the European electricity market, results in a number of challenges summarised below.

1.2.1 Structural changes to the generation portfolio

There will be substantial change to the region's generation fleet over the coming decades, as described in this report. Changes are already occurring, and Chapter 3.1 highlights certain trends by comparing the years 2010 and 2016. These trends are expected to continue; however, how they progress to the year 2040 is uncertain, and a number of ENTSO-E scenarios have been developed to reflect this, which are analysed in Chapter 3.2.

The following changes are expected in the generation portfolio across the region:

1. **A shift from thermal to renewable generation**. The integration of renewable energy sources is fundamental to enable the decarbonisation of society. There is an abundance of renewable energy sources across the North Sea Region—onshore and offshore wind, solar and hydro power—that can be exploited. Thermal plants' utilisation hours decrease over time and many plants are old; both developments indicate that some plants might disappear from the market in the medium term.

2. **A reduction in nuclear generation.** Despite a planned increase in nuclear capacity in Great Britain (GB) the region's overall trend is for a reduction in nuclear capacity, with planned phase outs in Belgium and Germany, and a partial phase out in France.

3. **A shift from coal to gas generation.** Existing coal-fired power plants are being phased out due to a combination of reaching their technical end of life and policies put in place to enable the carbon emission reduction of the generation portfolio. The phasing out of the existing coal and the aforementioned nuclear generation requires replacement capacity to be built in order to guarantee an adequate electricity system and the provision of certain system services. Flexible gas-fired generation takes a central role in this replacement capacity.

1.2.2 Power flows across the region

The future generation portfolio will drive large power flows across the North Sea Region. The diverse nature of the generation is a major factor, and has the following characteristics:

- Norway predominantly consists of hydroelectric generation, with its associated seasonal dispatch patterns.
- Renewable generation in GB and Ireland is dominated by wind generation, with its hourly variable output.
- Continental Europe has both a mix of wind and solar generation and a substantial share of gas-fired generation.
- The generation portfolio in France is dominated by nuclear power.

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This generation diversity across the region drives market exchange opportunities and consequently power flows between the four synchronous areas and also between the Member States. These power flows resulted in a number of main boundaries being previously identified in TYNDP 2016:

- Between Ireland and GB and Continental Europe;
- Between GB and Continental Europe and Nordics; and
- Between Nordics and Continental Europe West (Denmark, Netherlands and Germany).
- As described in this report, additional needs for wider area-cross-border reinforcements have been identified around the north-eastern part of France.

1.2.3 A requirement for new interconnection

Additional interconnection capacity is required across the region between synchronous areas and Member States. This additional capacity:

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

This additional capacity will drive larger power flows across Member State's internal grids in the future. As a result, existing transmission corridors will need to be reinforced, or new corridors developed to upgrade the internal grids to accommodate these developments.

1.2.4 Offshore RES and offshore infrastructure development

The Northern Seas comprise a number of marine areas- the North Sea, the English Channel, the Irish Sea, Skagerrak and Kattegat. These seas experience high wind speeds and areas of shallow water. Both characteristics mean there is potential for the development of significant quantities of offshore RES.

A consequence of this potential generation would be the requirement for significant offshore infrastructure development in the Northern Seas; already, ambitious offshore grid initiatives in the region are being investigated. These initiatives include:

- Collaborations at a political level;
- New research projects; and
- Industry level collaboration on visionary projects.

The integration of this offshore generation was analysed previously in studies carried out in 2011 by NSCOGI. Although, at a country level, expectations of offshore RES development are lower than during the NSCOGI investigations, the political awareness and stakeholder expectations towards offshore infrastructure development are high. Previous results from the NSCOGI studies are still valid in principle; however, the location of some of the elements and the year of realisation may change.

The ENTSO-E TYNDP18 includes the next version of the Northern Seas Offshore Grid infrastructure. This collates the individual foreseen subsea projects into one building block; however, the single projects will ultimately be developed by the various project promoters on a modular basis.

1.2.5 Ensuring security of supply

The expected changes in the regional generation fleet might challenge the security of supply of all the synchronous systems of the region.

Firstly, the weather will have a higher impact on the future energy system than it has today. While the Nordic system continues to be built on very high hydropower capacity including large hydro reservoirs, the Continental and the British systems are in all ENTSO-E scenarios composed of a mix of high share wind and solar generation units plus some thermal plants. Often when there is low wind or solar generation in one area, power can be imported from other areas with a greater production from wind/solar/hydro, thus helping the situation. However, there are instances where low RES production occurs in multiple adjacent countries.

Secondly, to reach the adequacy standards new flexible thermal generation is assumed in the scenarios. This new thermal generation is not necessarily economically viable in an energy-only market, hence (partially) relying upon capacity remuneration mechanisms.

To balance cross-regional production and consumption exploiting lower correlations of the same RES type and sharing the available thermal resources, interconnectors are supposed to contribute to ensure security of supply (adequacy and reliability). Thanks to the sharing of resources, interconnectors ensure security of supply in a more cost-effective manner compared to an isolated approach requiring more installed generation capacity on individual country level.

Reliability issues due to increasing system complexity and due to unforeseen interactions of control and protection systems must be avoided. Blackouts in non-European systems have shown that the coordination of market rules and network codes is a must.

1.2.6 Ensuring flexibility in the region

The increases in renewable generation can result in significant load ramps being experienced within countries. These large ramps in load result from fast changes to variable generation output occurring at the same time as changes to the load profile. A present day example of this is the so-called ‘duck curve’ load profile associated with the impact of solar generation. With the quantities of renewable generation described in the scenarios, TSOs will subsequently face challenges in maintaining system balance, as the size of the load ramps observed in Section 3-3 could not solely be met with a country’s installed thermal generation.

There is therefore an increased need for flexibility across the region, which could be provided by various sources, including additional interconnection, storage, fast acting peaking generation and demand side response. Storage could be beneficial to the system, particularly whenever new interconnection is not economically efficient. Short-term storage (for example, batteries and flywheels) and demand response have the potential to aid the system in terms of flexibility. These, however, tend to respond to localised events. Achieving full decarbonisation in the longer run (close to or beyond 2050) could require larger scale solutions, such as Compressed Air Energy Storage, power to gas and power to heat.

1.3 Future infrastructure capacity needs

The changes to the generation portfolio and the resultant power flows across the region drive the need for new transmission capacity. To enable this, the transmission network will require reinforcements both on cross-border and internal levels. This RegIP investigates the potential for additional cross-border capacity increases and their impact on the transmission network in general.

The initial phases of the TYNDP 2018 process considered the development of new scenarios for 2025, 2030 and 2040 and assessed future system needs for the long-term 2040 horizon. Part of this work involved identifying cross-border capacity increases for the 2040 scenarios. These capacity increases have a positive impact on the system. A European overview of these increases is presented in the European System Need report [link] developed by ENTSO-E in parallel with the RegIPs 2017.

Identified capacity increases for the North Sea Region are shown in Figure 1.2. 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 North Sea Region the 2040-needs are primarily described through:

- Further integration between Norway and Great Britain, due to price differences and due to the need for flexibility to optimise the RES generation (hydro/wind).
- Further integration between Norway and the synchronous Continental system (Denmark and Netherlands), due to i) price differences, ii) the need for flexibility to optimise the RES generation (hydro/wind) and iii) provision of support to Danish and Dutch security of supply in low-wind periods.
- Further integration between Great Britain and the Continental system (France, Belgium, Netherlands), due to i) price differences, ii) better optimisation of the RES generation and iii) challenged security of supply in high demand/low variable RES (wind and solar) periods.
- Further integration between Germany and France, Belgium and the Netherlands (east-west) due to i) optimisation of the production system and ii) challenged security of supply in high demand and low variable RES (wind and solar) periods.
- Further integration between Ireland and Great Britain/France due to i) price differences, ii) optimisation of the RES generation and iii) challenged security of supply in low-wind periods.

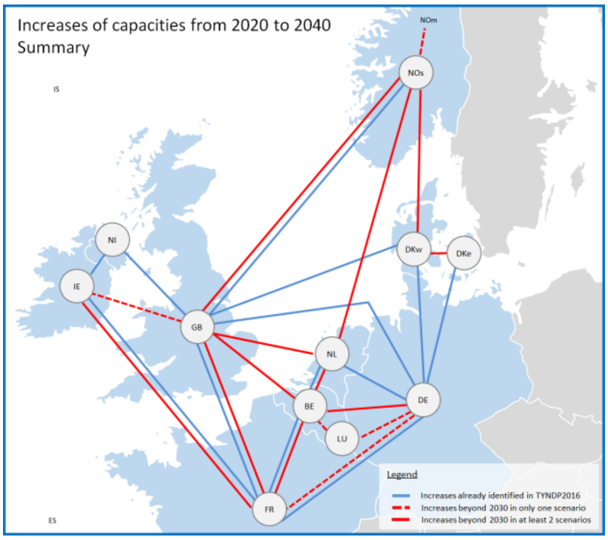

Figure 1.2: Cross-border capacity increases in the North Sea Region[1]

The identified cross-border capacity increases allow renewable energy to be shared across the region. However, the consumer can only truly benefit if the transmission network is able to transport the corresponding power flows. This is a significant challenge since the power flows:

- Become more international as the distance between the consumer and the location where the cheapest available energy is being produced increases; and,
- Become increasingly volatile and less predictable as a result of the variable nature of the renewable energy sources, i.e. the location where the cheapest production is available can quickly change.

These changes bring about a paradigm shift in the role of the grid: electricity grids will play a crucial role in facilitating RES integration on a European scale, enabling the transformation of the energy mix. Ultimately

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

it will allow European 2050 climate and energy policy objectives to be met, aiming to maximise the decarbonisation of our society.

The network analysis performed on the 2040 scenarios identified the congested areas of the grid, and the corresponding need to develop new transmission capacity. With their highly meshed structure, dense population and central location, the congestions are most pronounced in the Central Western European area. These congestions will require internal reinforcements to complement the additional cross-border capacities.

RGNS is on the way to closing the gap between today's grid and the 2040 needs. Figure 1-3 shows projects already 'in the pipeline', i.e. with status from under consideration to being realised in the medium term.

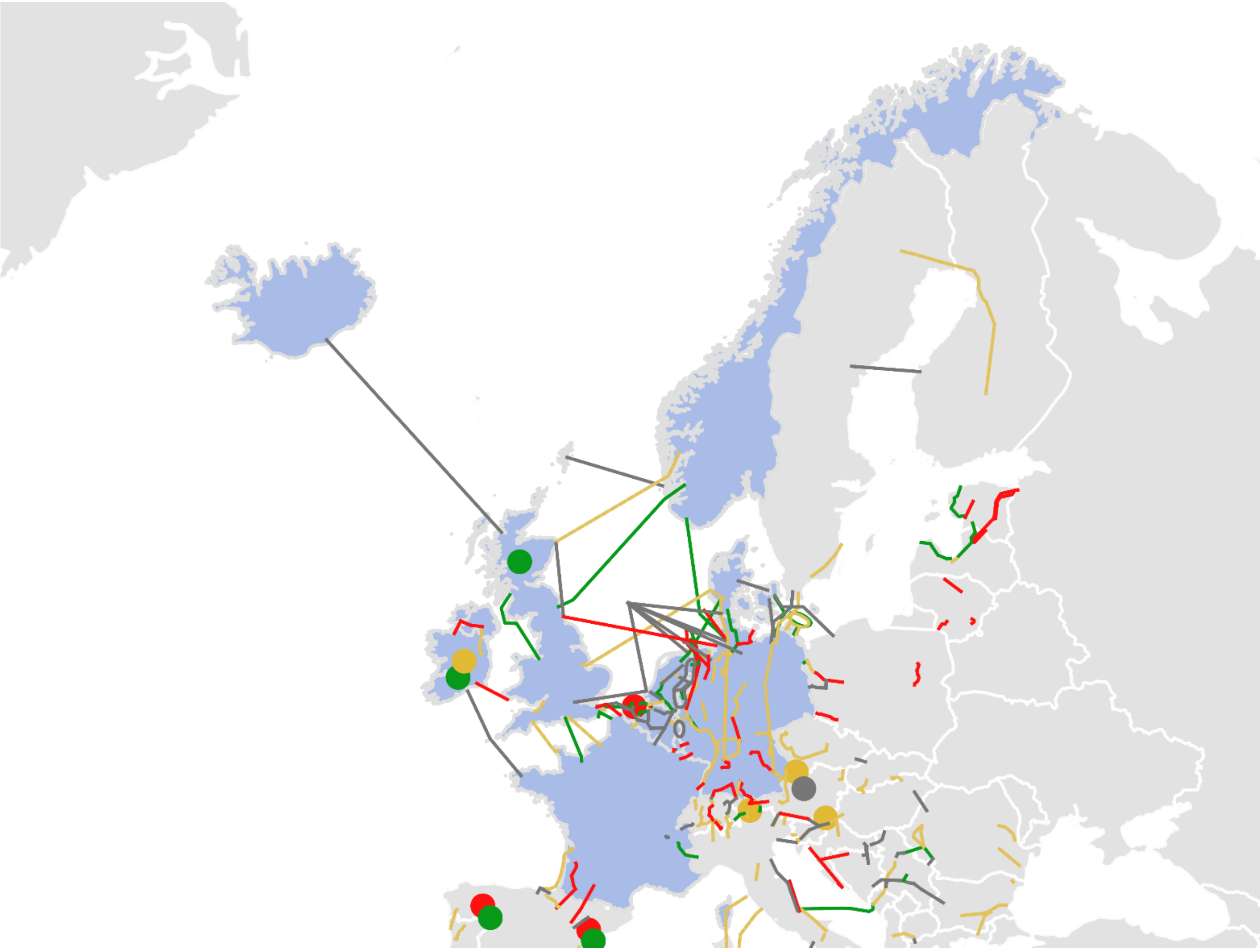

Figure 1.3: Promoted projects

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, where it is requested that TSOs shall establish regional cooperation within ENTSO-E and shall publish a RegIP every two years. TSOs may take investment decisions based on that RegIP. ENTSO-E shall provide a non-binding community-wide ten-year network development plan which is built on national investment plans and reasonable needs of all system users and 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 shall promote transmission grid development.

RegIPs are to provide detailed and comprehensive overview on future European transmission needs and projects in a regional context 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, providing an opinion on the TYNDP itself and its coherence with national plans, and giving an opinion on the EC's draft list of PCI projects;
- European institutions (EC, Parliament, Council) who have acknowledged infrastructure targets as a crucial part of pan-European energy goals, to give insight into how various targets influence and complement each other;
- The energy industry, including 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, to place national energy matters in an overall European common context;
- Organisations having a key function to disseminate energy related information (sector organisations, NGOs, press) for whom this plan serves as a 'communication toolkit';
- The general public, to understand what drives infrastructure investments in the context of new energy goals (RES, market integration) while maintaining system adequacy and facilitating secure system operation.

2.2 The scope of the report

The present RegIP is part of a set of documents, shown in Figure 2-1, comprising in a first step the following reports: a Mid Term Adequacy Forecast report (MAF), a Scenario report, a Pan-European Systems needs report and six RegIPs.

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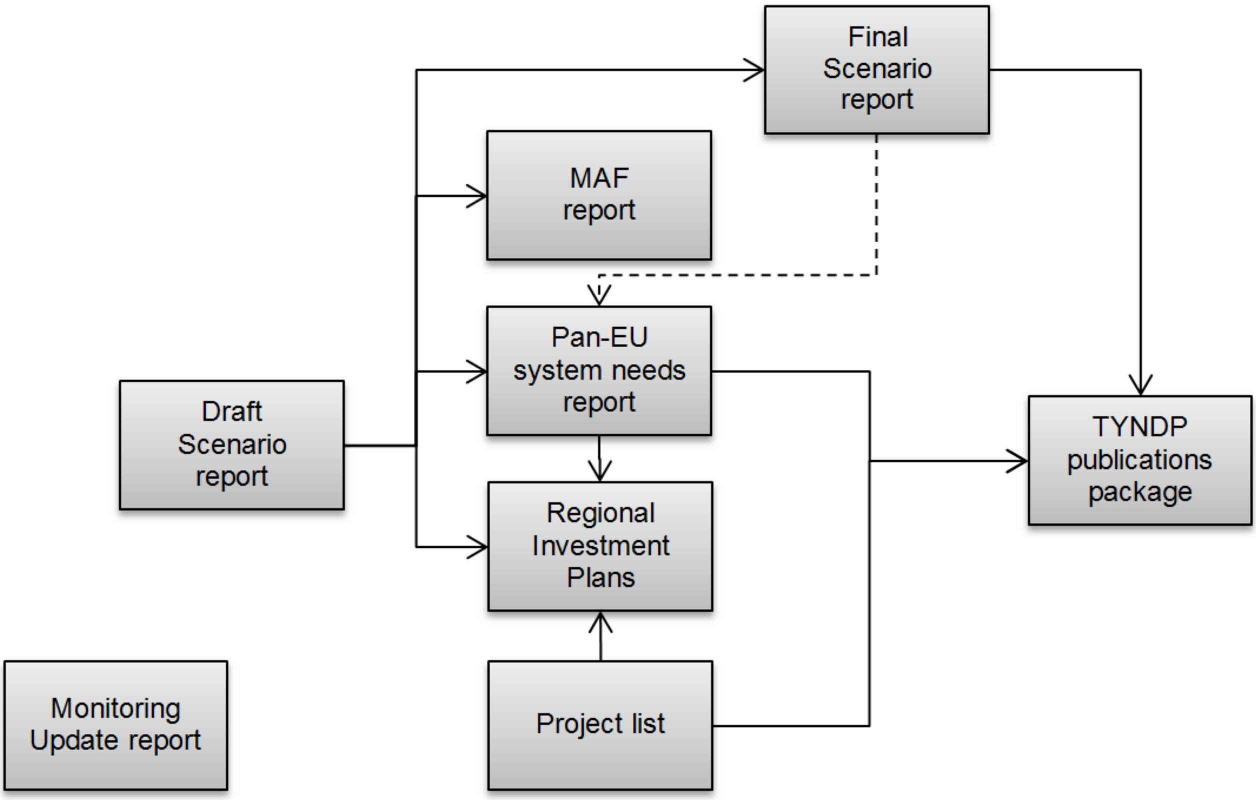

Figure 2-1: Document structure overview TYNDP2018

The general scope of RegIPs is to describe the present situation and actual as well as future regional challenges. The TYNDP process proposes solutions, which can help mitigate future challenges. This approach is based on five essential steps presented in Figure 2- below:

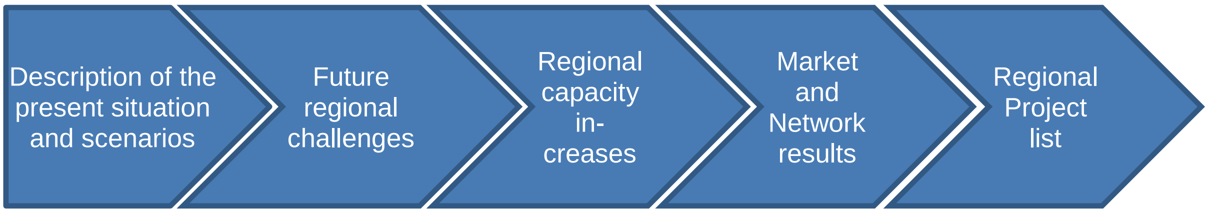

Figure 2-2: Mitigating future challenges – TYNDP Methodology.

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

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

- Chapter 1 gathers the key messages of the region.
- Chapter 2 sets out in detail the general and legal basis of the TYNDP work and 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. Future challenges of the region are also presented in this chapter when describing the evolution of generation and demand profiles with a 2040 horizon in consideration of a grid as expected by 2020.

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

The current edition of this Region Investment Plan takes into account the experience from the last processes including improvements, in most cases received from stakeholders during previous 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 determine demand profiles for each zone.
- A more refined approach of demand side response and electric vehicles.
- For the first time, several climate conditions have been considered as well.

The actual RegIP does not include the Cost-Benefit-Analysis (CBA)-based assessment of projects. These analyses will be developed in a second step and presented in the final TYNDP 2018 package.

2.3 General methodology

The present RegIPs build on the results of studies called "Identification of System Needs", which were carried out by a European team of market and network experts coming from the six regional groups of ENTSO-E's System Development Committee. The results of these studies have been commented on and, in some cases, extended with additional regional studies by the regional groups to cover all relevant aspects in the regions. The aim of the 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 also building 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.

2.4 Introduction to the region

The Regional Group North Sea (RG NS) under the scope of the ENTSO-E System Development Committee is among the six regional groups for grid planning and system development tasks. The countries belonging to each group are shown in 2-3 below.

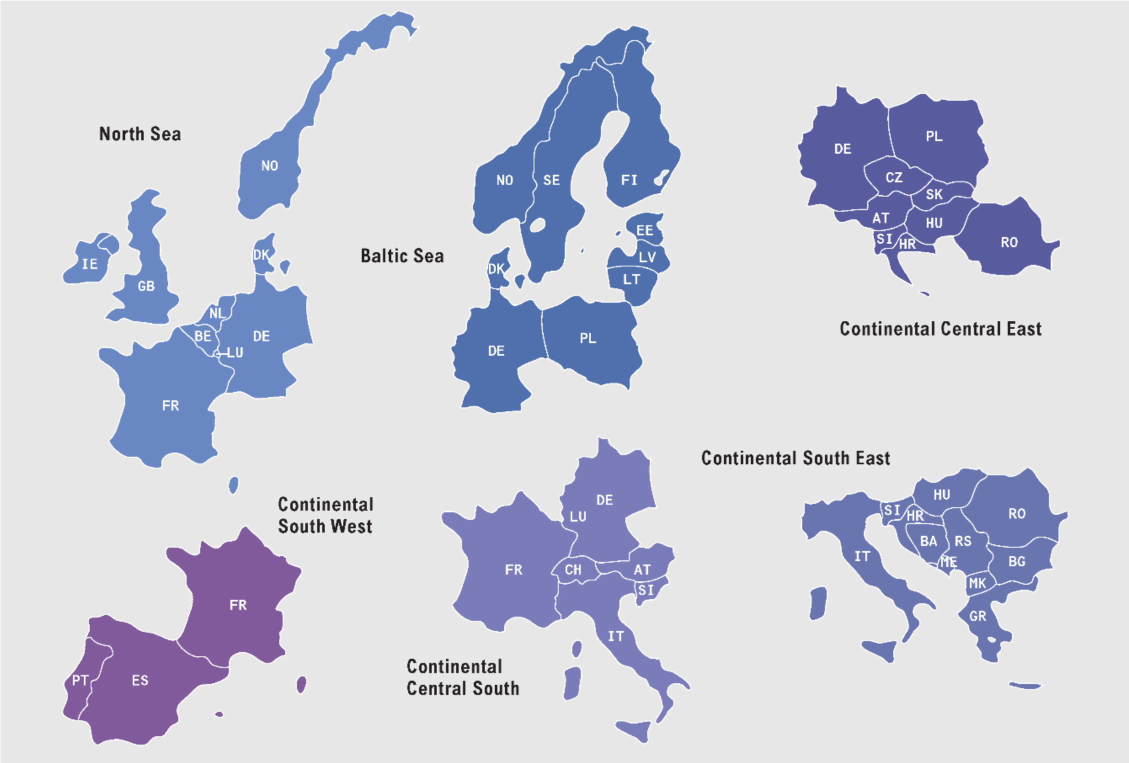

Figure 2-3: ENTSO-E regions (System Development Committee)

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

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

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

3 REGIONAL CONTEXT

3.1 Present situation

The Regional Group North Sea comprises four separate synchronous systems, shown in Figure 3-1. The four synchronous areas are linked with HVDC interconnectors. Most of the countries in the region are part of the Continental system (purple). Norway and East Denmark are part of the Nordic system (blue), while Great Britain (orange) and the island of Ireland (green) form their own islanded synchronous systems.

The majority of the grid is comprised of 220/275/380/400 kV overhead transmission lines. Norway also makes use of 300 kV circuits. 110-150 kV circuits are extensively used in the Danish and Irish transmission systems.

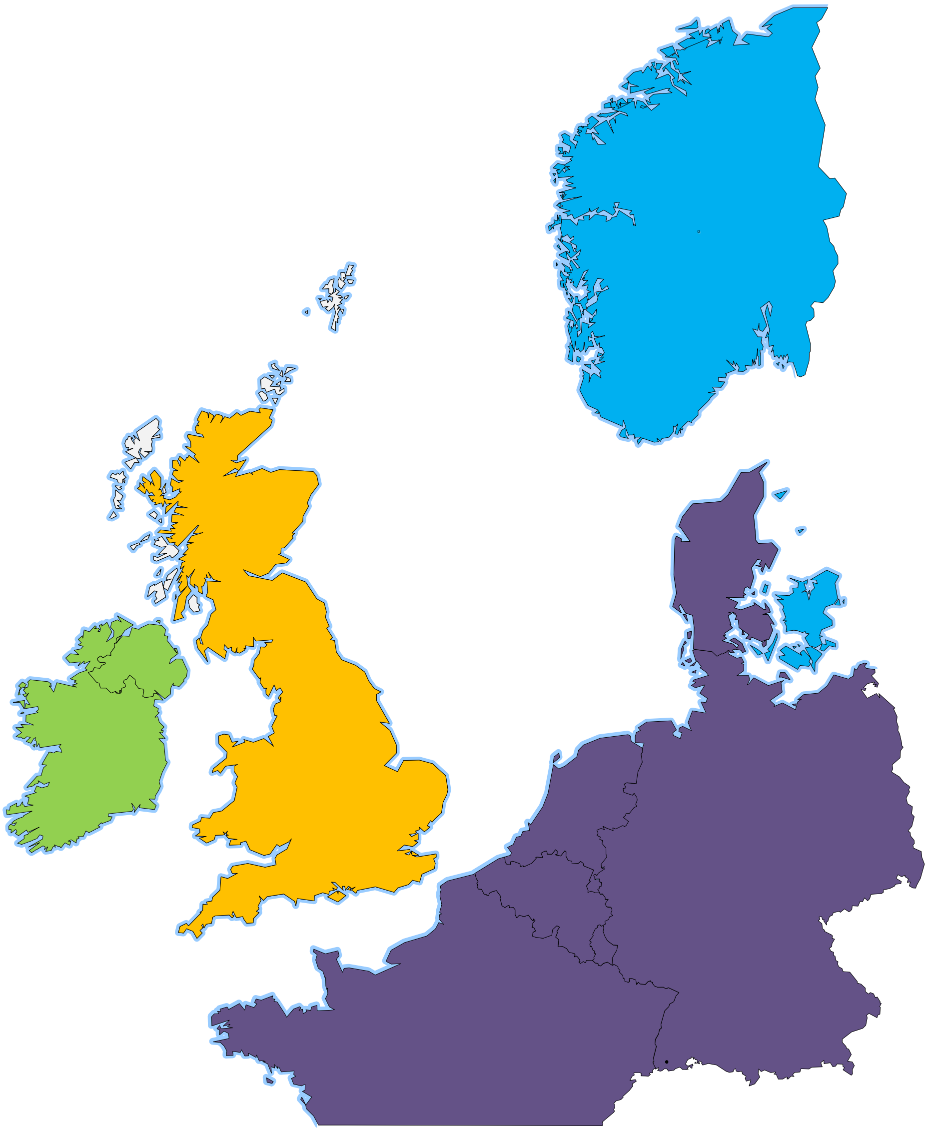

Figure 3-1: Synchronous areas of the North Sea Region

3.1.1 Generation capacity in the region

Figure 3-2 compares the installed generation capacities in the countries in the North Sea Region in 2010 and 2016. This provides a simple overview of how the generation portfolio has changed in the countries in recent years. Figure 3-2 also uses these figures to provide a regional overview.

The notable trend in the region is a decline in the installed capacity of fossil fuel and nuclear based generation and an increase in the installation of renewable generation. In 2010, these types comprised 68% of the region's generation capacity. By 2016, that figure had declined to 54%. There has been a reduction in the capacity of fossil-fuel-based generation in most countries, with the exception of Germany and the Netherlands. In Germany, there has been a closure of 10 GW of nuclear generation.

This reduction in capacity is being met with renewable generation across the region. The dominant renewable generation sources in the region are wind, solar and hydro, which have gone from comprising 31% of the region's generation capacity in 2010 to 46 % in 2016, with variable RES (wind and solar increasing from 14% to 29%). In particular, there have been large increases of variable RES in Germany and Great Britain. There have been significant increases in wind generation in Denmark, Ireland, Northern Ireland (NI) and the Netherlands.

Norway continues to have a generation portfolio dominated by hydro generation; however, there has also been some increase in wind generation in the country.

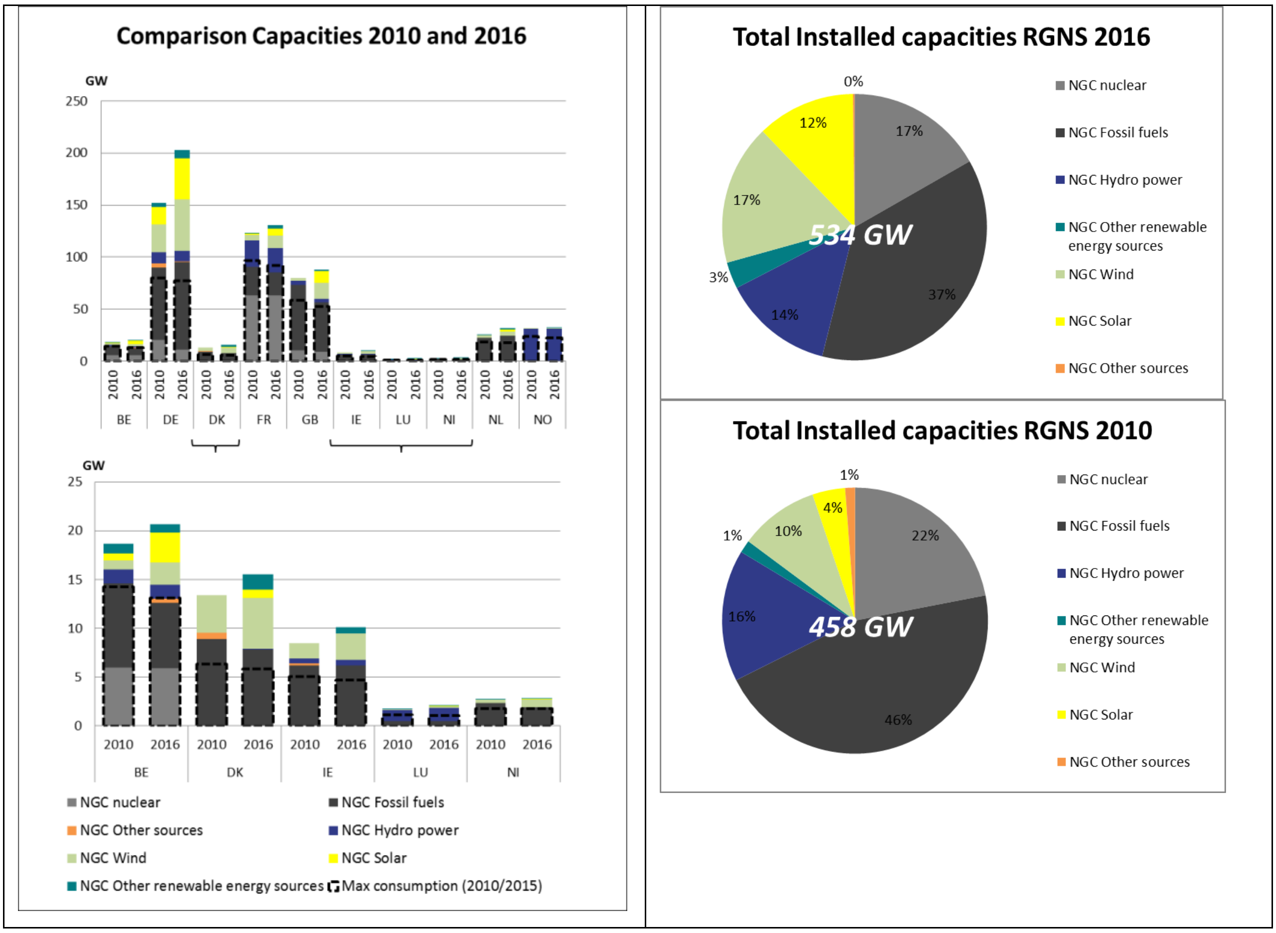

Figure 3-2: Installed generation and maximum consumption in the North Sea Region in 2010 and 2016

3.1.2 Energy production and consumption in the region

Figure 3-3 displays the annual energy production and consumption in the countries in the North Sea Region in 2010 and 2016. Figure 3-3 also shows the energy production for the region in 2010 and 2016.

As the generation portfolio has changed across the region from 2010 to 2016 with an increase in renewable generation, more countries are sharing their generation capacity via interconnection. This trend can be observed in Figure 3-5, comparing 2010 cross-border flows to 2015 cross-border flows.

Energy from fossil fuels and nuclear still supplies the bulk of the region's demand, however this has dropped from 81% in 2010 to 70% in 2016. RES generation has increased from 19% to 30%, with variable RES (wind and solar) having increased from 5% to 12% in this same period.

In general, the total demand has slightly increased across the region, however, in some countries (Belgium, Denmark and France) the demand has reduced between 2010 and 2016. As consumption in France is highly thermo-sensitive, consumption appears almost stable comparing 2010 and 2016 (around 470TWh) when adjusted values with climate conditions are considered.

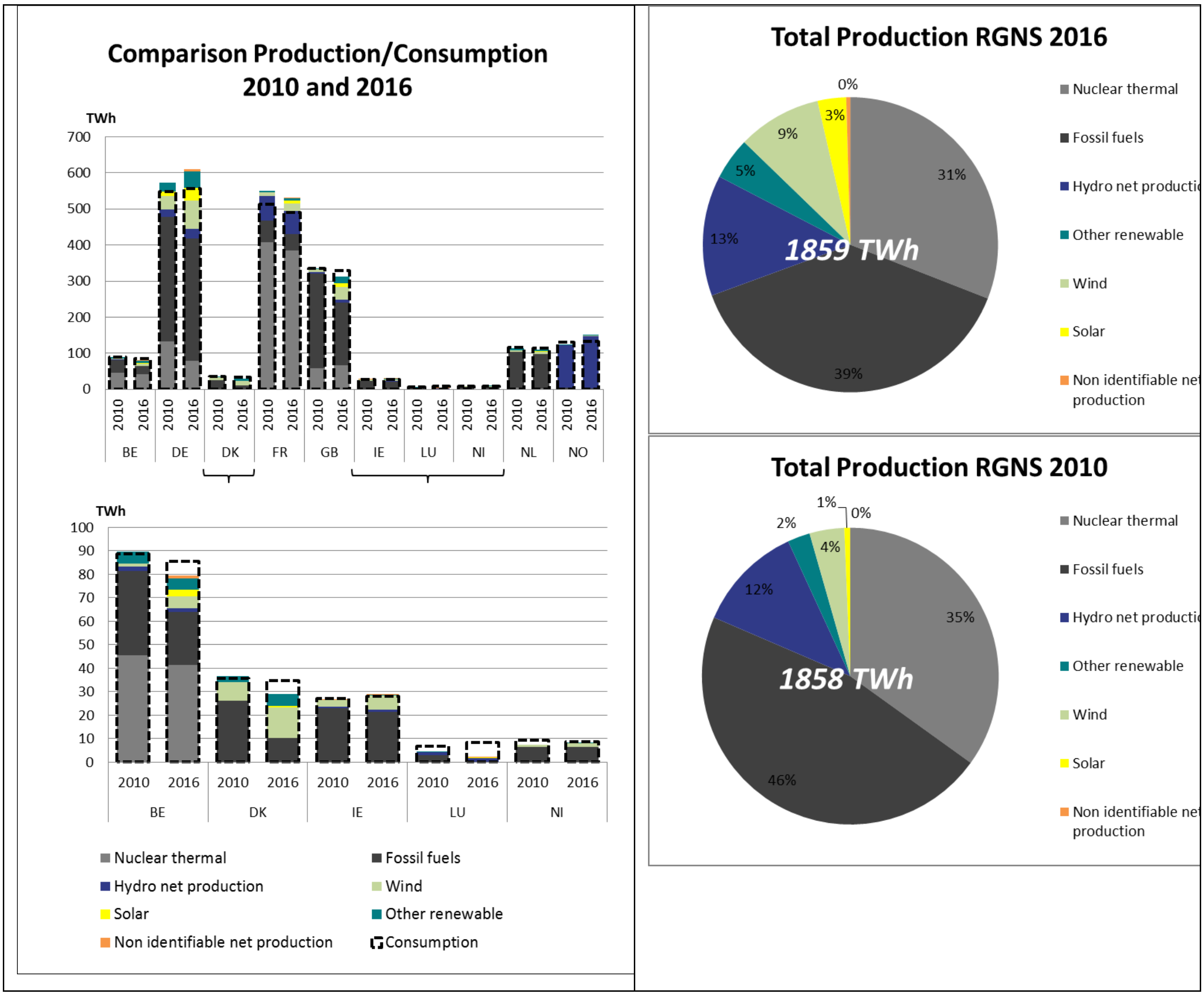

Figure 3-3: Annual generation by fuel type and annual consumption in the North Sea Region in 2010 and 2016

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3.1.3 Interconnection capacity in the region

Figure 3-4 shows the level of Net Transfer Capacity (NTC) in 2016 within the North Sea Region. These NTC values reflect that from a market integration perspective the continental system is strongly interconnected via AC interconnectors, while there are a number of offshore HVDC interconnectors linking Ireland and Great Britain, and also the Nordic system, to the continent.

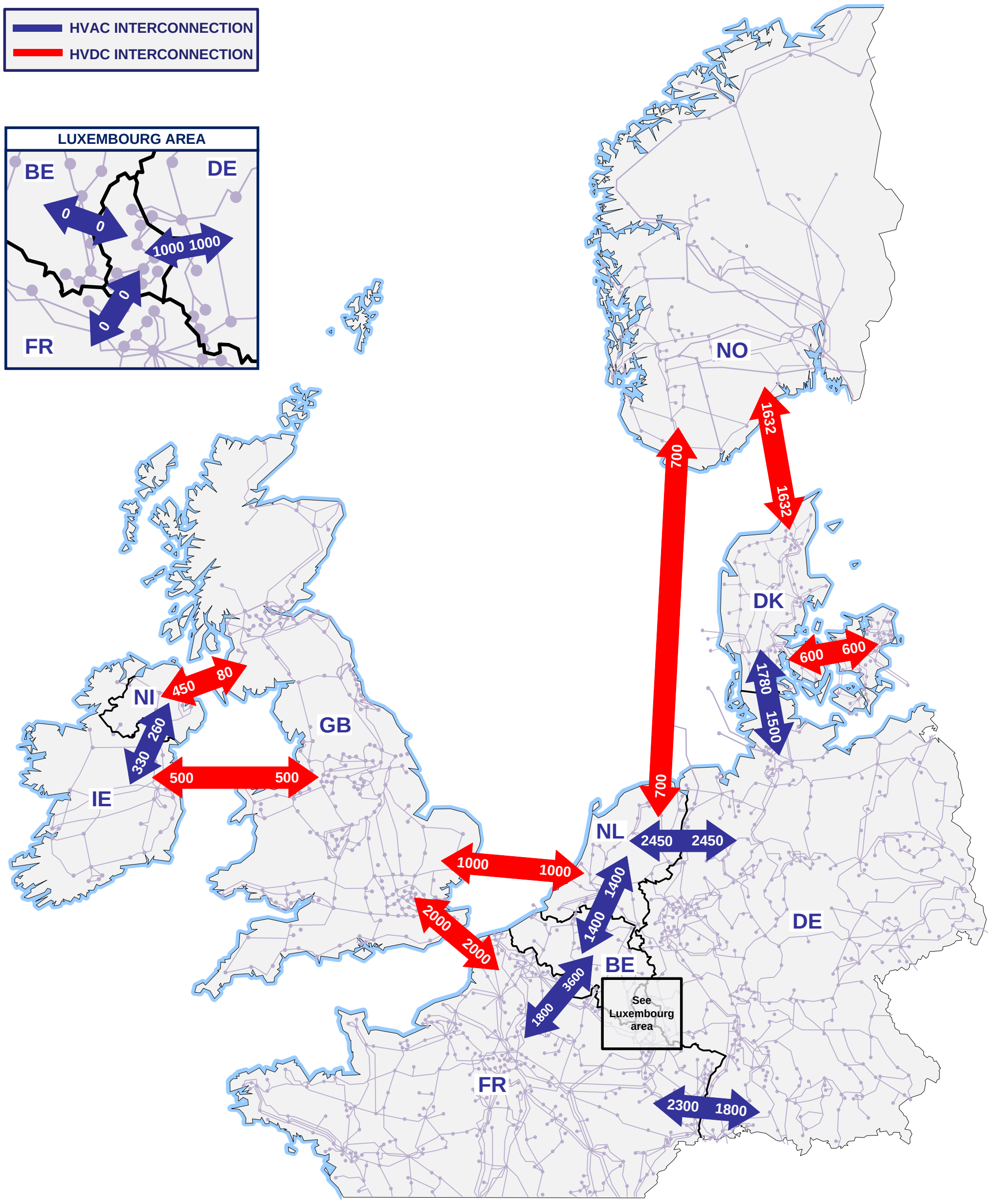

Figure 3-4: Current transfer capacities in the North Sea Region (source: derived from MAF2017[2])

Figure 3-5 shows the change in annual physical flows in GWh across the borders in the North Sea Region, comparing 2010 and 2015.

[2] transfer capacities as published in the MAF17 for 2020 time horizon minus the projects being commissioned between 2017 and 2020

There has been an increase in flows from Norway towards the continental system. Within the continental system, France continues to mostly export to neighbouring countries. There has been a large increase in imports into the Netherlands, mainly from Germany, where the large increase in renewables is driving an increase in exports from the country. From the Netherlands, there is an increase in flows to Belgium and, with the introduction of interconnection, to GB. Exchanges from France to GB have significantly increased. Flows to GB are likely driven by the closure of coal plants. With the introduction of interconnection, there are now exchanges between GB and Ireland. Exports from GB to NI reduced in 2015 compared to 2010, primarily due to a reduced availability of the interconnector in that year.

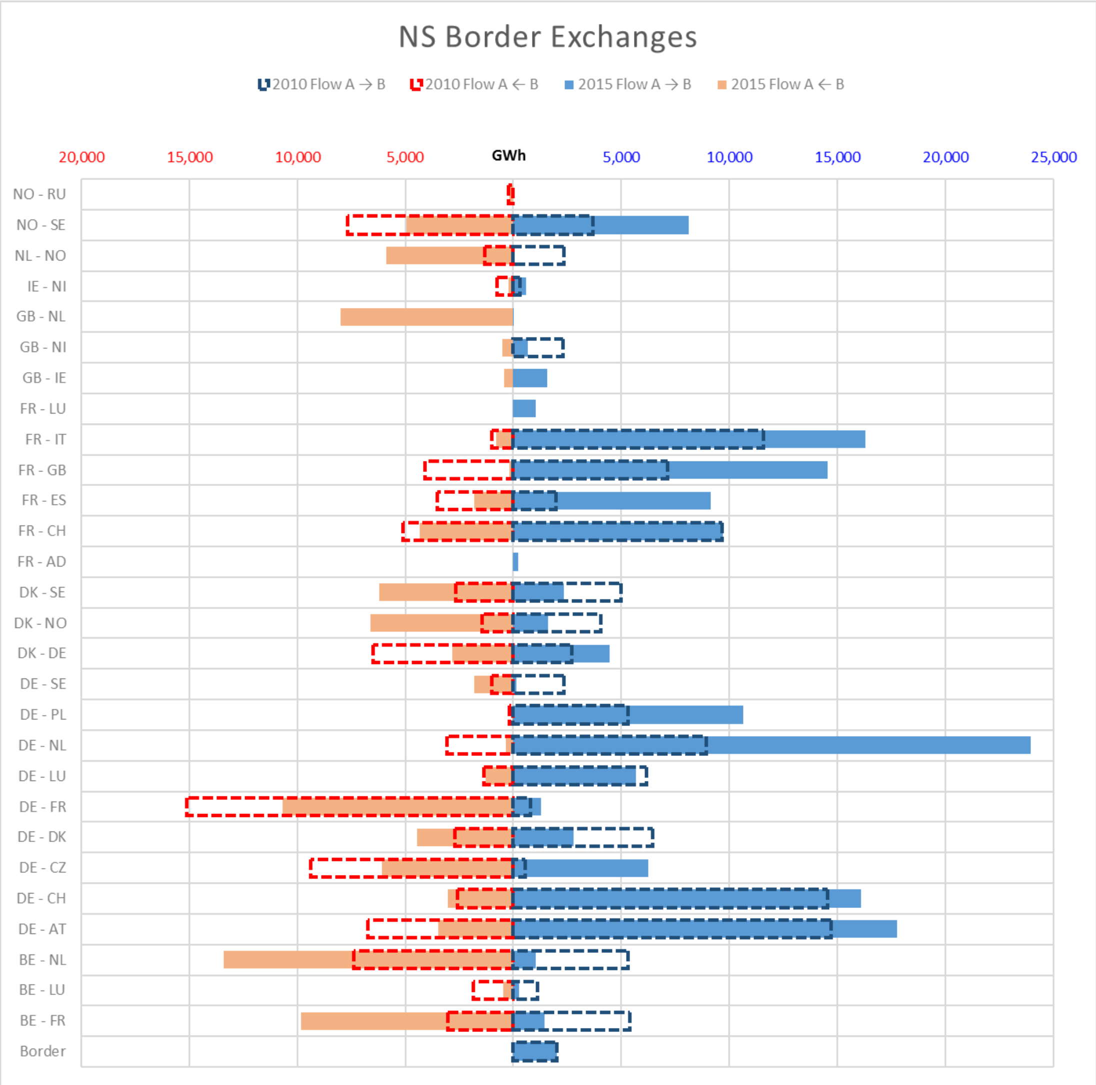

Figure 3-5: Annual cross-border flows, in GWh, in the region for 2010 and 2015 (source: ENTSO-E fact sheets)

3.2 Description of the scenarios

A detailed description of the scenario creation is available in the TYNDP 2018 Scenario Report[3]. This chapter summarises the process and puts it into regional context.

The Figure 3-6 gives an overview about the timely related classification and interdependencies of the scenarios in the TYNDP 2018 report and shows the transition from the actual situation, including the time points 2025 and 2030, to the year 2040.

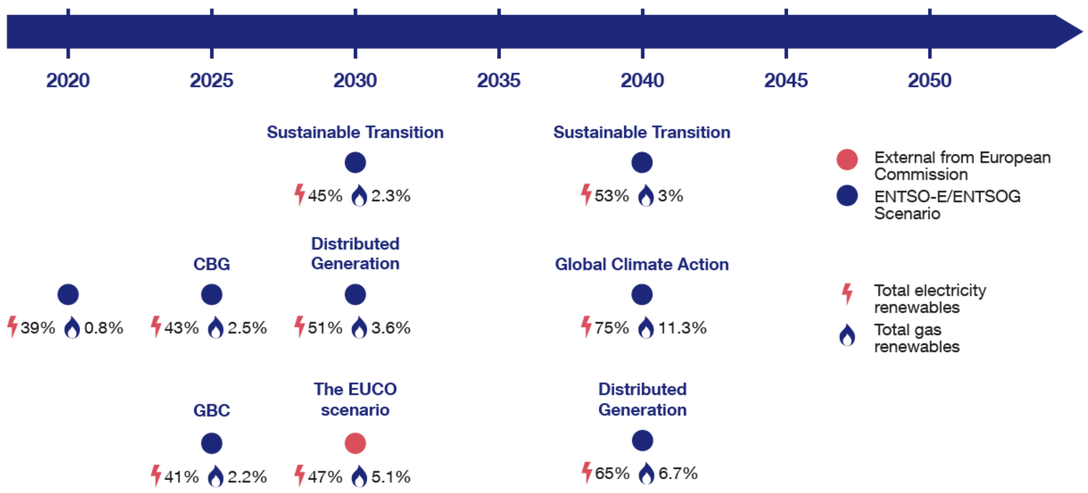

Figure 3-6: Scenario building framework indicating Bottom up and Top Down scenarios.

During the scenario building process two types of optimisation are applied:

1. **Thermal optimisation** of the thermal plant portfolio. Power plants which are not earning enough to cover their operating cost are removed. New power plants are added subject to a cost and benefit analysis. The methodology ensures a minimum adequacy of production capacity in the system with a maximum of allowed three hours energy not served (ENS) per country.
2. **RES optimisation** of the location of RES generation (PV, onshore and offshore wind) in the electricity system to maximise the value of RES production. This methodology was previously used in TYNDP 2016; however, it has been improved upon by utilising higher geographical granularity (additional nodes in the market model) and by assessing more climate years.

All 2040 scenarios are built using a top down approach with the data derived from the 2030 data set, as demonstrated in Figure 3-6. Boundary conditions of the scenarios are outlined in the following subsections.

[3] TYNDP 2018 Scenario Report: https://tyndp.entsoe.eu/tyndp2018/scenario-report

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3.2.1 Global Climate Action

Scenario "Global Climate Action" is based on a high growth of renewable energy sources (RES) and new technologies with the goal to keep the global climate efforts on track with the EU 2050 target.

The "Global Climate Action" story line considers global climate efforts. Assumptions are that global methods regarding CO2 reductions are in place, and the EU is on track towards its 2030 and 2050 decarbonisation targets. An efficient European Trading System (ETS) is supposed to be 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 found and capacity for development is available. As a non-variable renewable, bio methane is also developed. Due to the focus on environmental issues, no significant investment in shale gas is expected.

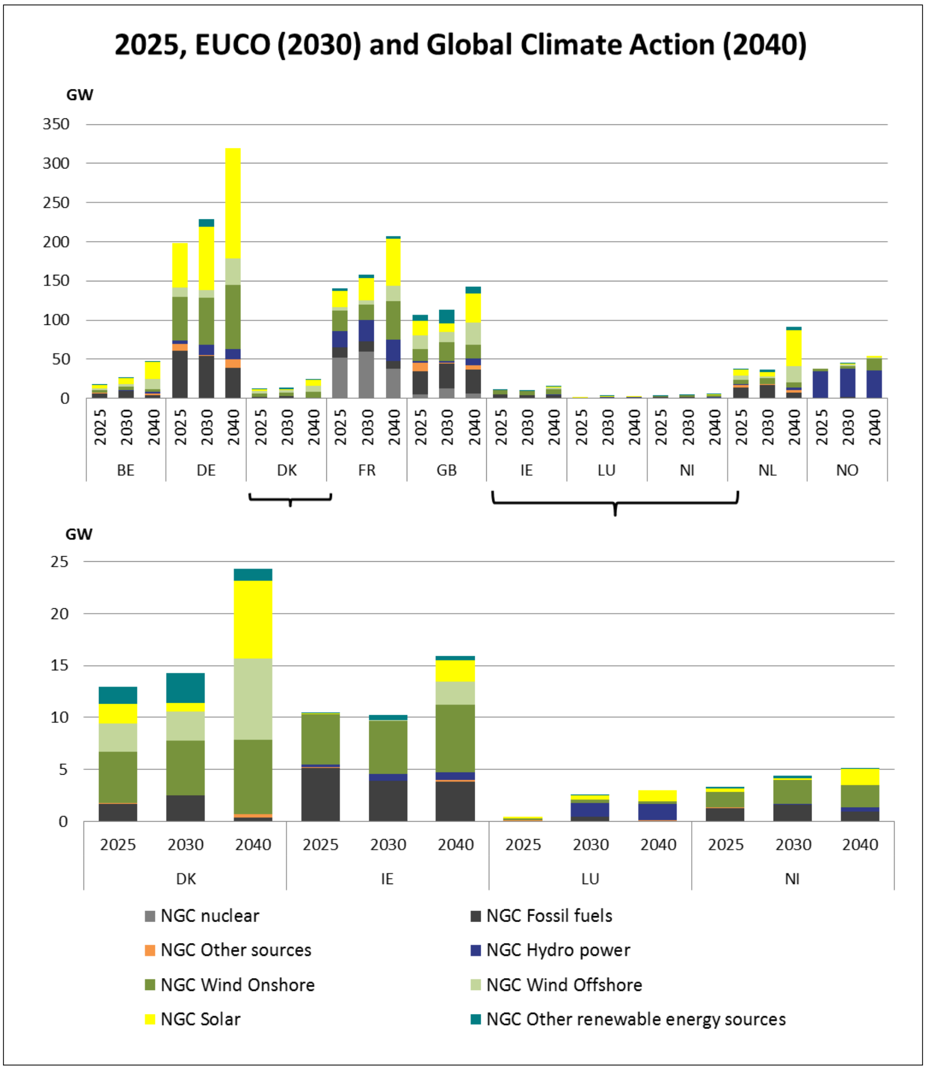

Figure 3-7: Installed generation capacities for scenario Global Climate Action[4]

The high growth of renewable generation for this scenario is very evident across the region. The most notable increase is observed in the large growth of solar generation by 2040. Germany, France, Great Britain and the Netherlands see large increases in installed solar capacity, with solar also more prominent in Denmark, Ireland, Northern Ireland and Belgium. There is a large increase in wind generation, both onshore (Germany,

[4] From 2025 to 2040, evolution could be non-linear as the approach to define each scenario can slightly differ: Bottom Up for 2025, External for 2030 and Top Down for 2040.

Ireland and Norway) and offshore (Germany, France, Great Britain, Belgium and the Netherlands). By 2040, the offshore wind generation capacity increases to 125 GW, the majority of which is located in the North Sea itself. This magnitude of development may lead to coordinated development amongst countries in the future. Several possible such scenarios are discussed in Chapter 5.

Between 2025 and 2040, there is a significant reduction in thermal and nuclear based generation. All nuclear generation is phased out in Germany and Belgium by 2025, alongside a reduction in nuclear capacity in France. In Great Britain there is an overall modest increase in nuclear generation by 2040. Thermal generation capacity has reduced in almost all countries by 2040. Overall, production fleets in the area will increasingly diverge between the countries.

Hydro remains the dominant source of generation in Norway by 2040, but there is development of onshore wind and solar generation.

Both Ireland and Northern Ireland see a decrease in thermal generation by 2040, and a notable increase in renewable generation capacity. This growth is driven by the aforementioned increase of solar generation, but also of hydro generation in both countries and significant development of offshore wind in Ireland.

Scenario “EUCO”

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

The EC’s scenario EUCO 30 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 upon by the European Council in 2014 but including energy efficiency target of 30%.

3.2.2 Sustainable Transition

Scenario “Sustainable Transition” primarily assumes moderate increases of renewable energy sources and moderate growth of new technologies in line with the EU 2030 target, but slightly behind the EU 2050 target.

In the scenario "Sustainable Transition" story line, climate action is achieved with a mixture of national regulation, emission trading schemes and subsidies. National regulation takes the shape of legislation that imposes binding emission targets. Overall, the EU is on track with 2030 target but resulting slightly behind the 2050 decarbonisation goals. However, targets are still achievable if rapid progress is made in decarbonising the power sector during the 2040's.

The trends observed in the region in the Global Climate Action (GCA) scenario are also seen in the Sustainable Transition scenario, but not to the same extent. Solar generation capacity increases in most countries, but not at the scale seen in the GCA scenario. Onshore and offshore wind development continues across the region, with 163 GW and 86 GW of capacity installed of each type respectively. Onshore wind provides the largest capacity of any generation type in Ireland, Northern Ireland and Denmark by 2040.

There is a reduction in thermal generation capacity across the region by 2040, but not to the same extent as observed in GCA. Nuclear again follows a similar pattern: a decrease in capacity in France and a modest increase in capacity in Great Britain. Once again, there is no nuclear generation capacity in Germany and Belgium across all time horizons.

Overall, in all countries, renewable generation capacity forms the majority of the full generation portfolio.

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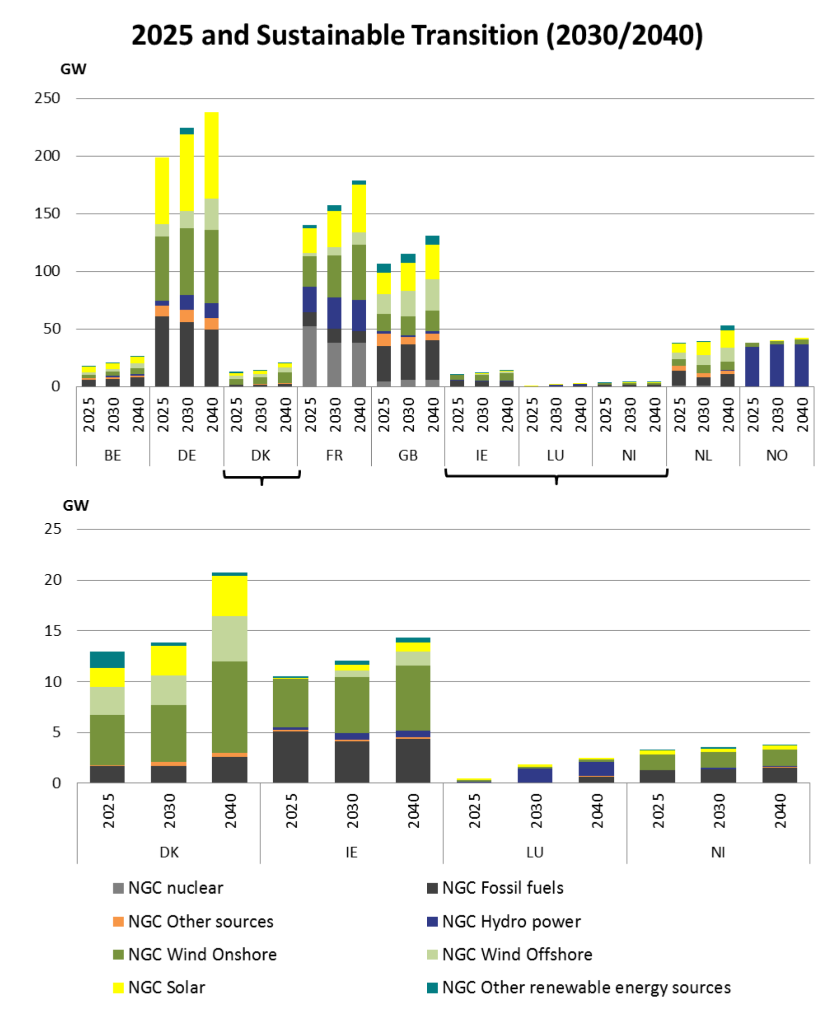

Figure 3-8: Installed generation capacities for scenario Sustainable Transition[5]

3.2.3 Distributed Generation

Scenario "Distributed Generation" covers a very high growth of small-size and decentralized often renewable based energy generation and energy storages including an increase of new technologies in the related area and is also largely in line with both the EU 2030 and 2050 goals.

In the "Distributed Generation" story line, 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 keeps the EU on track to 2030 and 2050 targets. A "prosumer" rich society has bought into the energy markets, so society is engaged and empowered to help achieve a decarbonised place to live. As a result, no significant investment in shale gas is expected.

[5] From 2025 to 2040, evolution could be non-linear as the approach to define each scenario can slightly differ: Bottom Up for 2025, Top Down for 2030 and 2040.

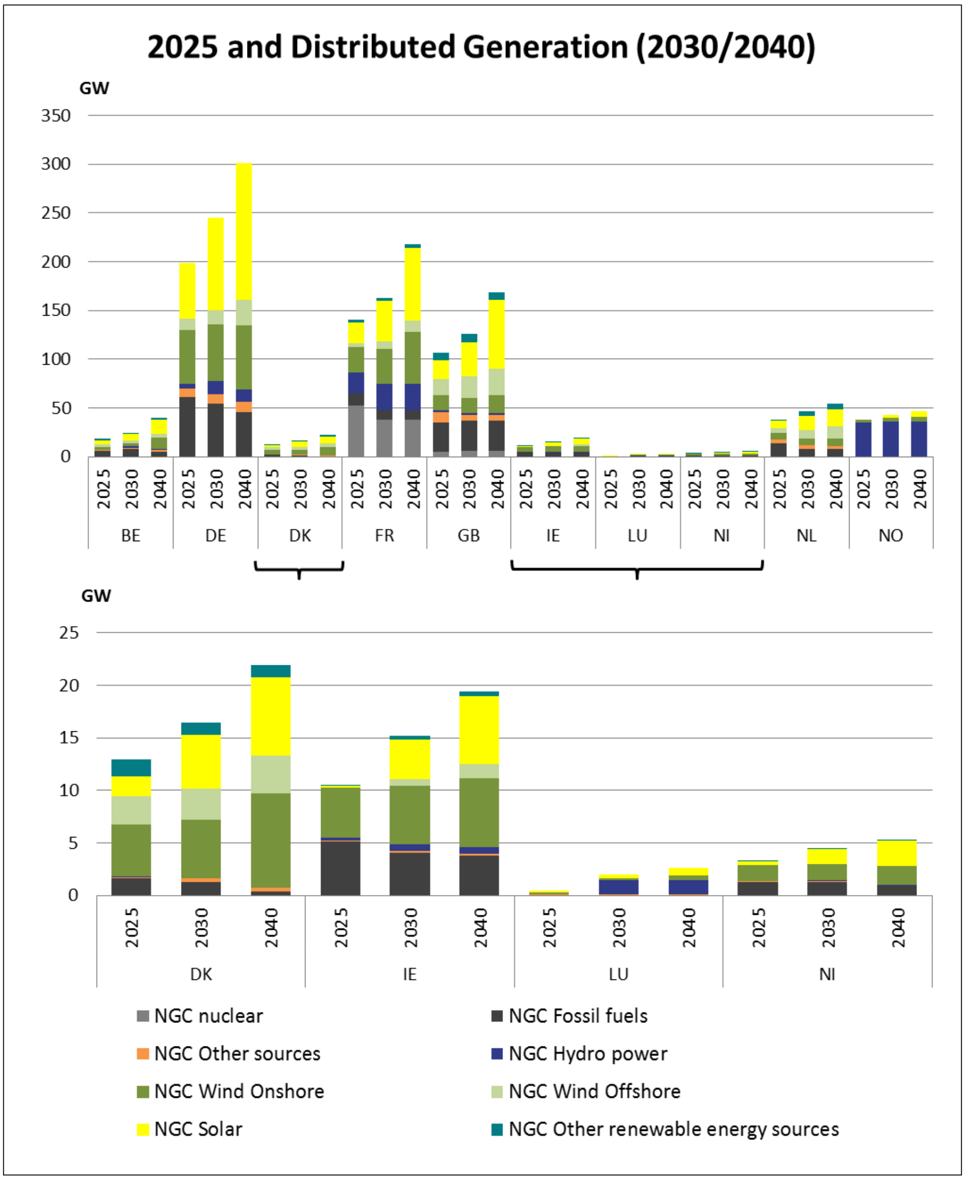

Figure 3-9: Installed generation capacities for scenario Distributed Generation[6]

In this scenario, there is a large increase in renewable generation across the region. With consumers playing a larger role in the energy market, domestic scale generation has increased significantly, and this tends to take the form of PV. As a result, all countries in the region see a large increase in the penetration of solar generation. Indeed, by 2040, it is the largest installed technology type in Belgium, Germany and Great Britain. The increase in other RES generation in France, Great Britain and the Netherlands is also indicative of the increased role of the consumer, as this generation includes small-scale biomass and biofuels.

The development of wind generation in the region (both onshore and offshore), and also thermal and nuclear generation, follows a similar pattern to that of the Sustainable Transition scenario.

[6] From 2025 to 2040, evolution could be non-linear as the approach to define each scenario can slightly differ: Bottom Up for 2025, Top Down for 2030 and 2040

3.3 Future challenges in the region

The European Market and Network Study Teams have carried out simulations mapping the 2040 scenarios against the expected 2020 grid.

These simulations reveal the challenges the future energy system would face without additional investments in electricity infrastructure beyond 2020:

- Poor integration of renewables (high amounts of curtailed energy);
- High CO2 emissions;
- High price differences between market areas;
- Modest Adequacy issues in several countries, (with the accepted ENS limit being violated in DE, GB, IE, NL);
- Flexibility issues and;
- Grid congestions: bottlenecks between market areas and inside these areas.

3.3.1 Market simulations on 2020 grid

The 2020 grid and its capability to support market exchanges is represented in the market model through the use of NTCs. The NTCs used as assumptions for the available market exchanges in 2020 are listed in Table 4-1. The charts in Figure 3-10 describe the regional challenges identified by the market simulations. The charts illustrate average results and ranges of simulations of three different climate years for all of the three long-term 2040 scenarios.

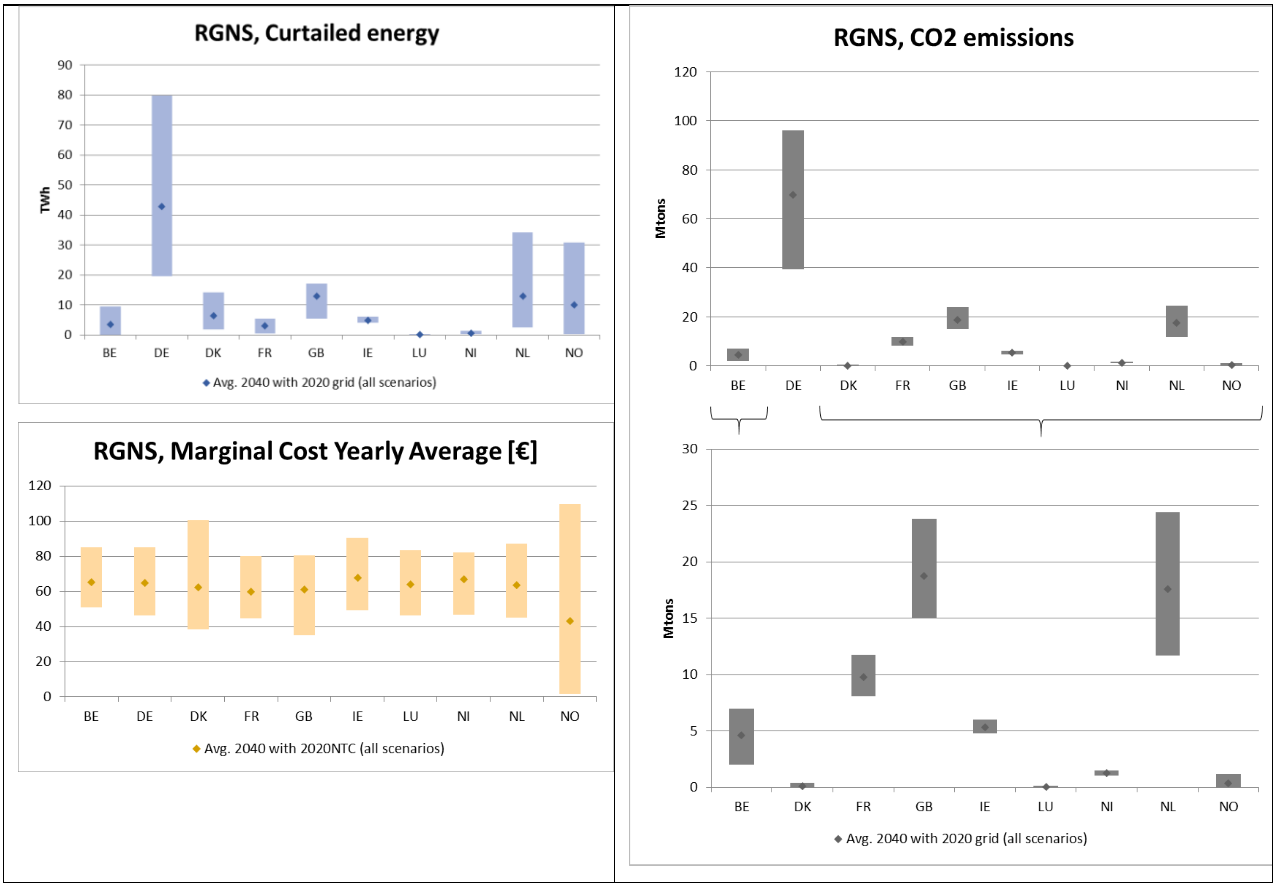

Figure 3-10: Results of Curtailed energy, CO2 emissions and Marginal Yearly Cost average

Poor integration of renewables

Figure 3-10 shows the average curtailed energy in the countries across the region for all scenarios. It also shows the range of curtailed energy across the scenarios. On average, countries are seeing between 3 TWh and 10 TWh of annual curtailed generation. In one case, Germany experiences almost 80 TWh of generation curtailment. This would equate to an average of over 9 GW of generation curtailment every hour of the year.

CO2 emissions

In the region, the highest emissions are to be found in Germany, as shown in Figure 3-10. Between 25% and 33% of German production is based on fossil fuels, as detailed in Appendix I of the Scenario Report. However, there is a large range of values for emissions depending on the scenario. Given the high curtailment of renewable generation in Germany, there is potentially a driver for new cross-border interconnection capacity to Germany. All other countries in the region see much lower emissions and a much tighter range across the scenarios.

High price differences

Figure 3-10 shows the average annual marginal cost considering all scenarios, and the range of average marginal costs across all the scenarios. There is a notable price convergence when simply considering the average price, with the marginal cost falling within €60 to €67. However, these prices are subject to change depending on the scenario. Nowhere is this more obvious than Norway, where there is a large range of costs depending on whether a wet or dry climate year is considered and its resulting impact on the hydro generation dispatch.

Figure 3-11 shows the average hourly price differences across the borders in the North Sea Region for all scenarios, and the range of price differences. These differences are examined in more detail in Figures 8-11, 8-12 and 8-13 in Appendix A.

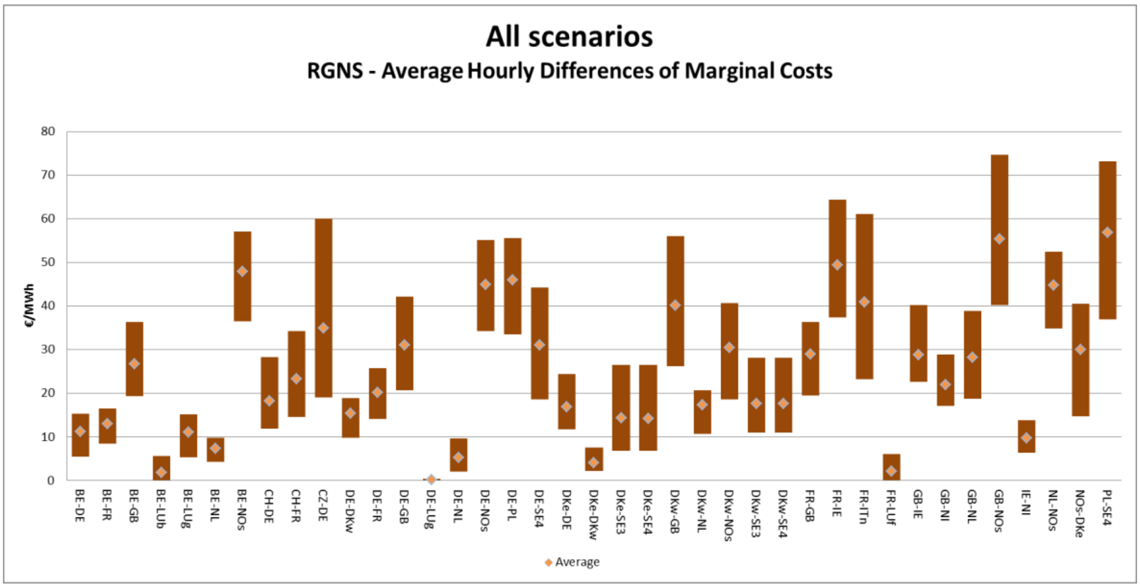

Figure 3-11: Average hourly price differences in the region for 2040 scenarios with 2020 grid

All three scenarios exhibit a common theme; namely, the highest average price differences are found between the more isolated systems of Great Britain, Ireland and Norway and the continental system.

Norway in particular sees some very high price differences to Great Britain in the Sustainable Transition and Distributed Generation scenarios. Unsurprisingly, the highest differences are observed during the 'dry' climate year of 1982. Norway also sees high price differences compared to the Netherlands and Germany.

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All three scenarios demonstrate significant price differences between Great Britain and the island of Ireland, and the continental system. This is unsurprising, due to the large quantities of renewable generation located in these islanded systems.

The continental system itself, being highly meshed and interconnected, exhibits much lower price differences between countries. At times there are still significant (> 10 €/ MWh) price differences between DK-DE; DK-NL; DE-FR; BE-FR.

Security of supply

Figure 3-12 shows the unserved energy for all countries in the region. The left-hand graph shows the total unserved energy in GWh in each country. Again, both the average value and the range for all the scenarios are shown. The right-hand graph shows the unserved energy as a percentage of each country's annual demand. As demonstrated in Figure 3-15, unserved energy is not a significant concern. The highest value, 67 GWh in GB, represents approximately 0.2% of the country's annual demand. The key reason why there is no significant security of supply issue is the fact that the scenarios are constructed to be in line with adequacy standards. To reach these adequacy standards, new flexible thermal generation is assumed in the scenarios. This new thermal generation is not necessarily economically viable in an energy-only market, hence, (partially) relying upon capacity remuneration mechanisms.

Thanks to the sharing of resources, interconnectors ensure security of supply in a more cost-effective manner compared to an isolated approach, which requires greater installed generation capacity at an individual country level.

Alternatively, if the level of installed generation capacity is maintained, the addition of additional interconnection capacity will reduce the amount of unserved energy. This effect is illustrated in Chapter 4 when comparing the unserved energy between the levels of interconnection capacity assumed in 2020 and in 2040.

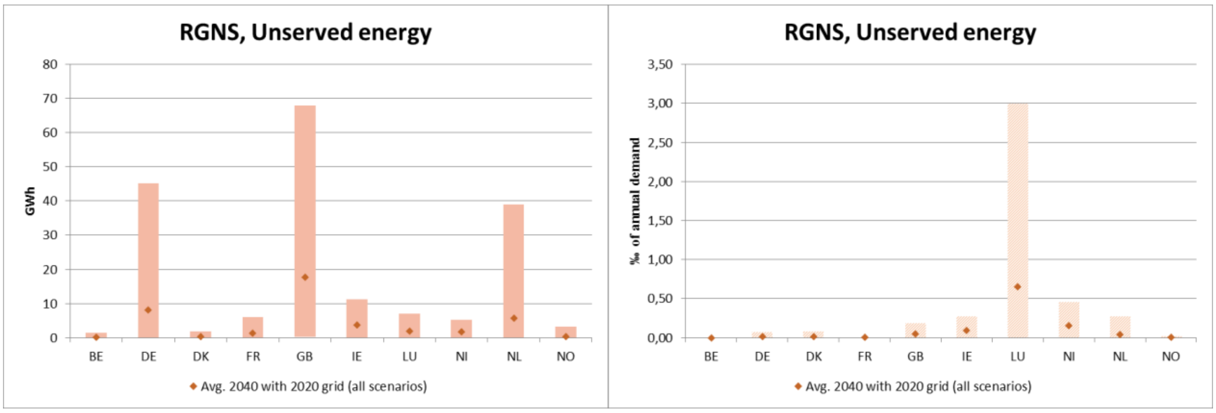

Figure 3-12: Unserved energy in the region, in energy terms (left) and as percent of demand (right)

Flexibility

Figure 3-13 highlights the challenge facing TSOs in maintaining system balance with large quantities of installed variable renewable generation. The load ramps shown represent the nine worst hours of the year. All countries experience large ramps when considering their peak load. In Germany, there is an average load ramp of 41GW across the scenarios for the percentile studied. This compares to the peak load in Germany of ~85 GW. Denmark experiences an average load ramp of 5.9 GW for the same scenarios, compared to a peak load of ~6,5 GW. These large ramps result from the sudden change in variable generation coupled with a change in load. This type of phenomenon is already observed with the installation of solar generation, resulting in the so-called duck curve of daily demand; solar generation output at midday leads to a large drop in load requirements, while the drop in solar output in the late afternoon coupled with the rise in evening demand leads to a steep ramp up in demand.

The results show load ramps that could not be met with a country's installed thermal generation and indicate an increased need for flexibility across the region, which could be provided by various sources, including additional interconnection, storage, fast acting peaking generation and demand side response.

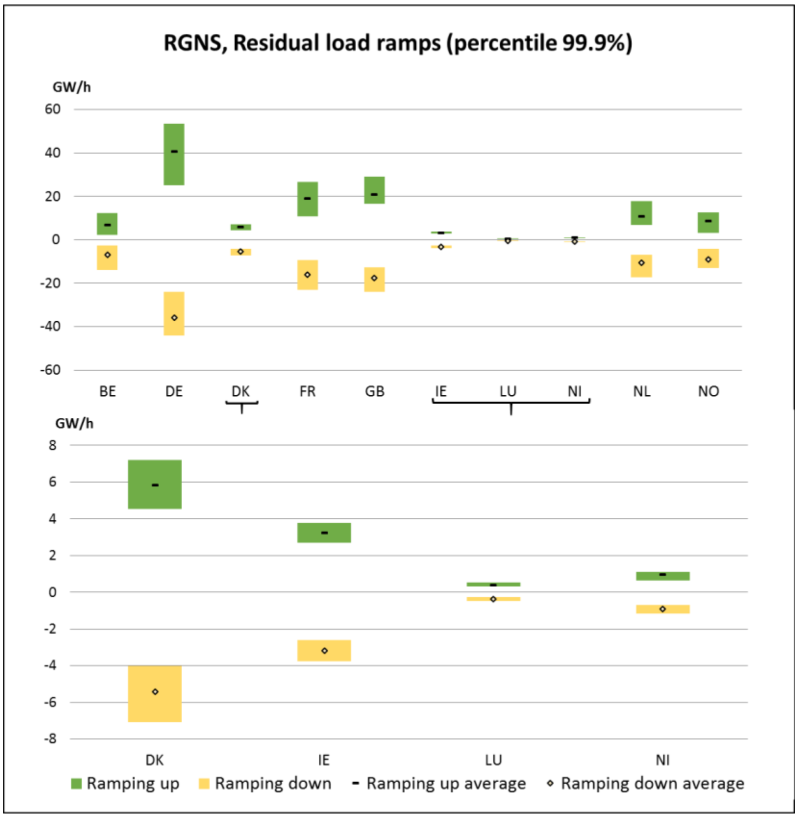

Figure 3-13: Residual ramp loads in the region for 2040 scenarios with 2020 grid

3.3.2 Network simulations on 2020 grid

Network studies carried out during the Identification of System Needs (IoSN) have been focused on the ability of cross-border ties, and internal TSOs' networks are able to accommodate the energy transition by 2040 in the scenarios at stake.

The market simulations deliver the hourly load and generation dispatch, which is used as an input by the network simulations to estimate the resulting power flows in the grid. The network simulations subsequently evaluate these power flows against the ability of the grid to transport them. This leads to the identification of congested areas in the grid, i.e. areas where the grid is not strong enough to transport the power flows and consequently acts as a bottleneck for the energy transition. Figure 3-14 illustrates the state of the cross-border connections, while Figure 3-15 highlights the state of the internal grids.

The result of the application of 2040 scenarios to 2020 grids can be analysed as follows:

1. Cross-border exchange capacities turn out to be generally insufficient to allow optimal cross-border exchanges resulting from economical operation of the European generation mix.
2. At the same time, even in the absence of additional cross-border capacity increases, the internal networks need reinforcements to accommodate the flows resulting from the new generation mixes described in the scenarios and leading to larger and more volatile flows crossing Europe.
3. Due to its highly meshed structure, dense population and central location within the North Sea area, the congestions are most pronounced in the Central Western Europe area. The fact that congestions are observed with a fully intact network, i.e. a network in N condition with no planned or unplanned outages, is a strong signal that investment in the grid is required.

The maps below show network study results of the 2040 scenario market data implemented in a 2020 network model. Figure 3-14 shows overloads on cross-border lines. In general, the interconnections are challenged in the 2040 scenarios by larger and more volatile flows and higher distances flows crossing Europe, due to the intermittent renewable generations. The maps in Figure 3-15 show the need for internal reinforcements for some of the same reasons as for the cross-border connections and to integrate the considerable amounts of additional renewable power generation.

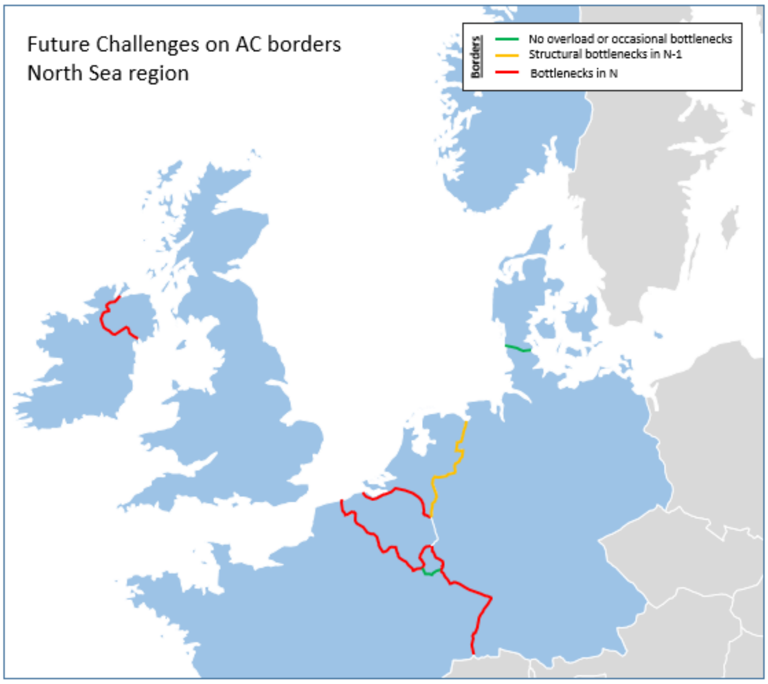

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Figure 3-14: Future Challenges on AC Borders

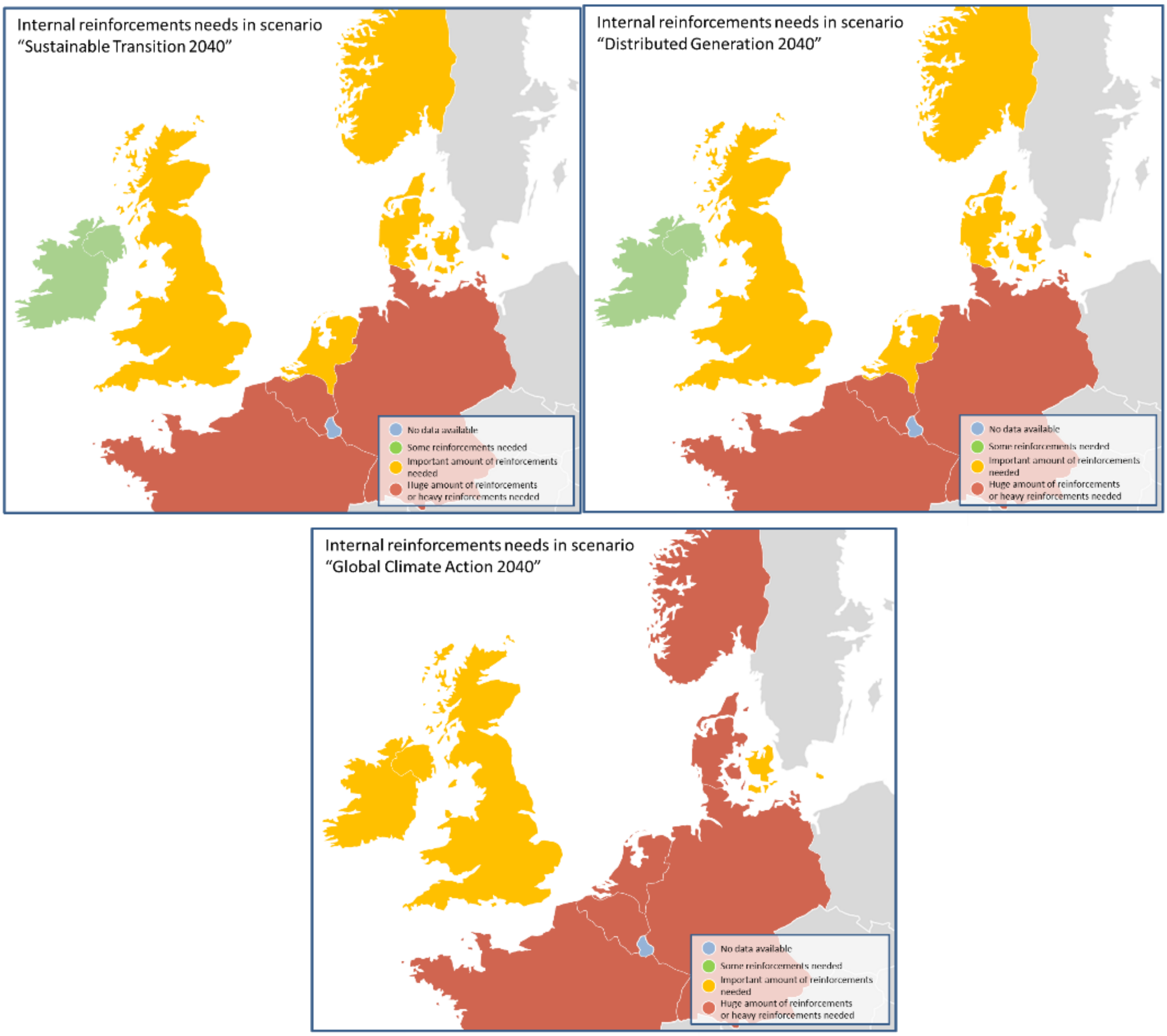

Figure 3-15: Future challenges inside the countries

4 REGIONAL RESULTS

This chapter shows and explains the results of the regional studies and is divided into four sections. A description of the methodology can be found in the IoSN report.

Subchapter 4.1 provides future capacity needs between market areas as identified by the market simulations during the IoSN process.

Subchapter 4.2 explains the regional market results in detail, whereas Subchapter 4.3 delivers a complementary view on the future capacity needs between and within market areas through network analysis.

Subchapter 4.4 introduces a methodological improvement for IoSN. The improvement consists in fostering an enhanced representation of the grid within the market simulations. In general terms this is referred to as flow-based market modelling (as used in the E-Highway 2050 study http://www.e-highway2050.eu/e-highway2050/).

4.1 Future additional cross-border infrastructure needs

The energy system of the North Sea Region is undergoing a transformation. Over recent years, onshore wind capacity has been developed at an increasing rate. More recently, in parts of the region, offshore wind generation and solar generation are being developed in significant quantities. This development of renewable generation provides the region with increased amounts of 'clean' generation. In addition, the thermal generation might be phased out and partly replaced by new peak units in the models during the thermal optimisation process. Finally, the nuclear generation across the region undergoes a major restructuring (see Chapter 3).

In addition, energy consumption across the region is undergoing a transformation, both regarding electrification in industry and transportation, as well as consumers becoming part of the production system (prosumers).

The potential changes of both the generation and consumption are described in the first phase of the TYNDP 2018 process, building new scenarios for 2030 and 2040 (see Chapter 3, building on the scenario report [link]) and assessing system needs for the long-term horizon 2040. As part of this work, cross-border capacity increases, which have a positive impact on the system, were identified. A European overview of these increases is presented in the European System Need report [link] developed by ENTSO-E in parallel with the RegIPs. Identified infrastructure capacity increases between market areas for the North Sea Region are shown in Figure 4-1. The system needs for the 2040-horizon were identified with respect to (1) market integration/socio-economic welfare, (2) integration of renewables and (3) security of supply. For the North Sea Region, the 2040-needs are mainly being described through:

- Further integration between Norway and Great Britain, due to price differences and due to the need for flexibility to optimise the RES generation (hydro/wind).
- Further integration between Norway and the synchronous Continental system (Denmark and Netherlands), due to price differences, due to the need for flexibility to optimise the RES generation (hydro/wind) and due to challenged Danish and Dutch security of supply in high demand and low variable RES (wind and solar) periods.
- Further integration between Great Britain and the Continental system (France, Belgium, Netherlands), due to price differences, due to better optimisation of the RES generation and due to challenged security of supply during periods with high demand and low variable RES (wind and solar).
- Further integration between Germany and France, Belgium, Luxembourg and the Netherlands (east-west and north-south) due to price differences, better optimisation of the RES generation and the

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potential to optimise the sharing of resources in order to ensure security of supply in the most cost-effective manner within CWE.

- Further integration between Ireland and Great Britain/France due to price differences, optimisation of the RES generation and challenged security of supply in low-wind periods.

Figure 4-1 shows the needs for cross-border capacity increases beyond the expected 2020 grid for each 2040 scenario. While mature projects from earlier TYNDPs have been added directly, other increases are shown together with the need(s) they fulfil according to the “IoSN methodology”. This comprises needs triggered by market integration (SEW) in the first instance, and subsequent and further needs triggered by security of supply (SoS) and/or renewable integration (RES) requirements.

The ratio between costs and benefit can be decisive for pursuing the development of these potential reinforcements. An overview of the standard costs used during this process can be found in Appendix 8.1.5.

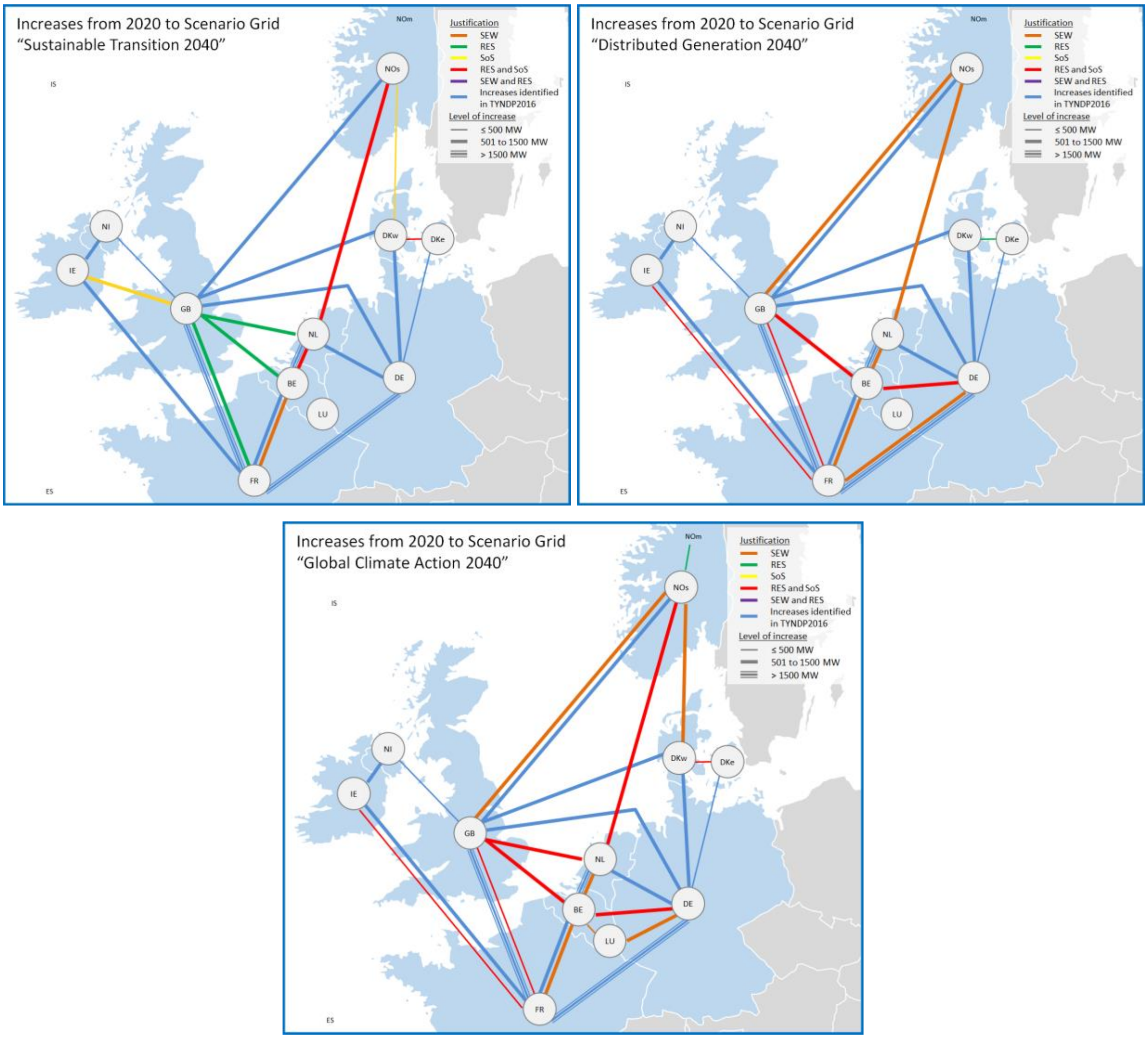

Figure 4-1: Identified capacity increase needs in the three studied 2040 scenarios in NS Region[7]

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

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The pathway towards 2030-2040-2050 is not set in stone and therefore the approach to develop the future grid is a modular one, delivering optionality to policy makers and incorporating flexibility to manage changes as they come along. This principle is shown in Figure 4-2.

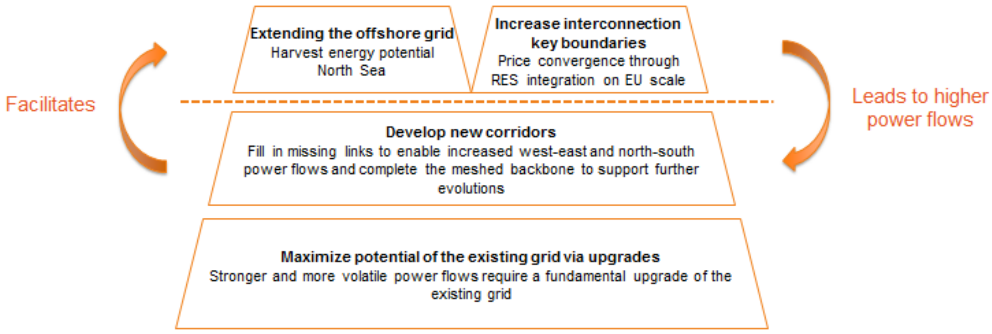

Figure 4-2: Future grid development pathway

The basis of the modular approach is looking for opportunities to maximise the potential of existing infrastructure, thus upgrading the capacity of existing substations and links. A typical example of reinforcing existing substations is the integration of phase shifting transformers, balancing the flows while making use of a continuously growing level of international coordination in grid operation.

Reinforcing the substations is a relatively low-cost investment enabling more efficient usage of the existing grid capacities. Yet in many cases, the existing connections simply require more capacity to transport the power flows. Recent evolutions in technology have made it possible to reinforce existing overhead lines in a cost-efficient manner. Thanks to the utilisation of higher capacity conductors, the capacity of existing overhead lines can be significantly increased up to double its capacity.

The development of new corridors is put forward if there remains a residual need for additional capacity. The analysis has indicated that, due to the scale and magnitude of the energy transition, reinforcing the existing substations and connections will not always be sufficient. In regions without existing infrastructure or high energy transfer, new corridors may be required.

From an acceptability point-of-view, new corridors are preferably developed as underground cable solutions. However, depending on the length of the connection, the voltage and the required transport capacity, this proceeding is not technically or economically viable. In many cases new overhead lines, eventually in combination with partial undergrounding, are the most appropriate solution. Subsequent studies will continue to monitor the needs and define the most appropriate solutions. This will be done in harmony with policymaking on European and national levels, which will continue to give shape to the (speed of) the energy transition, and in harmony with technological evolutions such as for example in the field on storage.

Table 4.1 shows different cross-border capacities as identified during the TYNDP 2018 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 2025 and 2030. These columns show the capacities of the reference grid 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 IoSN phase and are dependent on the scenario.

Table 4-1: Cross-border capacities expected in 2020, for the reference grid and identified during the IoSN phase

	NTC 2020		CBA Capacities		Scenario Capacities					
			NTC 2027 (reference grid)		NTC ST2040		NTC DG2040		NTC GCA2040	
Border	=>	<=	=>	<=	=>	<=	=>	<=	=>	<=
BE-DE	1000	1000	1000	1000	1000	1000	2000	2000	2000	2000
BE-FR	1800	3300	2800	4300	4300	5800	3800	5300	4300	5800
BE-GB	1000	1000	1000	1000	2500	2500	2000	2000	2000	2000
BE-LUG	300	180	300	180	300	180	300	180	800	680
BE-NL	2400	1400	3400	3400	4900	4900	4400	4400	4900	4900
CH-DE	4600	2700	5600	3300	6500	4100	6500	4100	6500	4100
CH-FR	1300	3150	1300	3700	2800	5200	3800	6200	3800	6200
CZ-DE	2100	1500	2600	2000	2600	2000	2600	2000	2600	2000
DE-DKe	600	585	600	585	600	600	600	600	600	600
DE-DKw	1500	1780	3000	3000	3000	3000	3000	3000	3000	3000
DE-GB	0	0	1400	1400	1400	1400	1400	1400	1400	1400
DE-FR	2300	1800	4500	4500	4800	4800	5800	5800	4800	4800
DE-LUG	1000	1000	1000	1000	2000	2000	2000	2000	3000	3000
DE-LUv	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
DE-NL	4250	4250	5000	5000	5000	5000	5000	5000	5000	5000
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-SE4	1700	1300	1700	1300	1700	1300	2700	2300	2700	2300
DKw-GB	0	0	1400	1400	1400	1400	1400	1400	1400	1400
DKw-NL	700	700	700	700	700	700	700	700	700	700
DKw-NOs	1640	1640	1700	1640	2140	2140	1640	1640	2640	2640
DKw-SE3	740	680	740	680	740	680	740	680	740	680
ES-FR-GB	0	0	0	0	0	0	0	0	0	0
ITcn-ITCO	300	300	400	400	400	400	400	400	400	400
FR-GB	2000	2000	6800	6800	6900	6900	5900	5900	5900	5900
FR-IE	0	0	0	0	700	700	1200	1200	1200	1200
FR-ITn	4350	2160	4350	2160	4350	2160	4350	2160	5350	3160
GB-IE	500	500	500	500	1500	1500	500	500	500	500
GB-IS	0	0	0	0	0	0	0	0	0	0
GB-NI	450	80	450	280	500	500	500	500	500	500
GB-NOs	0	0	2800	2800	1400	1400	2900	2900	2400	2400
IE-NI	300	300	1250	1200	1100	1100	1100	1100	1100	1100
NL-NOs	700	700	700	700	1700	1700	1700	1700	1700	1700
PL-SE4	600	600	600	600	600	600	600	600	1100	1100

* This capacity is used to connect the industrial grid in Luxemburg.

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4.2 Market results

This chapter shows the average results of the market simulations of all three 2040 scenarios with the 2040 scenarios grids in place. They complement those results in Section 3.3 and illustrate the impact of the increase in NTCs from 2020 values to 2040 values. These increases are shown in Table 4-1. The methodology is described in the "Identification of System Needs Report".

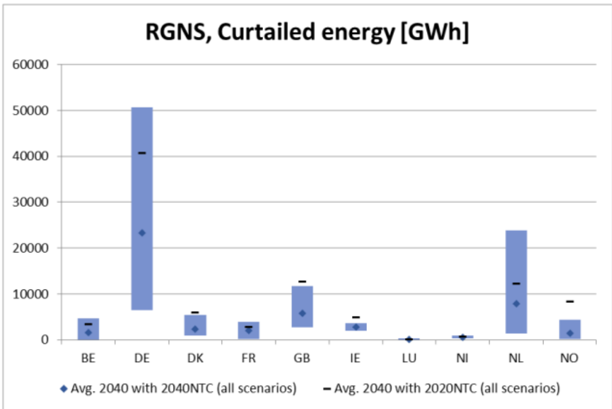

Figure 4-3: Curtailed energy in the three 2040 scenarios with identified capacity increases

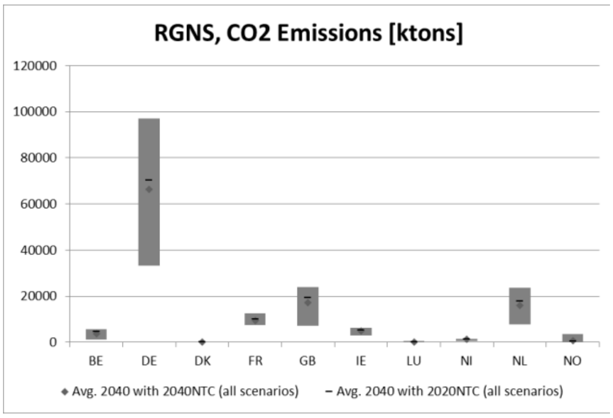

Figure 4-4: CO2 emissions in the three 2040 scenarios with identified capacity increases

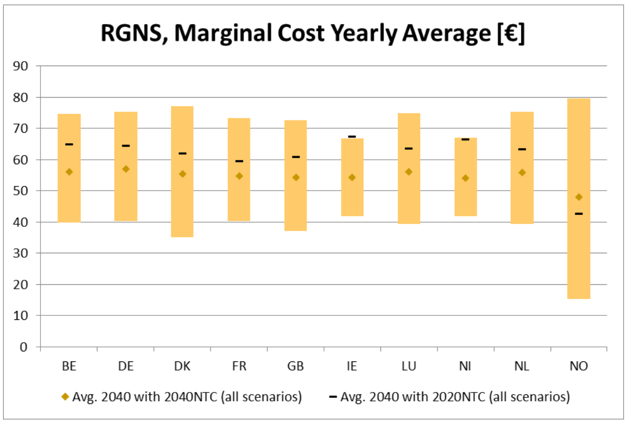

Figure 4-5: Yearly marginal cost average in the three 2040 scenarios with identified capacity increases

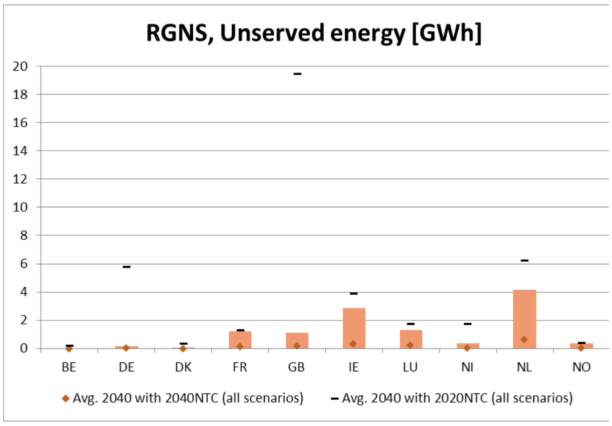

Figure 4-6: Unserved energy in the three 2040 scenarios with identified capacity increases

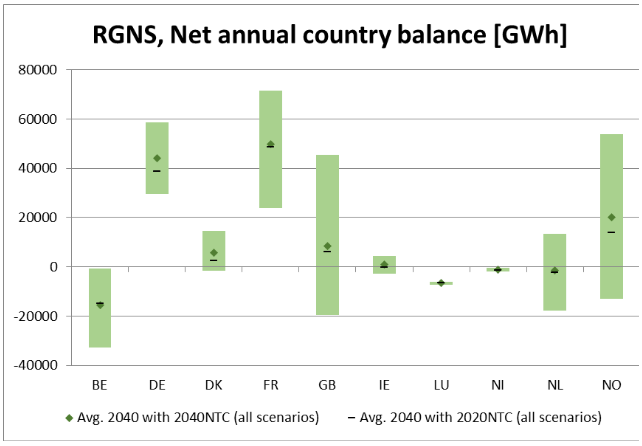

Figure 4-7: Net annual country balance in the three 2040 scenarios with identified capacity increases

4.2.1 An improved utilisation of renewables

Figure 4-3 demonstrates that curtailment has decreased across the region if the proposed grid reinforcements towards 2040 are realised. The most notable reduction is in Germany, where the average curtailment across the scenarios has dropped from 40 TWh with just the 2020 grid in place to 23 TWh when considering the 2040 grid. This is to be expected; additional interconnection between countries coupled with stronger internal grids allows countries to securely exchange power at times of surplus renewable output.

Despite the reduction in curtailed energy, it should be noted that there is still a significant amount of curtailment across the region, even with the 2040 NTCs in place. At times, surplus energy is being curtailed simultaneously in many countries across the region. In these instances, additional grid infrastructure may not be the optimal solution, and other options such as storage or power to gas may need to be considered.

Of course, the variable nature of most renewable generation, coupled with the large installed capacities in these 2040 scenarios, means that some level of energy curtailment will occur, as it is not economically viable to develop a system capable of exploiting the full annual output of this generation.

4.2.2 Decreased CO2 emissions

Figure 4-4 shows the impact on CO2 emissions if the proposed grid reinforcements towards 2040 are realised. Higher interconnector capacity will have some effects on the CO2 emissions, by allowing better integration of zero-emission renewables, as well as an increased use of gas instead of coal in thermal generation. The deployment of renewables has a higher impact than interconnectors on the CO2 emissions.

4.2.3 Improved market integration and decreased average price

On average, the price level of the countries in the North Sea Region are fairly close to each other in 2040 if the proposed 2040 grid is realised, as shown in Figure 4-5. Based on the scenario assumptions, Norway is expected to have a lower price than the other countries in the region. If the proposed 2040 reinforcements were not to be fully developed, the price differences between different countries are expected to be much higher.

As shown in Figure 4-8, the average price difference decreases if the 2040 grid is implemented. More interconnector capacity between countries will reduce price differences and develop a more effective and integrated market. Hence, it will be possible to import/export more power within a shorter period when the price differences are high, for example in dry years with higher price levels in the Nordic, or in periods when the variation in renewable production is high. The hydro based power market in the Nordics will be more integrated with the more thermal based market in continental Europe, and the price variation between dry and wet years will be lower.

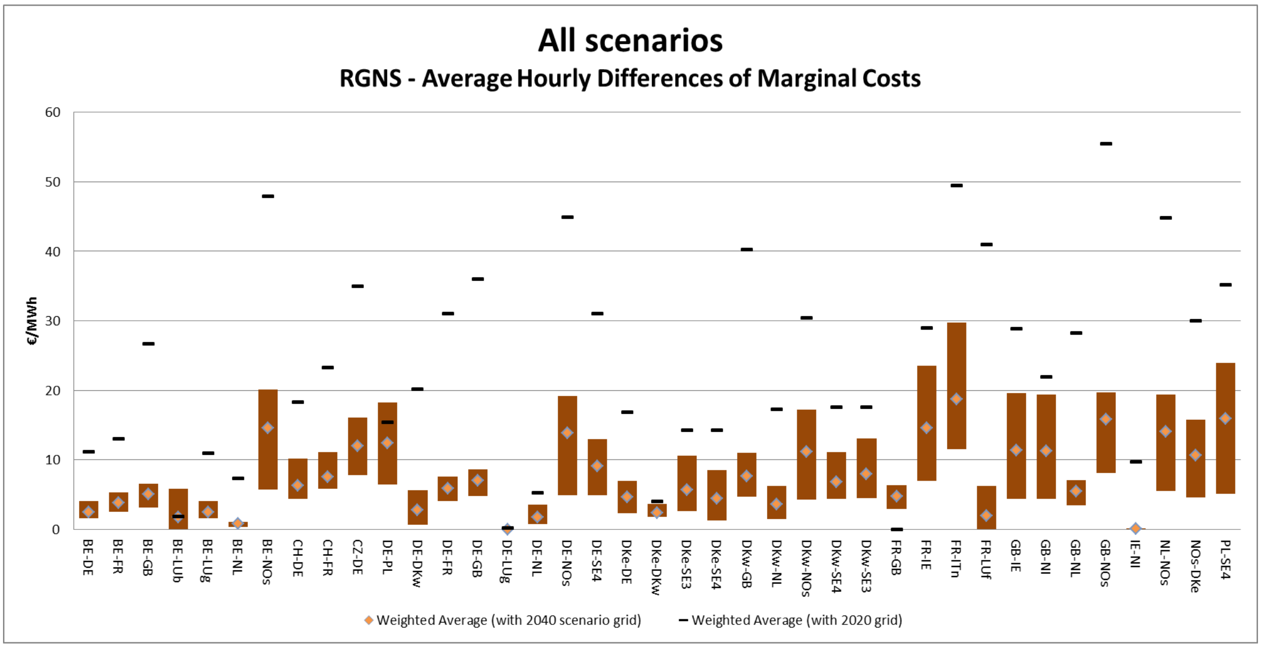

Figure 4-8: Average hourly price differences in NS region in the three studied 2040 scenarios with identified capacity increases

4.2.4 Capacity increases improving the security of supply

Figure 4-6 shows the impact on security of supply, measured through unserved energy, if the proposed grid reinforcements towards 2040 are developed. In line with the scenario design, the unserved energy was already insignificant when considering the 2020 NTCs (the highest recorded occurrence in GB accounting for 0.2% of the country's demand). Yet these results still demonstrate the principle that interconnectors contribute to ensuring adequacy through the sharing of resources. Based on the small numbers, unserved energy is not a very important indicator for greater interconnector capacity. There might be less expensive solutions to solve the unserved energy issue, e.g. investment in more production capacity, batteries or storage, demand response or load management.

Figure 4-7 shows the annual country balances (i.e. the remaining balance once all imports and exports into a country are considered). The results show, based on the scenario assumptions, that Germany, France and Norway are the main exporters within the North Sea Region. The annual country balance varies in wide range depending on the scenario, weather year (wet or dry) and the assumptions set for the study.

4.3 Network results

Chapter 3 illustrated that the grid is heavily congested in the new 2040 scenarios even before adding any further increase in cross-border capacities. In this chapter, the state of the grid is analysed for the resulting 2040 scenario capacities, thus including the increase in cross-border capacities as identified by the market studies.

The key findings are:

- The grid is heavily congested, especially in the CWE area, as it needs to accommodate both north-south and west-east power flows.
- These congestions are too strong to be solved only through optimisation of controllable devices.
- Structural grid reinforcements are thus needed to accommodate the expected power flows in 2040.
  - From north to south: additional corridors in DE, combined with upgrades of existing AC corridors (HTLS and PST measure) on the DE-NL and BE-NL borders, could evacuate more power flows. Reinforcement between northern DE to NL are even more useful when PSTs at the border between these countries are used to control the flows on the NL-DE border.
  - West to Northeast: from the NL/BE/FR coast further inland and onwards to DE/CH to evacuate power flows from the North Sea area (wind, UK/IE interconnections) and nuclear energy when FR is exporting, i.e. not in winter.

The next iterations of TYNDPs will give further shape to the 2040 grid architecture, identifying the most appropriate solution to alleviate the congestions. During this process it remains fundamental that the evolution of the interconnectors as well as the internal grids is synchronized across the region.

4.3.1 Expected power flows

The maps in Figure 4-9 and Figure 4-10 illustrate the power flows resulting from the 2040 GCA scenario capacities.

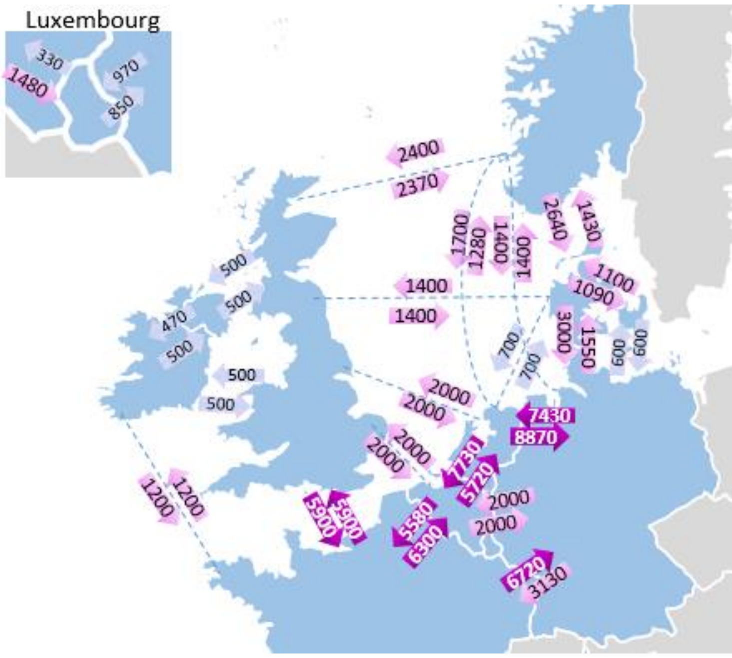

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Figure 4-9: Expected power flows in 2040 GCA scenario – 5th percentile (for both direction in MW) resulting from the 2040 scenario capacities

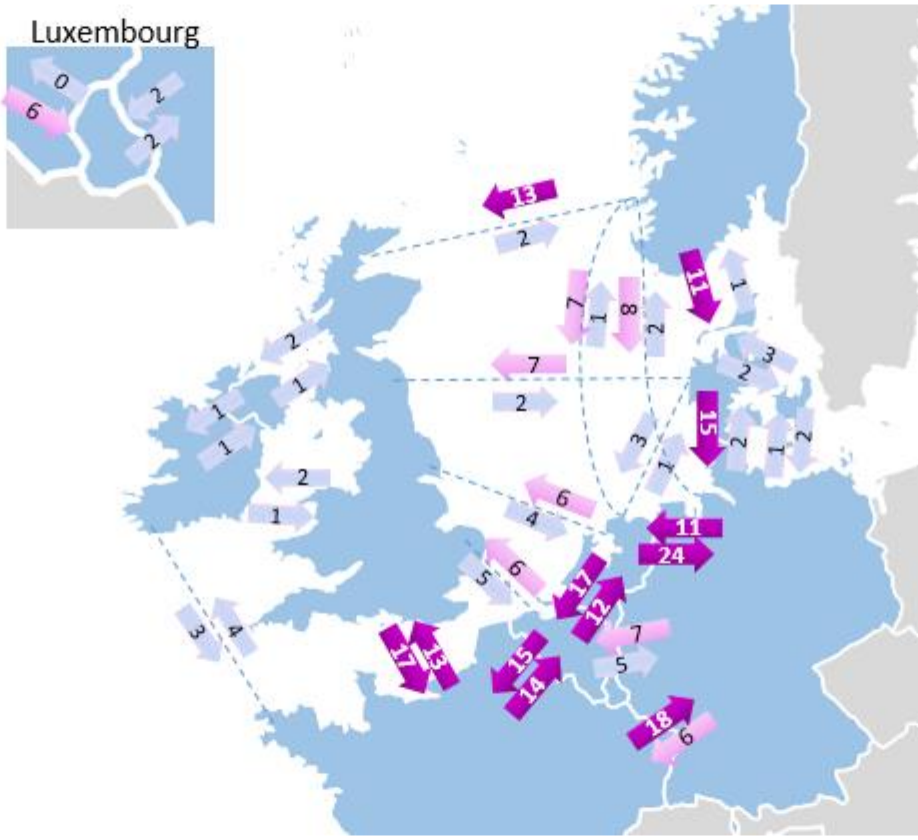

Figure 4-10: Expected power flows in 2040 GCA scenario – Yearly energy transfer (sum of physical flows, TWh) resulting from the 2040 scenario capacities

These figures illustrate that for the 2040 GCA scenario:

- At least 10% of the time (5th percentile values in each direction), the market uses the full capacity of the HVDC interconnectors. These are the connections between Ireland, Great Britain, the Nordics and the Continent as well as the connection between Belgium and Germany;
- The interconnectors between the Nordics, Great Britain and the Continent are predominantly used in export direction. Between Ireland, Great Britain and the Continent there is a quite balanced energy transfer on a yearly basis;
- The AC interconnectors on the DE-NL, BE-NL, FR-BE and FR-DE borders are facing high flows, with 5th percentile values around 5 to 8 GW. These flows are higher than the market capacities on the borders due to transit and loop flows occurring in a meshed network. Compared to the situation in 2015 (Figure 3-6), the yearly exchanges on these AC interconnectors strongly increase from ~10-25 TWh to ~25-35 TWh.

The power flows for the ST and DG 2040 scenarios are presented in Appendix 8.1.6. The power flows of the DG 2040 scenario are quite similar to the 2040 GCA scenario, while the power flows in the ST 2040 scenario are not as high for every border and direction as in the 2040 GCA scenario.

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4.3.2 Cross-border and internal congestions

The maps below are illustrative of the congestions detected on the Continent with the scenario capacities as displayed in Table 4-1. The gravity of the congestions is scaled using the FS^2 criteria; these criteria combines the frequency of a congestion (F) with the square of its severity (S^2).

The congestions displayed in Figure 4-11 are based upon the power flows from the ST 2040 scenario capacities and are for France, Belgium and the Netherlands generally representative of the power flows resulting from the DG 2040 and GCA 2040 scenario capacities. The key message is that with higher market capacities, the congestions become more pronounced.

The congestions in the Danish grid are more variable according to the scenario under analysis with no congestions in N state, and congestions in N-1 mainly occurring in the GCA 2040 scenario (see Appendix).

A further elaboration of these congestions and potential reinforcement measures can be found in Section 4.3.4.

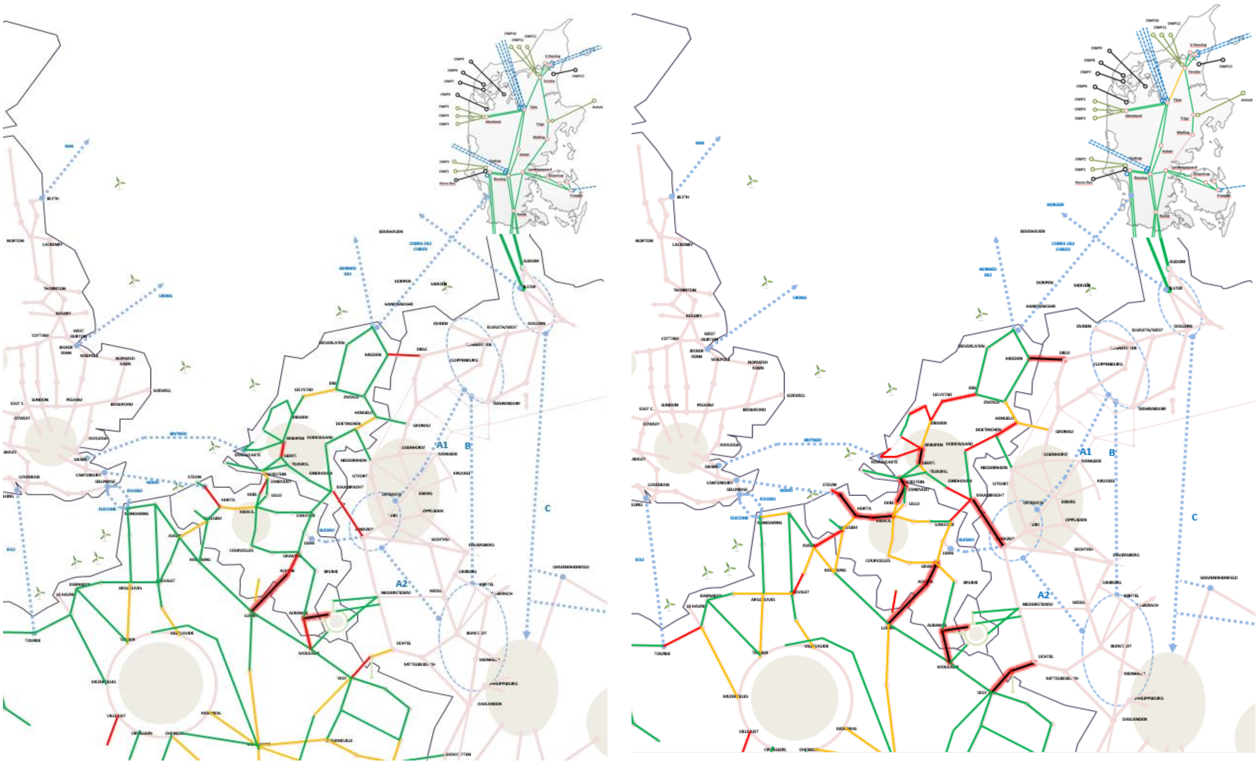

Figure 4-11: Congestions in the Continental grid in N state (left) and N-1 state (right) for the power flows resulting from the ST 2040 scenario capacities

4.3.3 Controllable devices

Controllable devices such as phase-shift transformers (PSTs) help to reduce congestion. An analysis has been performed upon the power flows resulting from the ST2040 scenario capacities, using the PSTs on the Belgium-France, Belgium-Netherlands, and Belgium-Luxemburg and Germany-Netherlands borders in a coordinated manner. For the sake of the exercise the full range of tap positions has been used.

Figure 4-12 illustrates the congestions both without (map on the left) and with (map on the right) PST optimisation. Congestions are again represented with the FS^2 criteria.

The key findings of the analysis are:

1. PSTs optimisation allows for an alternate distribution of flows in the region optimising the use of interconnectors as well as the internal grids. It must be noticed that no PSTs are yet installed on the FR-DE border, which explains why congestion is still active in the same range when comparing these two maps.
2. PST optimisation alone is insufficient to address the amount of congestions we are facing.

As congestion patterns are quite similar between the ST and DG and GCA scenarios, these findings are valid for all 2040 scenarios.

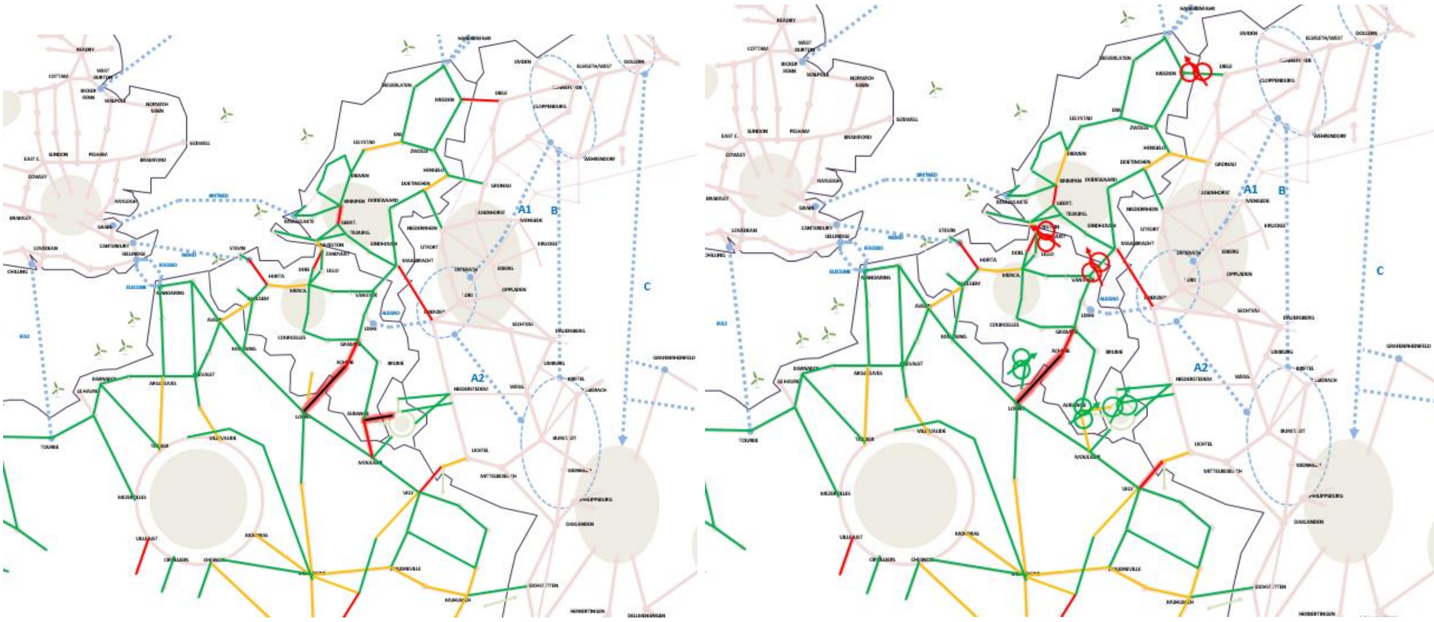

Figure 4-12: Effect of PSTs optimisation on grid congestion in CWE area (N situation for ST2040)

4.3.4 Description of the needed reinforcements

Due to a different mix of power plants and an increase of renewable energy plants being installed, the grid is already stressed in many parts even before adding the cross-border capacity needs identified by the IoSN study. Hence structural reinforcements are needed to make the 2040 scenarios safe.

The maps in Figure 4-13 give an appreciation of the additional amount of reinforcements required when adding the cross-border capacity needs as identified by the IoSN study. The reinforcements envisioned to make the 2040 scenarios safe can already incorporate (a large part of) the required transmission capacity to absorb the additional cross-border capacity increases. This explains the cases where countries are coloured red/orange in Chapter 3 and green here below.

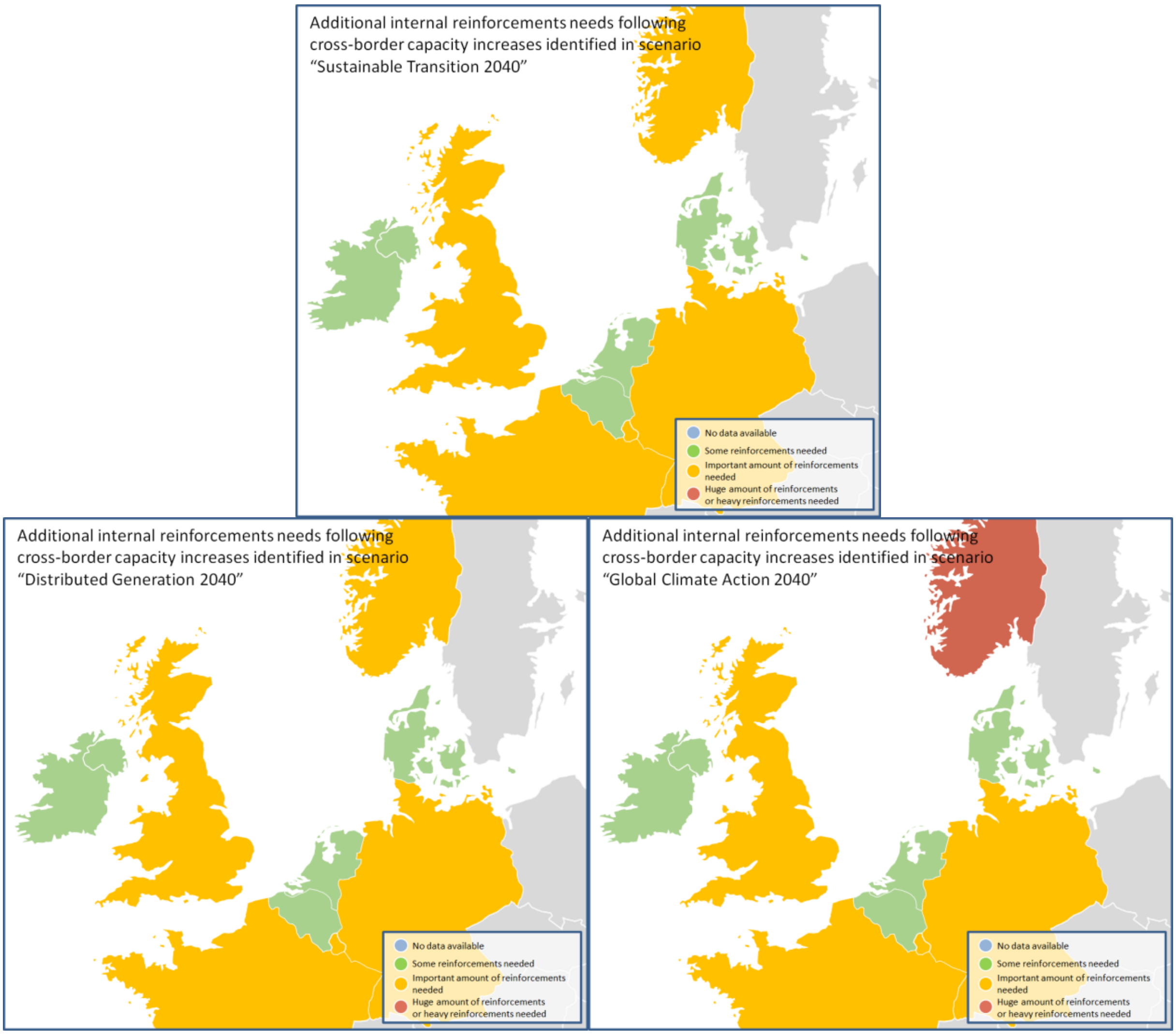

Figure 4-13: Impact of identified capacity increases on internal grid reinforcement needs in the three studied 2040 scenarios

Belgium

The Elia grid is highly loaded on both the north-south axis Netherlands-Belgium-France, and the west-east axis GB-Belgium-Germany, in both directions, combined with a significant increase of offshore wind power. Multiple reinforcements are being studied for implementation over the next 10 to 15 years.

These reinforcements, both internal grid and on the borders, will be integrated within the new national development plan which Elia is preparing for consultation around mid-2018.

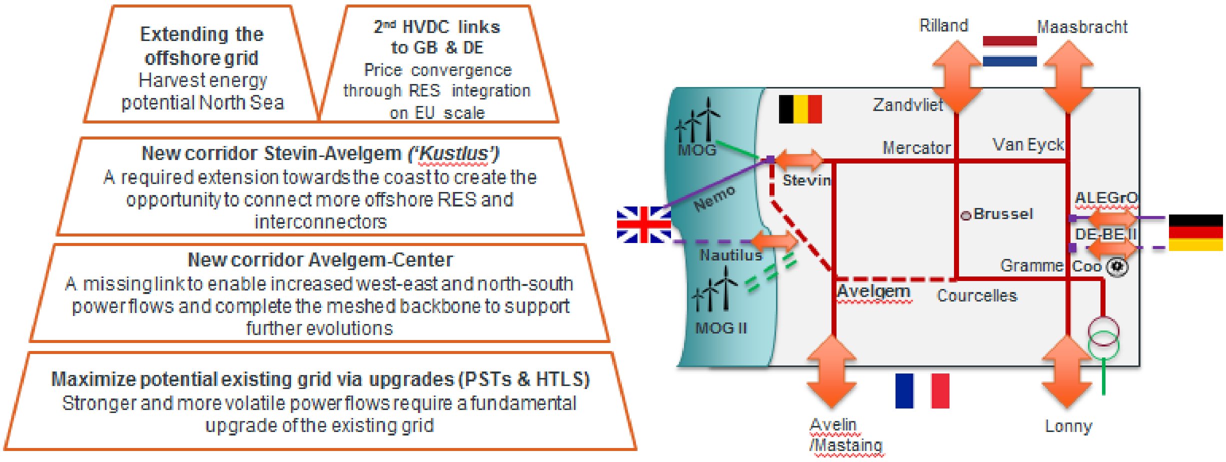

Figure 4-14: Evolution of the Belgian grid

Internal grid reinforcements

- An HTLS upgrade is studied for the VanEyck-Gramme-Courcelles-Mercator-VanEyck loop.
- A new ~6GW corridor between the Avelgem area to the Bruegel-Courcelles area allows alleviation of the high loading on the Avelgem-Horta-Mercator axis.
- Connecting the additional offshore wind requires the development of offshore infrastructure (MOG II) as well as an additional ~6GW corridor from Avelgem area to the coast, which should be linked with the first axis (Stevin).
- A possible increase of the pumped storage plant in Coo (connected to Brume, mainly in GCA2040) requires upgrades around Brume, on the Gramme-Brume-Aubange axis.

France-Belgium: The first step (already included in the grid model) consists of an HTLS upgrade on the western 380 kV lines FR-BE and PSTs on the 220 kV lines. From ~2025 onwards, the eastern 380 kV line FR-BE also will be overloaded after the planned closure of the nuclear power plants in Belgium. A short-term measure could consist of a PST to control the flows on this line. This is not a long-term solution, since the flow would be pushed towards the equally highly loaded border FR-DE. Long-term solutions are being analysed in a bilateral study with RTE and include further HTLS upgrades and potentially new interconnections.

Netherlands-Belgium: The western bottleneck close to the border inside Belgium can be covered by proper PST operation and topological measures. But optimising the existing PSTs NL-BE does not suffice in the long-term for the border itself. Already included in the grid model is a reinforcement of the western interconnection (Zandvliet-Rilland) with HTLS and additional PSTs. A similar reinforcement on the eastern axis (Van Eyck-Maasbracht) is to be studied and coordinated with further evolution on the DE-NL border.

DE-BE II and GB-BE II: 2nd HVDC interconnectors are under study, building upon the internal grid reinforcements to accommodate their additional power flows.

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Denmark

Concerning the west Danish power system (DKw), the studies carried out highlight the following:

Danish-German border

The technical rating of the cross-border lines which define the Danish-German border seems to be appropriate for handling the expected cross-border flows in the future, since no relevant congestions were identified for the three scenarios that were considered in the IoSN process.

Internal grid

In general, for the internal grid no major congestions need to be underlined in N condition among the three scenarios studied. However, it is true is that in a scenario where the interconnection capacity with Norway is increased and large wind power capacity is accommodated in the northern part of Jutland, as defined in the GCA2040, the N-1 situation can lead to frequent overloads in the north-south corridor between the Danish substations of Tjele and Revsing. The details can be found in Figures 4-12 and 4-13.

France

This section mainly focuses on northern and eastern part of the territory; further comments can be found in both CCS and CSW Regional Investments Plans.

After grid studies analysis in the N and N-1 situations, corridors concerned by congestion (on interconnectors and even internal grid) are located in the same area whatever the 2040 scenario.

Concerning interconnectors with Belgium, the situation is as described just above, and it is relevant to highlight the combined influence between flows on the France-Belgium border and flows on the France-Germany border. Despite the projects that are yet to be identified in the portfolio for these two borders, coordinated use of PSTs would probably not solve these congestions at that time horizon. As mentioned in the “Germany” paragraph, additional investments should be considered in case these congestions are confirmed in future pan-European studies.

Taking into account the main increase of capacity between France to Ireland and Great Britain (starting from 2GW in 2020 up to more than 7GW or even 7,6GW in 2040, depending on the scenario), no critical congestions are detected on the internal grid.

Congestion detected in the area of the Muhlbach substation close to the German border can be managed using new PSTs commissioned in 2016.

Congestion identified in the South of Paris Region is mainly driven by north-south (or south-north) bulk flows across France as a corridor between Spain and Northern Europe (GB and Germany), to integrate RES generation. Reinforcements, such as upgrading existing grid (substations and overhead lines (OHL)) are already identified and can be realised step by step, depending on the global increase of RES generation.

Germany

Due to the high amount of renewable installed capacity expected to be installed in 2030 and 2040, internal reinforcements in the German transmission grid are necessary. To evaluate which reinforcements are needed to be implemented, the German TSOs (50Hertz, Amprion, TenneT DE and TransnetBW) are working together on the German National Development Plan (NDP, German: Netzentwicklungsplan, NEP), which must be published by law every second year. To allow all stakeholders to participate in this process, two consultation phases are included. After publishing the NDP, the German regulator Bundesnetzagentur decides which projects are confirmed. As the German NDP published in 2017 focusses on 2030 and 2035, some additional reinforcements, which are not yet identified, may be required until 2040. All internal German bottlenecks will be resolved in this process.

The NDP takes also into account the results of the latest TYNDP to ensure that the German grid is prepared to provide the capacities needed for the TYNDP projects. For example, there is a discussion ongoing about additional DC links on the north/south axis for the time horizon 2035 to integrate the RES generation capacity.

Great Britain

Interconnection to Central Europe is connected along the southeast coast and this interconnection has significant influence on power flows in the region by being able to both import and export power with Europe. Most of the interconnectors will be connected south of boundary. Interconnection to Denmark is connected via the east coast and interconnection to Norway is connected via the northern region, both having the potential to drive increased power flows across the east coast and north region.

European interconnector developments along the south coast and east coast could potentially drive very high circuit flows, causing both circuit overloads and voltage management issues.

Southern Region

In the future, the southern network could potentially see a number of issues driven by future connections and behaviour. If the interconnectors export power to Europe at the same time that high demand power is drawn both into and through London, then the northern circuits feeding London will be thermally overloaded. The high demand and power flows may also lead to voltage depression in London and the South East.

If the South-East interconnectors are importing from the Continent and there is a double circuit fault south of Kemsley, then the South-East circuits may overload and there could be significant voltage depression along the circuits to Lovedean. This situation may also increase the thermal constraint on the southeast circuit.

Eastern Region

With the large amount of generation, predominantly offshore wind, nuclear and interconnection to Denmark, contracted to be connected in the area, supply may significantly exceed the local demand, which could cause heavy circuit loading. The East Anglia transmission network to which the future generation will connect has eight 400 kV double circuits. The potential future increase in generation within this region, including the impact of interconnector flows, could cause the network to experience very heavy circuit loading.

Northern Region

Presently, most of the northern transmission network is oriented for north-south power flows with connections for demand and generation along the way. At times of high wind generation the power flow will mostly be from north to south, with power coming from both internal boundary generation and generation further north in Scotland. When most of this area and Scotland are generating power, transmission capability can be very limited. Furthermore, interconnection flow between GB and Norway has the potential to influence the power flow across the northern area.

Western Region

Future nuclear generation connecting in North Wales, low-carbon and the new interconnectors with Ireland have the potential to drive increased power flows eastward into the Midlands where power plant closures are set to occur, and demand is set to remain fairly high.

With future additional interconnector connections, the south and east region will potentially be unable to support all interconnectors importing or exporting simultaneously without network reinforcement. Overloading can be expected on many of the southern and eastern circuits.

Ireland and Northern Ireland

In Ireland, a Transmission Development Plan (TDP) is prepared annually and submitted to consultation. Additionally, new transmission project proposals are subject to a rigorous assessment and consultation process. In Northern Ireland (NI), a process for delivering a TDP is underway, and a development framework for transmission projects is being prepared.

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As a result, any bottlenecks identified as part of the analysis in this report would be required to be identified as part of the aforementioned processes before being considered for development.

The results of the network analysis indicate that, with the large increase in installed renewable capacity by 2040, the internal transmission network in both Ireland and NI comes under pressure in all scenarios. The location and severity of overloads is dependent on where the new generation is located, for example, the large increase of offshore wind generation in Ireland in the GCA scenario would stress the transmission network in the east of the country.

Generally, the main issue in Ireland and NI is transporting remotely located renewable generation to the main backbone transmission system; this may be achievable with upgrades to the existing network. Regarding the large volume of renewable generation in the GCA scenario, the analysis highlighted issues on the transmission network. Additionally, further interconnection into Ireland and NI would impact on the results; depending on where it is located, it could stress or reduce power flows.

Luxembourg

The interconnector IC BeDeLux between Luxembourg and Belgium was put into operation in October 2017. A 220 kV phase-shift transformer is integrated at Schifflange (LU) and the Luxembourg network is being reinforced by creating a loop around Luxembourg City, including substations for in feed at lower voltage levels, hereby enabling the existing line Aubange (BE)-Schifflange (LU) to figure as interconnector and thus improve the security of supply of the region.

The recently published Luxemburgish Network development plan NPD Lux 2040 noticed a major transition of the energy system in Luxembourg. The current heavy industry is evolving to smaller, specialized and energy-efficient industries. These new industries announced their establishment in Luxembourg in the coming years. In addition, the growing digitalization observed in different areas like logistics, e-commerce and electronic data storage and management will heavily impact the transmission and distribution networks. The number of electric and plug-in hybrid vehicles, including electric buses, is rising due to public incentives.

The electricity consumption and peak load of Luxembourg is currently rising faster than expected. The load and consumption of Luxembourg is expected to further increase until 2050 from currently 700MW to 1300MW (depending on the scenarios).

Luxembourg is almost completely depending on energy imports. In order to accommodate these additional flows due to the load increase expected in Luxembourg and additional transit flows on the DE-LU border towards Belgium, reinforcement is planned on the DE-LU border comprising the construction of two new 380 kV substations in Germany (Aach) and Luxemburg (Bofferdange). The new substations will be connected via a new AC link to allow higher cross-border capacity between Germany and Luxembourg.

The 2040 GCA scenario market and network simulations identify the need to reinforce the BE-LU border in addition to the already planned 400 kV reinforcement on the DE-LU border in order to accommodate the flows on the west-east axis GB-Belgium-Germany. Further studies are needed to analyse potential internal reinforcements across the area. For Luxemburg this could include reinforcements on a 400 kV level in addition to the 220 kV loop around the city of Luxembourg (Lux-Ring) put into operation in 2017.

The Netherlands

The network analysis for the 2040ST scenarios shows highly loaded locations in the NL 380 kV grid. The main reasons for these highly loaded locations are the transit flows between Germany, Belgium and France as well as the connection of new offshore wind generation, mainly on the west coast.

Internal lines

Essential for further increase of interconnection capacity on the Dutch borders is the strengthening of the central 380 kV ring in the Netherlands. The transit flows from Germany to Belgium and even to France contribute significantly to the observed overloading of internal 380 kV lines in 2040. The corridor mostly

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affected by these transit flows is the northern part of the central 380 kV ring which facilitates transport from North Germany to the west side of Belgium and passes Amsterdam.

Even the planned upgrade of these circuits by using HTLS conductors does not completely solve the congestions resulting from the 2040 scenarios. Additional measures need to be developed to solve the remaining congestions.

The eastern part of the central 380 kV ring becomes more highly loaded due to the new interconnection Doetinchem-Niederrhein, located in the middle of the NL-DE border. The planned use of HTLS conductors in this part of the central 380 kV ring appears to be sufficient for solving the observed 2040 congestions.

The connection of offshore wind generation, mainly on the west coast of the Netherlands, results in a large power flow from west to east (coast to mainland). Depending on the amount of connected offshore wind, this can lead to overloads in the western 380 kV lines between the coast and the main 380 kV ring. A more distributed selection of connection points for the offshore wind parks to the 380 kV grid is important to reduce the overloads observed towards 2040.

One part of the west side of the main 380 kV ring, Krimpen-Geertruidenberg, is affected by the transit flows, connected offshore wind and possible increase of the interconnection capacity towards the UK. This part of the main 380 kV ring is heavily loaded. The planned upgrade by using high capacity HTLS conductors is not enough to mitigate the overloads towards 2040. Other solutions need be examined.

NL-DE border

Relevant cross-border projects, presently under construction, were taken into account. These are the new 380 kV cross-border line Niederrhein-Doetinchem in the middle and the upgrade of the existing 380 kV cross-border line Meeden-Diele in the north.

Based on the network study results, it is concluded that good coordination of the PSTs in Meeden-Diele is beneficial and reduces the frequency of overload for this cross-border line. For 2040 the PSTs, however, do not suffice on their own to completely prevent overloads in the northern part of the NL-DE border, even with utilisation of the full range of the PSTs.

Studies with the neighbouring TSO Amprion have been started to optimise the remaining two interconnections, Hengelo-Gronau in the north and Maasbracht-Siersdorf in the south, which, under the analysed conditions, show overloads towards 2040.

NL-BE border:

The planned upgrade of the cross-border connection Rilland-Zandvliet in the west with two additional PSTs and increased line capacity is taken into account in analysing the 2040 scenarios.

The upgraded PST configuration in Zandvliet in the west and present PST configuration in the east interconnection Maasbracht-Van Eyck help to reduce the frequency of overload on the cross-border lines between Belgium and the Netherlands. The upgraded PST regulation in Zandvliet, however, increases the north-south and south-north flows between Belgium and the west of the Netherlands, leading to increasing overloads in the south-west part of the NL main 380 kV ring, especially between Krimpen and Geertruidenberg. Although PST regulation decreases the observed overload, not all overloads towards 2040 can be avoided; additional solutions need to be studied.

NL-GB and NL-NO interconnections

To improve the Dutch security of supply and RES integration performance towards 2040, a need to further increase the NTC between Norway and the Netherlands and Great Britain and the Netherlands has been identified. The increase of NTCs for these borders can be implemented only via the construction of new HVDC lines between the countries.

The increase of the NTC between Great Britain and the Netherlands has a substantial effect on the internal Dutch grid, as it further increases the power flows from west to east when it is connected in the same area as

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the offshore wind connections. The connection point of the NL-UK HVDC connection to the internal 380 kV grid will determine the severity and location of possible overloads towards 2040.

The NTC increase between Norway and the Netherlands increases the flows from north to south and vice versa. Depending on the connection point, this could aggravate the congestion in the northern part of the central 380 kV ring. As mentioned earlier, the planned HTLS conductors in this corridor are not sufficient to solve all congestions towards 2040, and additional measures will be studied.

Norway

To evaluate which internal reinforcements are needed, the Norwegian TSO (Statnett) develops the Norwegian Grid Development Plan, which by law must be published every second year. If high amounts of renewables are installed, like in scenario Global Climate Action, huge internal reinforcements in the Norwegian transmission grid are necessary. In scenarios Sustainable Transition and Distributed Generation, the number of new renewables is lower, hence a lower need for internal reinforcements.

4.4 Alternative approach based on a flow-based market model

During the IoSN process, ENTSO-E experimented in parallel with a new method based on a flow-based approach similar to the one used within the E-Highway 2050 project. The tested method relies on the integration of a simplified model of the physical grid directly into the market model, which allows the main congestions on the grid to be identified directly, and therefore facilitates quick analysis. The simplified model is shown in Figure 4-15.

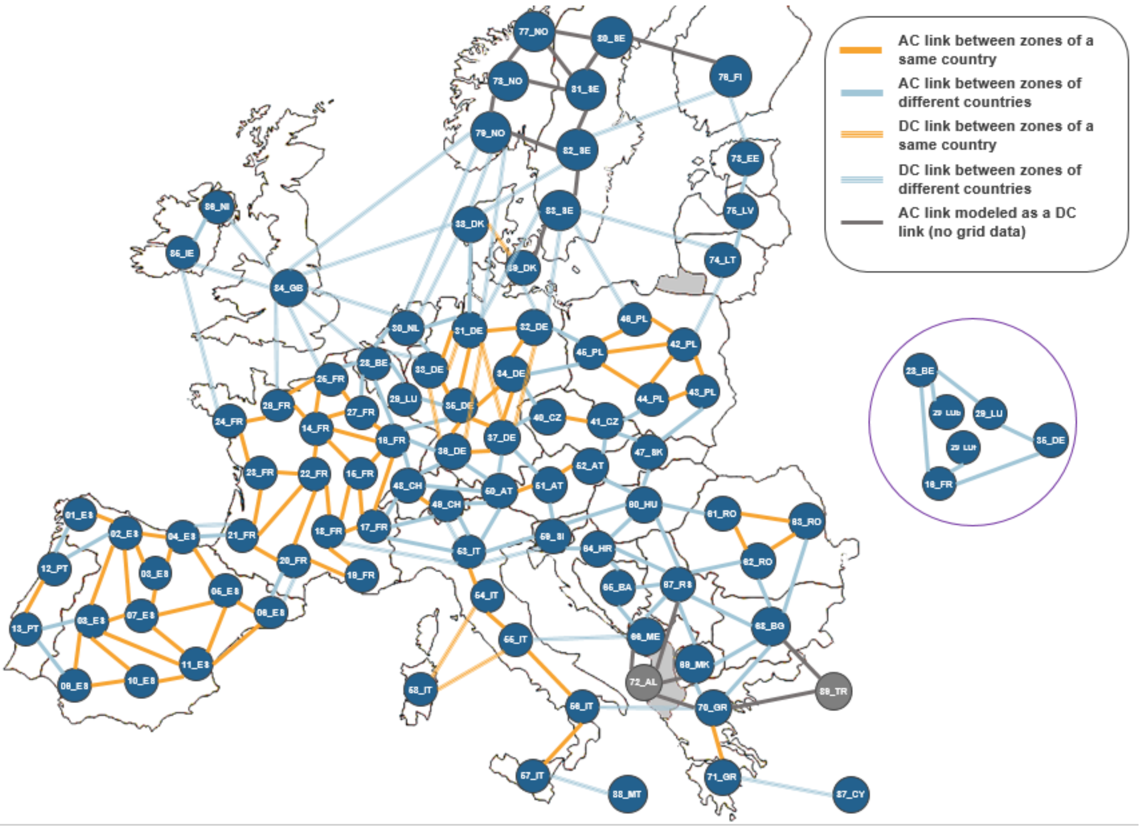

Figure 4-15: Flow-based market model structure

As this method is described in the IoSN report, only the main conclusions are presented here:

- Flow-based market models account for the physical grid when using new scenarios for which the NTCs are not well known.
- Flow-based market models make the link between the different reinforcements: which one to be built first, what are the correlations between the congestions, etc.
- Flow-based market models give a first indication of the economic value of a physical grid congestion and helps focus on the mitigation of the related most important bottlenecks.
- For modelling purposes, flow-based market models are based on a division of existing market nodes into smaller market nodes; this leads to a re-allocation of the simulated power plant dispatch and therefore to different flows.

Figure 4-16 shows an example of the identified set of reinforcements using flow-based market modelling for the ST2040 scenario and indicates the potential changes in generation, e.g. more RES can be exploited, replacing parts of the thermal fleet. The identified needs are consistent with the needs described in Chapter 4.3.

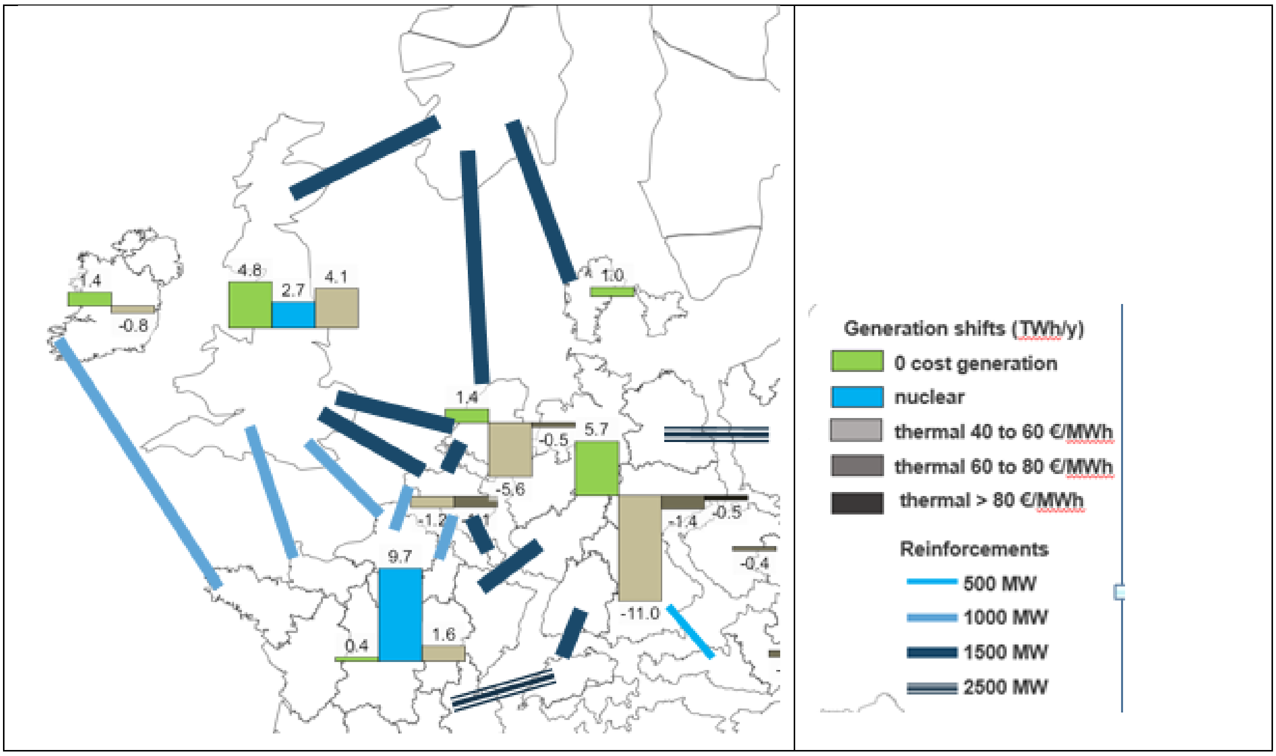

Figure 4-16: System needs identified and impact on generation mix in ST 2040 with a flow-based market model

For the North Sea Region with many HVDC subsea connections, the example shows that this method gives relevant and consistent results. Noteworthy is the higher level of need to connect GB and Ireland to the Continent in comparison to the SEW loop of the default IoSN-methodology.

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5 Additional regional studies

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

5.1 Challenges of operation with high RES

The island of Ireland comprises two jurisdictions, Ireland and Northern Ireland, which are operated as one electricity market, the Single Electricity Market (SEM). The SEM is a small system and is not synchronously connected to either Great Britain or continental Europe. When considering synchronous systems across Europe, the SEM will have the highest penetration of non-synchronous renewable generation by 2020, as shown in Figure 5-1. These values are based on targets defined in the 2010 National Renewable Energy Action Plans (NREAP).

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

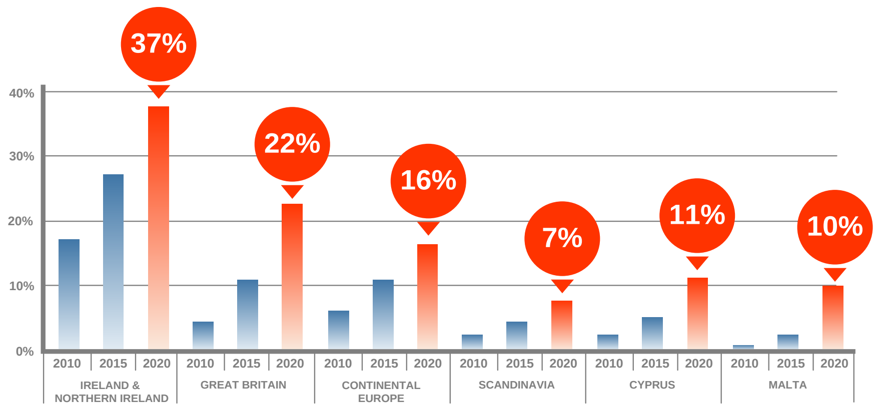

Figure 5-1: Penetration of non-synchronous renewables in each European synchronous system 2010—2020

The large increase in penetration of asynchronous renewable generation has therefore led to several challenges. Issues with operating with a high penetration of renewable generation include:

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

5.1.1 System non-synchronous penetration

To simplify matters, a metric was derived to take into account all operation constraints. This metric is referred to as the System Non-Synchronous Penetration (SNSP). The total amount of non-synchronous generation (renewable generation and HVDC interconnection imports) is considered against the total synchronous generation operating at all times. To simply meet 2020 renewable energy targets, there is a requirement for at least 75% SNSP. This would allow curtailment to be kept low enough to allow renewable generation to remain investable.

A report in 2010 investigated the operational range of the SEM synchronous system in 2020, and the results are shown in Figure 5-2. The green area represents a range where there are no technical challenges, and therefore up to 50% SNSP could be achieved. The red area represents a range where technical issues jeopardise stable operation, i.e. beyond 75% SNSP. The report concluded that operation up to 75% SNSP could be achieved with a number of 'additional adaptions of the power system'.

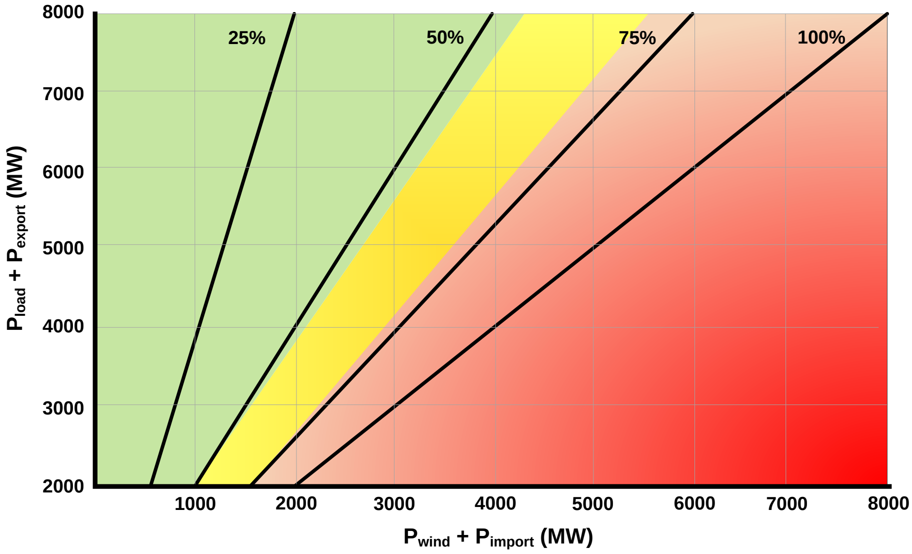

Figure 5-2: Allowable operation range of the SEM synchronous system by 2020

The DS3 (Delivering a Secure Sustainable Power System) Programme was set up by the Irish TSOs to manage the challenges of operating a system with a high penetration of renewable generation. Ultimately, it will achieve the need for a 75% SNSP. A number of requirements were identified to meet this target:

- An increase in the allowable RoCoF limit from 0.5 Hz/s to 1.0 Hz/s;
- A reduction in the number of minimum thermal generators dispatched at all times;
- A reduction in the minimum inertia required at all times;
- The introduction of a Fast Frequency Response (FFR) system service;
- An improved voltage control strategy at both transmission and distribution levels; and
- Better management of voltage induced frequency dips at high levels of SNSP.

5.1.2 Operation beyond current limits

Consideration is being given to how to ultimately operate the system with a SNSP beyond 75%. Several developments have occurred in recent years to suggest this target may be possible. These include:

- An improved dynamic reactive response from wind farms;
- The extensive use of appropriately located synchronous compensators;
- A change in the renewable energy portfolio due to an increase in PV applications; and
- New technologies, such as demand side management, energy storage and rotating stabilisers.

Further interconnection with neighbouring systems will also potentially be a requirement. A large set of studies, similar to the aforementioned DS3 programme, will ultimately be needed to determine whether such aspirations can be met. Increased coordination between transmission and distribution system operators along with enhanced regulatory and policy support will also likely be required. This is particularly true given that customers will become more active participants in the future, with domestic scale generation and technologies like electric vehicles having a larger impact on the generation and demand balance.

5.2 Controllable devices

The results of the IoSN screening show important north-south and west-east flows across the North Sea Region. These flows are driven by RES generation located in northern Europe, northern Germany, Ireland, the UK and northern France. Congestions are frequently observed on the 2030 reference grid when the 2040 scenarios are applied; this is despite infrastructure projects currently under construction or under consideration to facilitate RES integration and to connect isolated areas in the region.

To transfer high volumes of energy across long distances, HVDC projects appear as good options not only when considering offshore infrastructure.

To enhance market integration and help TSOs safely operate the grid at close to real time, additional systems such as phase shifting transformers (PST) are used. They allow the optimisation of capacity calculation by regulating flows on main power lines, while taking into consideration hourly updated patterns for load and generation. This optimisation must be considered when interpreting market results and for maintaining security of supply.

PSTs and, to an extent, HVDC enable TSOs to control power flows and use the existing system more efficiently, also potentially avoiding redispatch associated with congestion management. As a result, the installation of such control devices could delay or avoid the need for new AC OHL by improving the reliability of the system and making optimal use of the existing transmission capability.

5.2.1 Phase Shifting Transformers (PSTs) for controlling cross-border flows

PSTs are usually installed at existing substations. In the North Sea Region, they are primarily installed to control flows on 380 kV and 220 kV overhead line AC interconnectors.

When considering 220 kV interconnection, the main purpose of PSTs installed at a border is to manage the power flow across the interconnector itself, while also considering any parallel 380 kV interconnection. This is particularly important during an N-1 situation. Overall, any power ‘shifted’ to other lines is limited, while the total transfer capacity across the concerned border is increased.

For 380 kV PSTs installed at a border, their main purpose is to guarantee the safety of both the cross-border interconnector and the internal grid. They achieve this by limiting loop flows induced by high power flows crossing the regional grid. At the 380 kV level, ‘shifted’ power will affect other 380 kV interconnectors, even those on neighbouring borders. PST optimisation therefore must be considered with a coordinated approach to guarantee security completion and allow a relevant capacity calculation on a particular region. This is true no matter what planning horizon is being investigated. An example of this consideration is the flow-based calculation used in the CWE area.

PSTs can be relatively quickly deployed. They can help to optimise capacity calculation and secure system operation. They can also help maintain a certain level of cross-border capacity, for example during long periods of infrastructure outages. Although PSTs enable the control of power flowing along a line, the actual power flow itself is still a function of the meshed grid situation, and the power flow can only be ‘shifted’ to alternative paths. PSTs must be seen as an addition and ultimately do not replace the need to upgrade existing transmission lines and/or build new transmission lines.

An upgrade with PSTs can be particularly interesting when combined with an upgrade of existing overhead lines (for example, an upgrade to higher capacity conductors like HTLS). This combination delivers both flexibility and additional transmission capacity at a relatively low investment cost.

5.2.2 High Voltage Direct Current (HVDC) system

As the regional grid is not a ‘copper plate’ and is subject to capacity restrictions, market transactions between two bidding areas frequently induce ‘unplanned’ power flows in other areas. TSOs must manage these flows which are not controlled by market-based capacity allocation mechanisms. To fulfil the criteria for secure system operation, it may be necessary to decrease cross-border capacities available for the market on borders affected by these loop flows.

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To alleviate this problem of unplanned flows, market design could be part of the solution, such as making use of the aforementioned flow-based allocation. In addition, the flexibility of the power system could be increased by taking advantage of controllable devices such as HVDC connections.

Unlike PSTs, the power flow through an HVDC line is fully controllable and not influenced by the power system. Therefore, as a remedial action, rescheduling of HVDC connections could be implemented to relieve congestion on the regional grid. This would be dependent on the HVDC connections having any required spare capacity. This would reduce the influence of market players and lead to possible schedule changes between TSOs overriding the market schedule. An example of this would be the multilateral cooperation agreement between PSE-O, 50Hz, EnDK and SvK, in place since 2008.

Considering the large number of planned HVDC links in the North Sea Region, similar agreements could be envisaged involving relevant parties.

5.3 Northern Seas Offshore Grid infrastructure

The following sub-chapters give a short overview of activities and projects related to the Northern Seas Offshore Grid infrastructure, where Northern Seas TSOs are involved. They range from Member State activities and research projects to joint investigations on a new concept for a hybrid approach.

5.3.1 A bit of history

In Europe, debates on electricity offshore grid infrastructure started around the year 2007 following earlier changes in the European power sector, e.g. an increased focus on interconnections between countries. European Energy Market liberalization packages (1996, 2003 and 2009) opened for discussions of existing high electricity price differences between the Member States and market regions caused by different power production portfolios and fuel mixes, calling for cross-border connections on- as well as offshore.

From 2009, TSOs and regulators started cooperating intensely inside their newly established associations, ENTSO-E and ACER, on tasks defined by European politics, such as European grid planning. Already ENTSO-E's first editions of the Ten-Year Network Development Plan (TYNDP) showed a number of subsea interconnections crossing the Northern Seas. Interconnections to large hydropower capacity in Scandinavia had been identified as well as a beneficial complement, introducing more generation flexibility to the continental and UK power systems.

The European Energy Policy Directive, including the binding RES targets from 2009, called for further cross-border interconnections facilitating the balancing of variations and the sharing of reserves. At that time, it became clearer that the connection of offshore wind might face challenges in terms of cost, available onshore grid connection capacity and marine spatial restrictions. Additionally, the lower utilisation rates of OWP connection cables called for new ideas and cost-effective methods of connection. The idea of offshore grids became a matter of interest and the first EU offshore grid projects started, e.g. a Greenpeace study from 2008 and EWEA's 2009 offshore report.

5.3.2 Offshore grid studies and policy development

An offshore grid interconnecting offshore wind and national power systems was now assumed to be an important element towards reaching the European energy policy targets.

The *Energy Infrastructure Package* (EIP), published by the European Commission (EC) in 2010, included a specific communication on offshore grids, which was setting the framework for further policy actions. In this context, the Intelligent Energy Europe–funded Offshore Grid study delivered important inspiration concerning the benefits of clustering wind plant connections into hubs.

At the same time, at a regional level the energy ministries of the ten countries around the Northern Seas (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the United Kingdom) signed a memorandum of understanding in December 2010 forming the North Seas

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Countries' Offshore Grid Initiative (NSCOGI). Within this framework, the region's key stakeholders (ministries, TSOs and national regulators, together with the EC) gathered to identify a joint regional basis for offshore infrastructure development. In December 2012, the first outcomes on grid integration were published and final reports focusing on market and regulatory issues followed in 2015. At that time, ENTSO-E's Regional Group Northern Seas supported NSCOGI with its technical expertise concerning the grid integration. Today, in general, at a country level, expectations for offshore RES development are lower than they had been at times of NSCOGI investigations, but the political awareness and stakeholder expectations towards offshore infrastructure development have increased.

5.3.3 ENTSO-E offshore grid studies

Due to former studies looking at higher offshore wind level, conclusions made at that time are still valid and are briefly recalled below. All studies looked at a time horizon of 2030, which implies that the level investigated at that time might materialize even later

In February 2011, ENTSO-E produced its first analysis of potential offshore grid development in the Northern Seas for 2030, concluding that the investigated scenario, with 83 GW of offshore wind, would benefit from a coordinated integrated ('meshed') design. Such a scenario would save investment costs, maximise the utilisation of large-scale assets, and increase the security of energy supply. It would also be technically more complex than classical radial solutions. Considering the above-mentioned studies' results, NSCOGI's comprehensive offshore grid study analysed two designs, radial versus meshed (see Figure 9), evaluating investment costs, savings in electricity production costs, effects on CO2 emissions and country-by-country changes for electricity imports and exports.

Approach and Results

The 2012 NSCOGI study compared different designs, 'radial and meshed'. The meshed design had the same interconnection level as the radial design but included hybrid projects, i.e. combinations of offshore wind farms and interconnectors in single projects in additional to single offshore meshes. The study assumed 55 GW of offshore wind. The assumptions were provided by the ten governments, together with assumptions about all other fuel types. The NSGOGI grid study showed only marginal differences in costs and production cost savings between the two design types for the 55 GW scenario, whereas a sensitivity analysis with roughly twice as much offshore wind (117 GW) presented increased advantages for a meshed solution. Both designs resulted in rather similar infrastructure expenses (~30 bn€), showing a slight preference for the design including hybrid projects with respect to benefits. This amount is to be spent on top of the 77 bn€ regional expenses to reach the 2020 'starting' level of the study identified in the TYNDP12. The 117 GW offshore wind sensitivity in the same study already showed differences in identified on- and offshore infrastructure investments (either 53 or 57 bn€, due to saved km infrastructure lengths) between 2020 and 2030.

These high volumes are not expected before 2020 and are still quite uncertain for 2030, as political targets have not yet been defined.

The study concluded that offshore grid infrastructure will be built in a modular way, with every step influencing existing and future projects. Thus, it is not possible to identify a final efficient design a priori.

Moreover, it was concluded that even if an offshore grid is preferable as a general concept, it may not offer the best solution for all offshore generation projects. A final determination will depend on their locations and on possible connection options. Thus, these hybrid projects will be subject to case-by-case studies.

In the TYNDP14 edition comparison was made between the NSCOGI grid study, the TYNDP14 analysis itself and a study launched by the EC. Conclusions drawn from this comparison were that the Northern Seas Offshore Grid Infrastructure will be composed of various kinds of technology (AC and DC technologies) and of various designs as well. The studies had used the term 'meshed' in different ways, thus ENTSO-E closed this discussion. ENTSO-E assumes a parallel development between different designs: i) point-to-point interconnections, ii) radial offshore wind connections (single or via hubs), iii) hybrid projects (combination of offshore wind connections and interconnections) and iv) multiterminal offshore platforms combining

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interconnections. ENTSO-E foresees a modular and stepwise offshore grid development with choices being made on a case-by-case basis evaluating technical and economic parameters. A compact hybrid offshore design could be envisaged in cases where scheduling and technology requirements for interconnection and wind connection (DC or AC / voltage level) match. In any case, the cooperation between all stakeholders of all countries involved is essential.

TYNDP16: Comparing the results for the different Visions, it was observed that no matter what future evolves, the North Sea Region aims at building a robust infrastructure fulfilling the needs of the different Visions. While the infrastructure in TYNDP16, Vision 1, was merely used for the transport of conventional energy (i.e., regional CO2 savings emissions increase, regional RES integration is smallest), the SEW/GTC benefits were in the same order of size magnitude as for the other three Visions. The results illustrate the complementariness between the different projects integrated in the offshore grid infrastructure, jointly delivering a substantial market and RES integration benefit in line with the assumptions and corresponding needs of the different Visions.

It was concluded that the project package proposed by the Regional Group North Sea TSOs and Third Parties is fit for the purpose.

The ENTSO-E TYNDP16 summarised the foreseen individual subsea projects into one single project and evaluated its costs and benefits. This approach is followed up in the **TYNDP18**, where individual elements might have been adjusted, as the individual modules each follow their own project plan. Figure 5.3 gives an indication of the current status of promoted subsea and supporting onshore projects until 2030 with, in total, fewer projects being submitted to the TYNDP process compared to the TYNDP16.

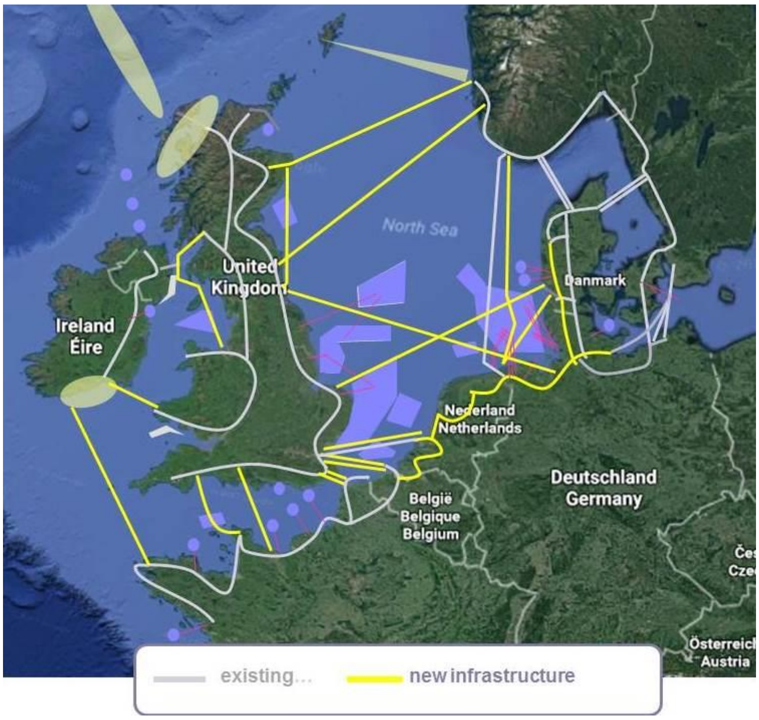

Figure 5-3: Draft Offshore Grid Infrastructure TYNDP18

Table: Projects developing the offshore potential in the Northern Seas towards 2030

Country/ies	Project ID	Project Name	Com-missioning	Offshore interconnection Capacity [MW]
FR, GB	25	IFA 2	2020	1000
FR, GB	153	France – Alderney – Britain (FAB)	2022	1400
FR, GB	172	Eleclink	2019	1000
BE, GB	74	Thames Estuary Cluster (NEMO)	2019	1000
BE, GB	121	Nautilus: 2nd link Belgium – UK	Earliest 2028	1400
FR, IE	107	Celtic Interconnector	20265	700
GB, NO	110	North Sea Link	2021	1400
GB, NO	190	NorthConnect	2022	1400
DE, NO	37	NordLink	2020	1400
DKW, NL	71	COBRA Cable	2019	700
DKW, GB	167	VIKING link	2022	1400
FR, GB	247	AQUIND Interconnector	2022	2000
FR, GB	285	Gridlink	2022	1400
GB-NL	260	New GB –NL interconnector	2030	1000-2000
IE-GB	286	Greenlink	2023	500
GB-NO	294	Maali	2025	600
BE	75	Modular Offshore Grid	2020	1000
BE	120 + 329	Modular Offshore Grid 2 + New onshore corridor	2030 + 2028	2000
GB-DE	309	NeuConnect	2022	1400

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5.3.4 North Seas Countries' Energy Collaboration

The Northern Seas Countries' Energy cooperation (NSCEC) is a joint activity of ten Member States around the Northern Seas (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the United Kingdom) that was established in 2016. It can be considered as the follow-up to the NSCOGI collaboration, which had been established in 2009. While NSCOGI was owned and organised by the Member States, NSCEC is jointly chaired by the European Commission and Member States and is based on a political declaration setting the scene for offshore development. The NSCES aims to:

- Facilitate the cost-effective deployment of offshore renewable energy, in particular wind; and,
- Promote interconnection between the countries in the North Sea Region.

The collaboration is divided into four support groups focusing on different fields:

1. Maritime spatial planning;
2. Development and regulation of offshore grids and other offshore infrastructure;
3. Support framework and finance for offshore wind projects and,
4. Standards, technical rules and regulations in the offshore wind sector.

The work plans for the period 2016 to 2019 of each support group are published on the NSCEC homepage.

The primary focus of the North Sea Region's TSOs is in observing the work of Support Group 2, providing input on request. This infrastructure support group observes offshore developments concerning interconnections and offshore wind in order to identify potential hybrid project clusters.

5.3.5 PROMOTioN

The PROMOTioN (PROgress on Meshed HVDC Offshore Transmission Networks) project is a research project funded by the European 'Horizon 2020' research and innovation programme. 34 partners will collaborate for a period of four years, with the aim of taking the concept of meshed HVDC infrastructure a step further. The PROMOTioN consortium consists of wind turbine manufacturers, TSOs in the North Sea Region, offshore wind developers, asset providers, academia and consulting companies.

The project focusses on eliminating the technical and regulatory barriers associated with a meshed offshore HVDC grid. Identification of potential cost reductions for converter technology is one of the fields of investigations.

The project starts with the assumption that necessary international regulation and financial support instruments are underdeveloped. It also assumes that there is a lack of operational experience with the required protection and fault clearance technologies associated with HVDC grids. The PROMOTioN project aims to demonstrate the following two essential technologies:

- **HVDC grid protection systems**. An HVDC grid protection system will be developed and demonstrated utilising multi-vendor methods within a full scale of Multi-Terminal Test Environment. The multi-vendor approach will ensure interoperability with regards to DC grid protection.
- **HVDC circuit breakers**. The project will for the first time demonstrate the performance of existing HVDC circuit breaker prototypes to provide confidence and demonstrate technology readiness of this crucial network component.

Additionally, a Diode Rectifier Unit is being considered as a possible cost reducing technology. This technology concept challenges the need for the more complex VSC converters, thus reducing investment and maintenance costs and increasing availability.

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On top of this technology development, the PROMOTioN project aims to develop an international regulatory and financial framework, essential for the funding, deployment and operation of meshed offshore HVDC grids.

The PROMOTioN project commenced in January 2016 and will be completed in January 2020. Intermediate publications are all available on the official website.

5.3.6 The North Sea Wind Power Hub

The North Sea Wind Power Hub (NSWPH) is a joint initiative started by TSOs, aimed at involving further partners as well. Cost saving potentials related to offshore platforms are assumed to be activated by building artificial islands instead, perhaps merging cross-sectorial assets as well.

To help realise the Paris Climate agreement, the development of offshore wind will be an essential element. Currently, the wind industry is promoting a stable 4 GW/year pipeline to make and keep the wider offshore industry competitive[8] According to them, to meet the 2050 projections would require an increase in build rate to at least 6GW/year.

However, offshore wind farm developments will increasingly be located further from shore, thus requiring innovative solutions to limit the costs of construction, maintenance and infrastructure.

In March 2017, TenneT TSO B.V. (Netherlands), Energinet (Denmark) and TenneT TSO GmbH (Germany) put forward a joint vision on how to make the transition to remote large-scale offshore wind feasible and affordable via the NSWPH concept.

The NSWPH is centred around building an artificial island in the North Sea. Large amounts of offshore wind located nearby could be connected to this island via AC technology and, from the island, multiple HVDC connections will connect into surrounding North Sea countries. The advantages of this conceptual idea, according to the promoter, include:

- Allowing for synergies in infrastructure by combining wind farm connections and regional interconnectors;
- Enabling the construction of traditionally costly offshore equipment in an onshore environment, for example, offshore HVDC platforms.; and
- The allocation of offshore wind farm logistics, assembly centres and crew on the island.

The Dogger Bank area seems to be a potential location, as there five countries' borders meet, waters are shallow, and more countries might wish to participate. The goal of the project is to collaborate with regional parties and allow both the cost-effective connection of remote offshore wind in the Dogger Bank area and the development of a resilient, interconnected, regional transmission system. The concept is demonstrated in Figure 5-4.

[8] http://www.greenpeace.org/international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf
http://www.ewea.org/fileadmin/files/library/publications/position-papers/EWEA_2050_50_wind_energy.pdf

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Figure 5-4: North Sea Wind Power Hub with Energy Island concept (left) and the option of increased regional interconnection (right)

The promoters' present concept would involve up to three islands, each covering an area of 6 km2. The creation of these islands would involve the dredging of 200 million cubic metres of sand. Each island is anticipated to facilitate approximately 30 GW of offshore wind generation, connected via AC connections. The islands themselves would be interconnected via 15 HVDC links, each of 2 GW in size. Overall, between 70 GW and 100 GW of offshore wind generation, covering an area of between 11,000 km2 and 20,000 km2, could be connected to these islands. Hard substrates would cover an area of about 4.4 km2, equivalent to about 0.02 % of the total Dogger Bank area. This area is presently part of the Natura2000 network. The implementation of a project of this scale would require considerable studies into the environmental impact of such infrastructure.

Potential costs and benefits

The NSWPH concept aims to facilitate the efficient connection of large volumes of offshore wind generation and interconnect it to countries in the North Sea Region. It would contribute to a reduction in carbon emissions and avoid RES curtailments. By bringing a significant increase in interconnection capacity to the North Sea Region, it would be expected to contribute to SEW and to flexibility in the regional power system.

The NSWPH concept targets a reduction in investment costs so that the overall costs are comparable to those of AC based connections of near to shore wind farms, when considering the both wind farm and connection to shore costs.

According to project promoters, the NSWPH concept is estimated to provide a 7% LCOE (levelized cost of energy) reduction for offshore wind when compared to present close to shore AC connected offshore wind.

Promoters emphasize that NSWPH is still a conceptual project, which will be further studied and refined. Aside from the considerable engineering challenge to deliver this type of project, work is required to ensure market arrangements can cope with such hub concepts in the middle of the North Sea without unduly restricting capacities, and that regulatory frameworks can cover the transmission investments needed.

The project will continue to further analyse investigating the flexibility required of a power system targeting decarbonisation before 2050 and the potential reduction in costs associated with the concept.

The NSWPH concept has been submitted as Project Candidate to the TYNDP 2018.

5.4 PLEF generation adequacy assessment

The Pentalateral Energy Forum is the framework for regional cooperation in central western Europe (AT-BE-DE-FR-LU-NL-CH) towards improved electricity market integration and security of supply. The further development of a coordinated approach to security of supply in the Pentalateral region was defined as one of the key objectives by the governments of the PLEF countries.

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In this framework, Transmission System Operators of the PLEF countries have in the last four years carried out two Generation Adequacy Assessments studies.

The first PLEF Generation Adequacy Assessment, issued in 2015 and based on the Political Declaration of the Pentalateral Energy Forum of 7 June 2013 in which the Ministers of Energy requested a Pentalateral Generation Adequacy Assessment, provided a first probabilistic analysis of electricity security of supply in Europe conducted from a regional perspective, thus making it possible to better assess generation adequacy jointly, on a regional scale covering the Penta countries. The know-how on methodology as developed by the Penta TSOs has since then been transferred and applied within the association of European electricity TSOs in ENTSO-E in the Midterm Adequacy Forecast (MAF).

In June 2015, the Penta ministers defined in their 2nd Political Declaration further milestones on security of supply, on market integration and on flexibility, including the aim for further improvements of the common methodology to assess security of supply on the regional level as developed by the TSOs. They continue to publish a bi-annual report on the status of security of supply in the central western European region, first appearing in 2017.

The declaration was followed by a roadmap prepared together with the Penta TSOs defining the contents of the next adequacy study, taking into account important insights gained from the first study by the Penta TSOs on the need to further improve the methodology of the assessments. Since the completion of the roadmap, Penta TSO have intensively worked together to carry out the new study establishing an improved level in adequacy assessment.

The second Pentalateral Generation Adequacy Assessment, published in January 2018, emphasizes two main aspects. The first goal is the development of state-of-the-art methodologies, high quality data collection and enhanced adequacy modelling techniques. Applying these methods, the second goal is to provide the best possible adequacy assessment for the Penta Region on the horizons defined by the ministries (short term, 2018/2019, and medium term, 2023/2024). These results provide decision-makers with a more holistic assessment of potential capacity scarcities in the Penta Region.

One of the main achievements of the study is the implementation of the FB (Flow-Based) approach at the regional level. The approach for FB-Market-Coupling (FB-MC) is a significant step towards more realistic modelling of the operational planning currently in practice. Moreover, the future potential of Demand Side Flexibilities and their contribution to generation adequacy has been studied in more detail.

The results of the study show that adequacy margins will become tighter on the midterm horizon (2023/2024).

The study also highlights the key role played by planned interconnection projects, which not only enhance market integration but also increase the security of supply. The grid projects considered in the PLEF region up to 2023/24 clearly improve the level of security of supply within the region, more specifically in Belgium and France. Without them, the LOLE from these two countries in 2023/24 would exceed 10hrs, two to three times more than the LOLE of the base case.

Furthermore, probabilistic approaches such as the ones used in this PLEF GAA are key to assessing the contribution to security of supply of future interconnectors. A method based on probabilistic assessments is currently being evaluated within the framework of the ENTSO-E CBA.

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6 Links to national development plans

Table 6-1 provides a link to the development plan of all countries in the North Sea Region, where available. No development plan is currently published in Northern Ireland.

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

Country	Company/TSO
Belgium	http://www.elia.be/nl/grid-data/grid-development/investeringsplannen/federal-development-plan-2015-2025
France	French NDP 2016 website: http://www.rte-france.com/fr/article/transition-energetique-et-revolution-numerique-plus-de-10-milliards-d-euros-d
The Netherlands	Summary: https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_samenvatting.pdf General: https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_Deel_I_web.pdf Onshore: https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_Deel_II.pdf Offshore: https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/TenneT_KCD2017_Deel_III.pdf
Germany	https://www.netzentwicklungsplan.de/
Great Britain	http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Electricity-ten-year-statement/ http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Network-Options-Assessment/ http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/
Ireland	http://www.eirgridgroup.com/site-files/library/EirGrid/TDP-2015-CER-Approved-(2).pdf
Northern Ireland	N/A
Denmark	https://en.energinet.dk/About-our-reports/Reports/Summary-of-RUS-Plan-2016 https://www.energinet.dk/-/media/Energinet/Projekter-KTR-HFV/Dokumenter/Netplanlaegning/Reinvesterings---Udbygnings--og-Saneringsplan-2016.pdf?la=da
Norway	http://www.statnett.no/Global/Dokumenter/NUP%202017-endelig/Nettutviklingsplan%202017.pdf
Luxembourg	https://assets.ilr.lu/energie/Consultations/20141103_d%C3%A9veloppement-d%C3%A9cennal-RT/Etude-reseau-2013-2035-220-kV.pdf#search=%C3%A9tude%20r%C3%A9seau

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7 PROJECTS

The following projects were collected during the project calls. They represent the most important projects for the region. To include a project in the analysis, it must fit several criteria. These criteria are described in the ENTSO-E practical implementation of the guidelines for inclusion in TYNDP 2018[9]. The chapter is divided between pan-European and regional projects.

7.1 Pan-European projects

The map below shows all project applicants, submitted by project promoters during the TYNDP 2018 call for projects. In the final version of this document (after the consultation phase) the map will be updated, showing the approved projects. Projects are in different states, which are described in the CBA guideline:

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

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

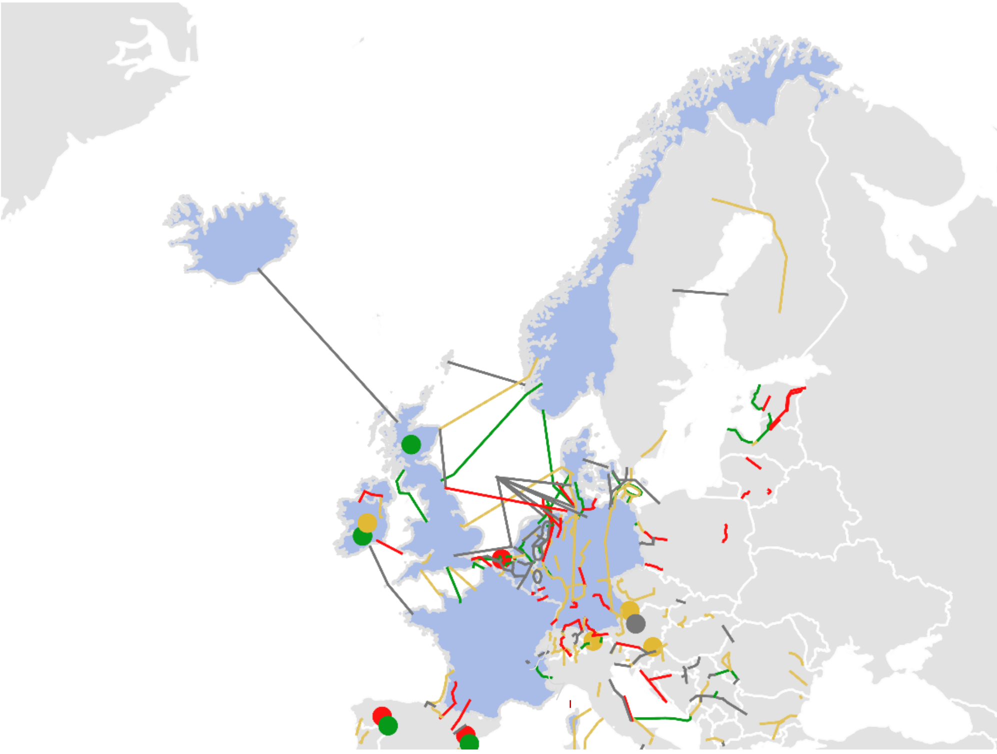

Figure 7-1 TYNDP 2018 Projects: Regional Group NS

[9] https://thales.entsoe.eu/sites/tyndp2018/Steering Group and Coordination Team Documents/170822_ENTSO-E practical implementation of the guideliens for inclof proj in TYNDP 2018_after webinar 22 Aug 2017.docx

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7.2 Regional projects

In this chapter the NS projects of ‘regional’ and ‘national’ significance are listed, as they are needed for substantial and inherent support of the pan-European projects’ inclusion into the future transmission systems. All these projects include appropriate descriptions and the main driver, i.e., why they are designed to be realised in the future scenarios, together with the expected commissioning dates and evolution drivers, if they were introduced in the past Regional Investment Plans.

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

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

Country	Project Name	Investment		Expected Commissioning year	Description	Main drivers	Included in RegIP 2015?
		From	To				
FRANCE	Long Term perspective in Eastern France			>2027	Reconductoring or upgrade 220kV OHL as 400kV.	Market and RES Integration	Yes
FRANCE	Lille-Arras	Avelin	Gavrelle	2021	An existing 30-km 400-kV single circuit OHL in Lille area will be substituted by a new double circuit 400kV OHL.	SoS, RES integration The project aims at ensuring the security of supply, taking into account RES generation volatility	Yes
FRANCE	Cergy – Persan	Cergy	Persan	2018	Upgrade of an existing 35-km 225 kV line to 400-kV between Cergy and Persan (north-western Paris area) and connection to Terrier via an existing 400kV line.	SoS, Market and RES integration	Yes
FRANCE	Havre - Rougemontier	Havre	Rougemontier	2019	Reconductoring of existing 54km double circuit 400kV OHL to increase its capacity.	Connection of new generation in Le Havre area	Yes
FRANCE	Sud Aveyron			2020	New substation on 400kV Gaudière-Rueyres for local RES integration. 2020 subject to its authorization.	RES integration	Yes
FRANCE	Massif Central South	Gaudière	Rueyres	>2027	Upgrade of the existing 400 kV overhead line, under study.	Security of supply, RES, Market integration	No*
FRANCE	Eguzon - Marmagne 400kV	Eguzon	Marmagne	2022	Reconductoring existing 400 kV OHL (maintenance), under study.		No*
FRANCE	Façade Atlantique Upgrade of the North-South 400 kV corridor between Nouvelle-Aquitaine and Vallée de la Loire, under study			2030	Upgrade of the North-South 400 kV corridor between Nouvelle-Aquitaine and Vallée de la Loire.	RES, Market integration	No*
GERMANY		Pulgar (DE)	Vieselbach (DE)	2024	Construction of new 380kV double circuit OHL in existing corridor Pulgar-Vieselbach (104 km). Detailed information given in Germany’s Grid Development.	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 PSTs in Hamburg/Ost. Detailed information given in Germany's Grid Development.	RES integration	Yes
GERMANY		Krümmel (DE)	Hamburg/Nord (DE)	2030	Reinforcement of existing 380 kV OHL Krümmel - Hamburg/Ost.	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 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 existing corridor between Irsching and Ottenhofen.	RES integration	Yes
GERMANY		Dollern (DE)	Alfstedt (DE)	2024	New 380-kV-OHL in existing corridor in Northern Lower Saxony for RES integration.	RES integration	Yes
GERMANY		Unterweser (DE)	Elsfleth/West (DE)	2024	New 380-kV-OHL in existing corridor for RES integration in Lower Saxony.	RES integration	Yes
GERMANY		Conneforde (DE)	Unterweser (DE)	2024	New 380-kV-OHL in existing corridor for RES integration in Lower Saxony.	RES integration	Yes
GERMANY		Klostermannsfeld (DE)	Querfurt (DE)	2025	New 380 kV OHL in existing corridor between Klostermannsfeld and Querfurt. Detailed information given in Germany's Grid Development.	RES integration	Yes
GERMANY		Niederrhein (DE)	Utfort (DE)	2030	New lines and installation of additional circuits, extension of existing and erection of several 380/110kV-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 220kV substation Farbwerke Höchst-Süd will be upgraded to 380kV and integrated into the existing grid.	RES integration / Security of supply	Yes
GERMANY		Several		2019	This investment includes new 380/220kV transformers in Walsum, Sechtem, Siegburg, Mettmann and Brauweiler. Some of them are already installed, others are under construction.	RES integration / Security of supply	Yes
GERMANY		Lippe (DE)	Mengede (DE)	2030	Reconductoring of existing 380kV line between Lippe and Mengede.	RES integration / Security of supply	Yes
GERMANY		Several		2019	This investment includes several new 380/110kV transformers in order to integrate RES in Erbach, Gusenburg, Kottigerhook, Niederstedem, Öchtel, Prüm and Wadern. In addition, a new 380kV substation and transformers in Krefeld Uerdingen are included.	RES integration / Security of supply	Yes
GERMANY		Büttel (DE)	Wilster (DE)	2021	New 380-kV-line in existing corridor in Schleswig - Holstein for integration of RES, especially wind on- and offshore.	RES integration	Yes
GERMANY		Junction Mehrum (DE)	Mehrum (DE)	2019	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	New 380-kV-line Borken - Mecklar in existing corridor for RES integration.	RES integration	Yes
GERMANY		Borken (DE)	Gießen (DE)	2022	New 380-kV-line Borken - Gießen in existing corridor for RES integration.	RES integration	Yes

GERMANY		Borken (DE)	Twistetal (DE)	2021	New 380-kV-line Borken - Twistetal in existing corridor for RES integration.	RES integration	Yes
GERMANY		Wahle (DE)	Klein Ilsede (DE)	2018	New 380-kV-line Wahle - Klein Ilsede in existing corridor for RES integration.	RES integration	Yes
GERMANY		Hoheneck (DE)	Engstlatt (DE)	2022	New 380kV OHL Pulverdingen-Oberjettingen (45 km) and new 380kV OHL Oberjettingen-Engstlatt (34 km) and new 380 kV OHL Hoheneck-Pulverdingen (13 km).	Security of supply	Yes
GERMANY		Birkenfeld (DE)	Ötisheim (DE)	2019	A new 380kV OHL Birkenfeld-Ötisheim (Mast 115A). Length:11km.	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 380kV double circuit OHLs, decommissioning of existing old 220kV double circuit OHLs, extension of existing and erection of several 380/110kV-substations. Length: 108km.	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	Project of new 380kV double circuit OHL Neuenhagen-Vierraden-Bertikow with 125km length as prerequisite for the planned upgrading of the existing 220kV 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 new 380kV double circuit OHL between the substations Wustermark and Neuenhagen with 75km length. Support of RES and conventional generation integration, maintaining of security of supply and support of market development. Detailed information given in Germany’s Grid Development.	RES integration / Security of supply	Yes
GERMANY		Pasewalk (DE)	Bertikow (DE)	2021	Construction of new 380kV double circuit OHLs in north-eastern part of 50HzT control area and decommissioning of existing old 220kV double circuit OHLs, incl. 380-kV-line Bertikow-Pasewalk (30 km).Support of RES and conventional generation integration in North Germany, maintaining of security of supply and support of market development. Detailed information given in Germany’s Grid Development.	RES integration / Security of supply	Yes
GERMANY		Röhrsdorf (DE)	Remptendorf (DE)	2025	Construction of new double circuit 380 kV OHL in existing corridor Röhrsdorf-Remptendorf (103 km).	Security of supply	Yes
GERMANY		Wolmirstedt (DE)	Wahle (DE)	2022	Reinforcement of existing OHL 380 kV. Detailed information given in Germany’s Grid Development.	RES integration	Yes
GERMANY		Vieselbach (DE)	Mecklar (DE)	2023	New double circuit OHL 380 kV line in existing OHL corridor. Detailed information given in Germany’s Grid Development.	RES integration	Yes
GERMANY		Conneforde (DE)	Unterweser (DE)	2029	New double circuit OHL 400 kV line in existing OHL corridor (33 km).	RES integration	TYNDP 2016

GERMANY		Area of Altenfeld (DE)	Area of Grafenrheinfeld (DE)	2027	New double circuit OHL 380 kV in existing corridor (27 km) and new double circuit OHL 380 kV (81 km). Detailed information given in Germany's Grid Development.	RES integration	TYNDP 2016
GERMANY		Gießen/Nord (DE)	Karben (DE)	2025	New 380-kV-line Gießen/Nord - Karben in 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	New 380 kV OHL in existing corridor between Querfurt and Wolkramshausen. Detailed information given in Germany's Grid Development.	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.	Security of supply	No
GERMANY		Güstrow (DE)	Gemeinden Sanitz/Dettmannsdorf (DE)	2025	New 380 kV OHL in existing corridor between Güstrow - Bentwisch - Gemeinden Sanitz/Dettmannsdorf. Detailed information given in Germany's Grid Development.	RES integration	No
GERMANY		Güstrow (DE)	Pasewalk (DE)	2025-2028	New 380 kV OHL in existing corridor between Güstrow – Siedenbrünzow – Alt Tellin – Iven – Pasewalk. Detailed information given in Germany's Grid Development.	RES integration	No
GERMANY		Wolkramshausen (DE)	Vieselbach (DE)	2024	New 380 kV OHL in existing corridor between Wolkramshausen-Ebeleben-Vieselbach. Detailed information given in Germany's Grid Development.	Security of supply	No
GERMANY		Thyrow (DE)	Berlin/Südost (DE)	2030	New 380 kV OHL in existing corridor between Thyrow and Berlin/Südost. Detailed information given in Germany's Grid Development.	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		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
GERMANY		Wolmirstedt (DE)	Wahle (DE)	2027-2029	New 380 kV OHL in existing corridor. Detailed information given in Germany's Grid Development.	RES integration	No
Denmark	Endrup-Idomlund	Endrup (DK)	Idomlund (DK)	2022	Upgrade of existing 150 kV line to 400 kV.	RES integration, Security of supply	

(*) These projects were in the TYNDP2016 list

8 APPENDIX A

8.1 Additional Figures

8.1.1 Present situation

Generation capacities and energy consumption/production for the region, zoomed in to show smaller countries.

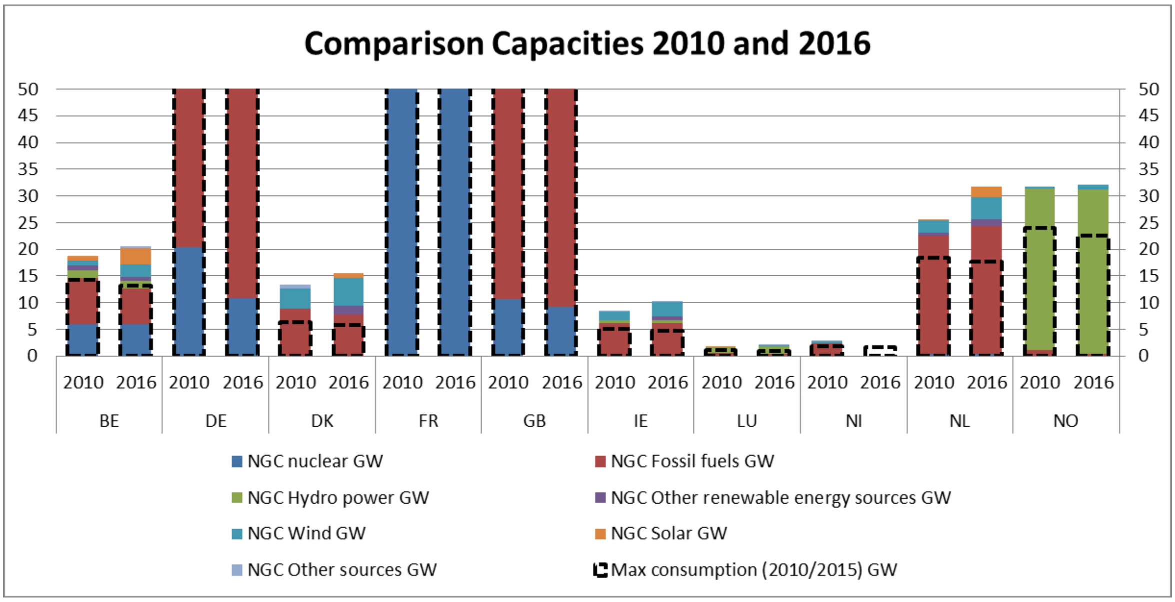

Figure 8-1: ENTSO-E regions (System Development Committee)

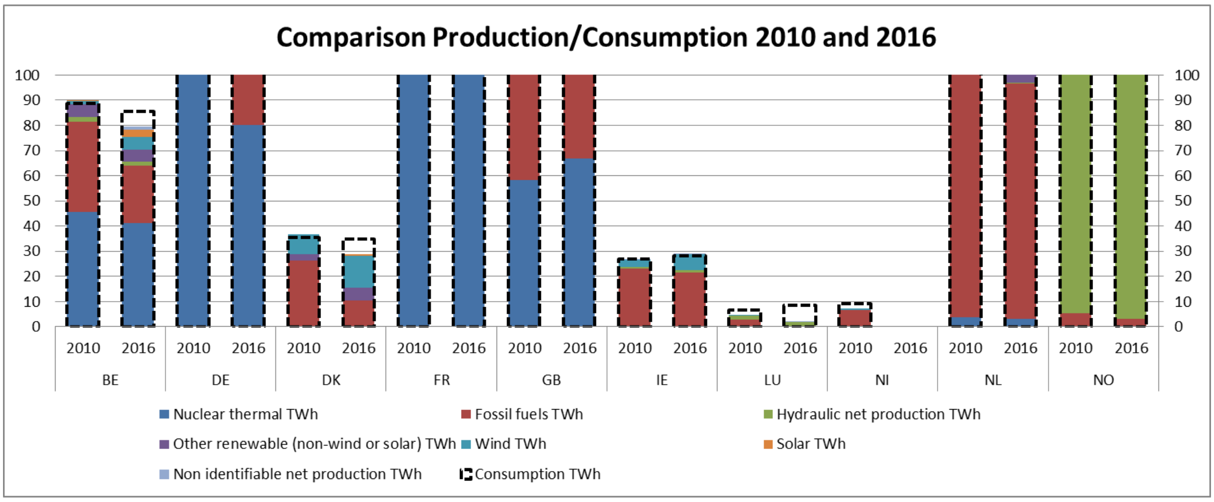

Figure 8-1: ENTSO-E regions (System Development Committee)

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8.1.2 Scenarios

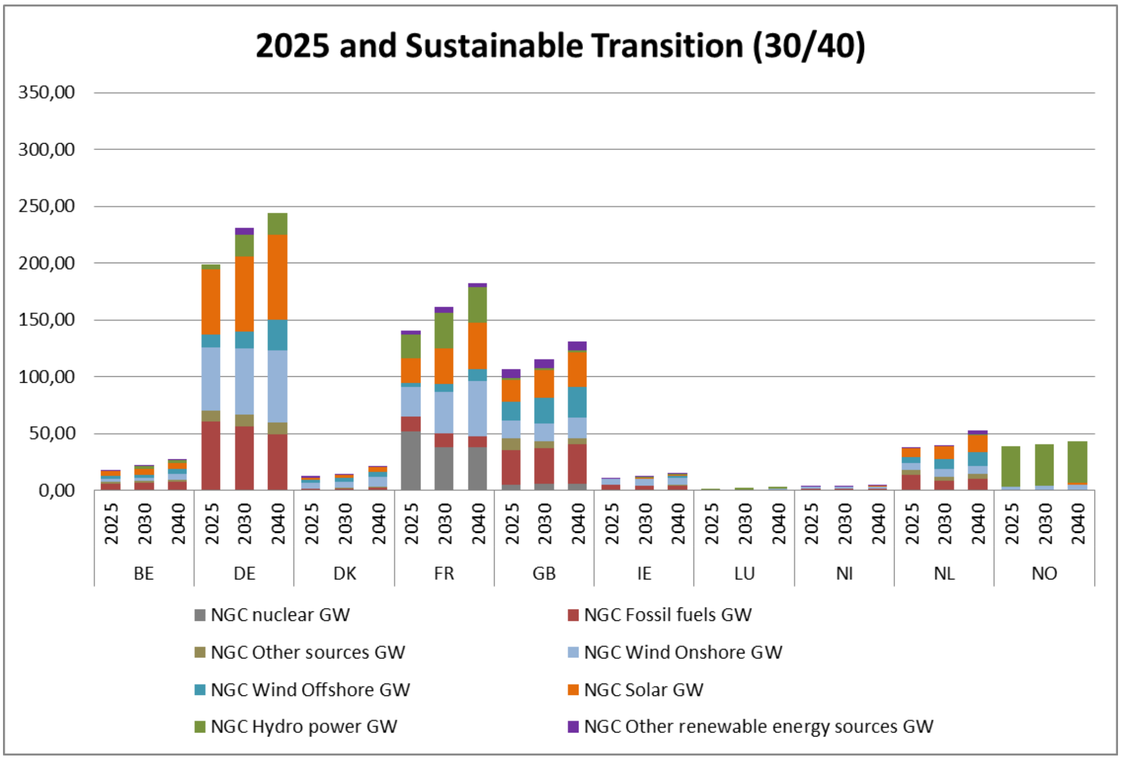

Figure 8-3: Sustainable Transition

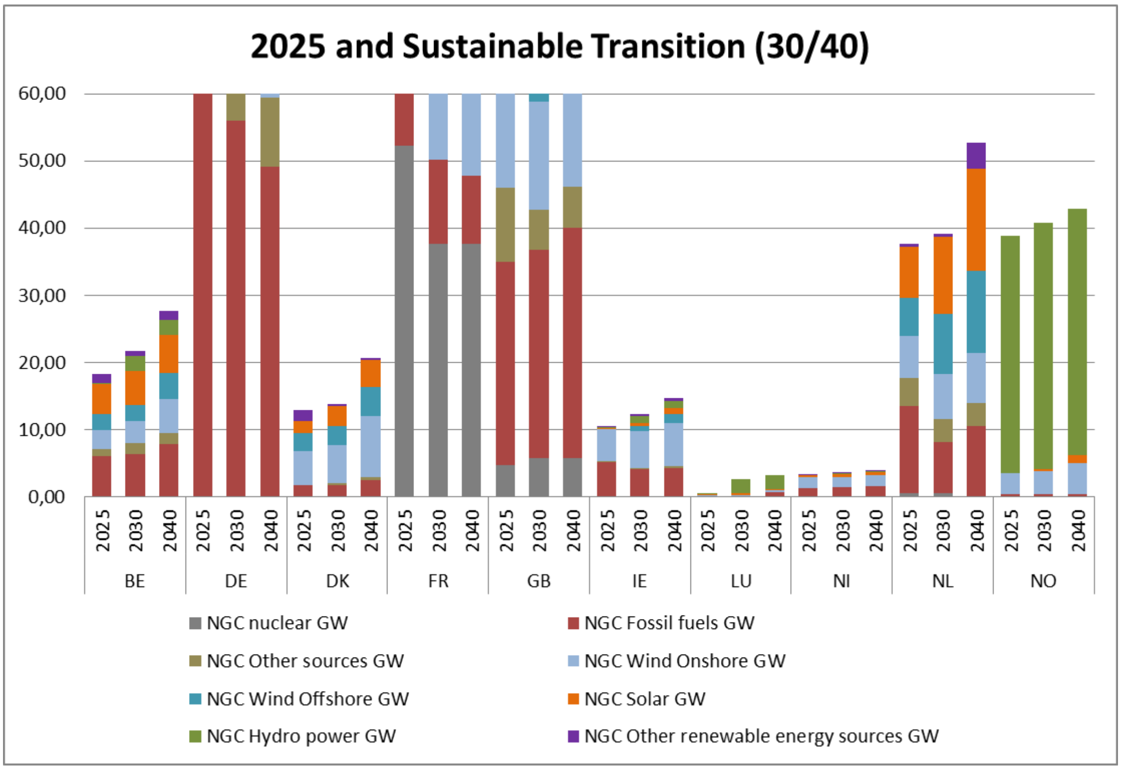

Figure 8-4: Sustainable Transition, smaller countries in more detail

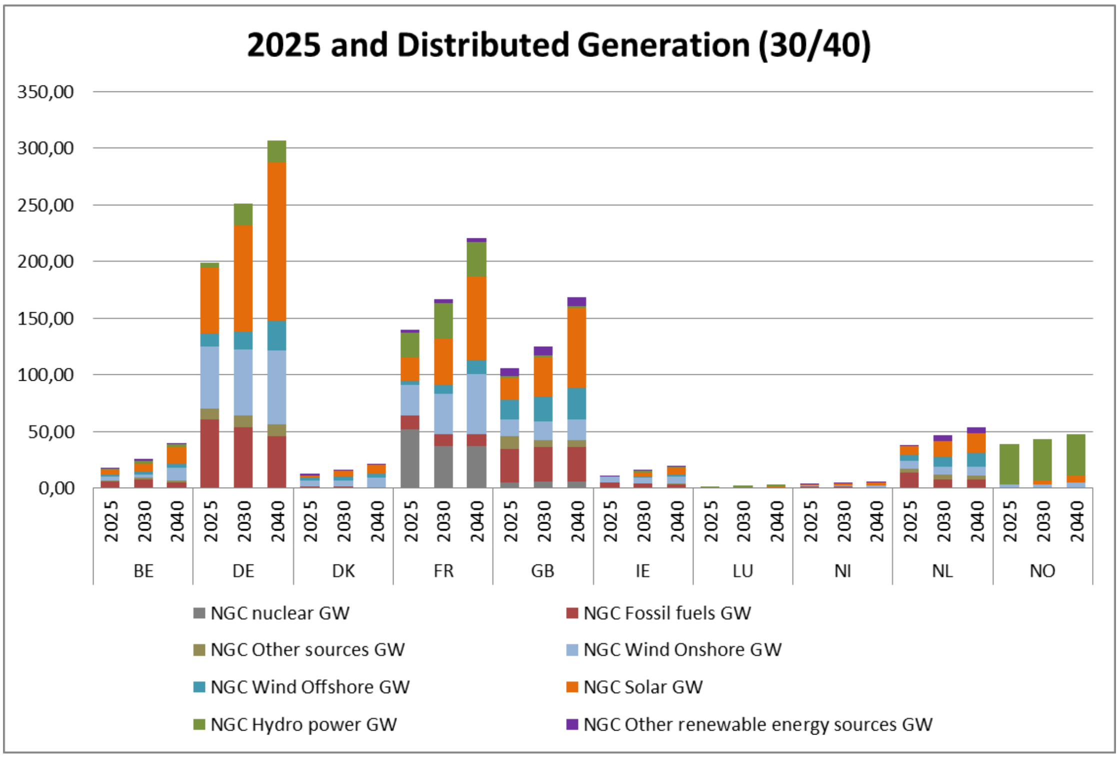

Figure 8-5: Distributed Generation

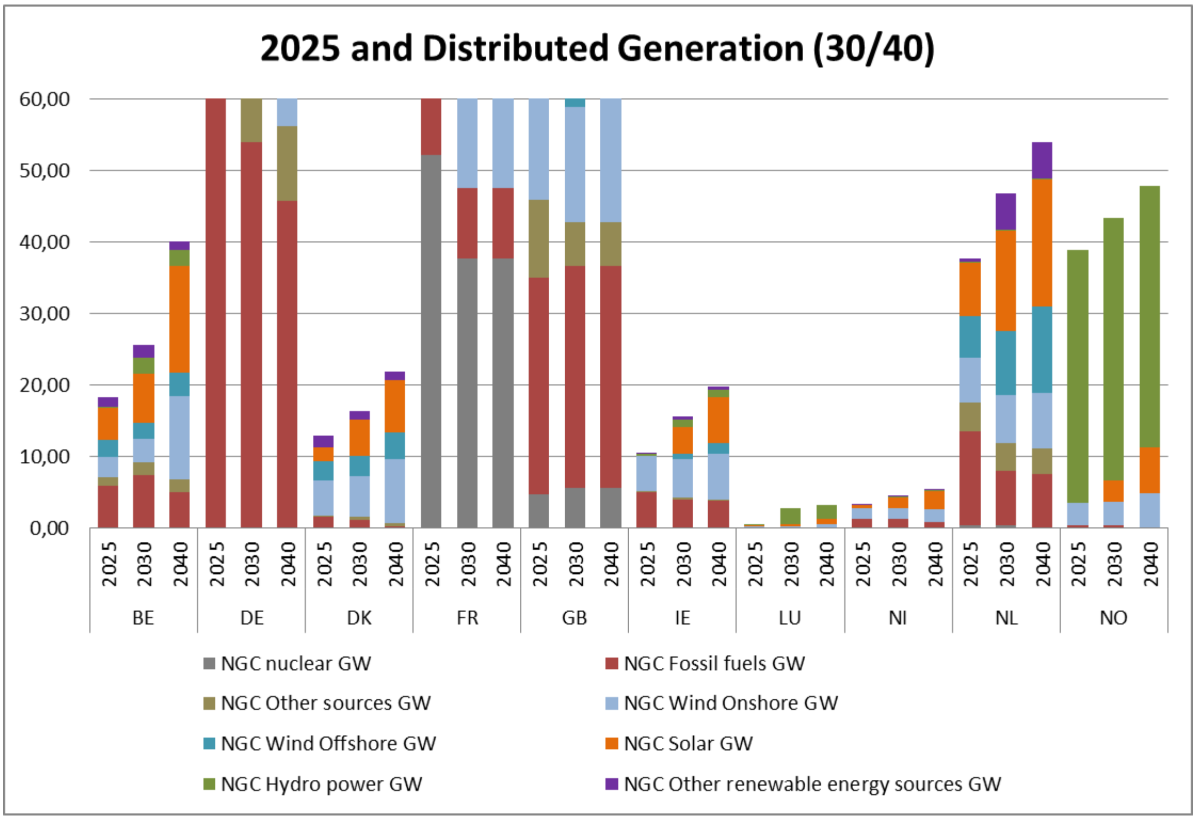

Figure 8-6: Distributed Generation, smaller countries in more detail

8.1.3 Future challenges

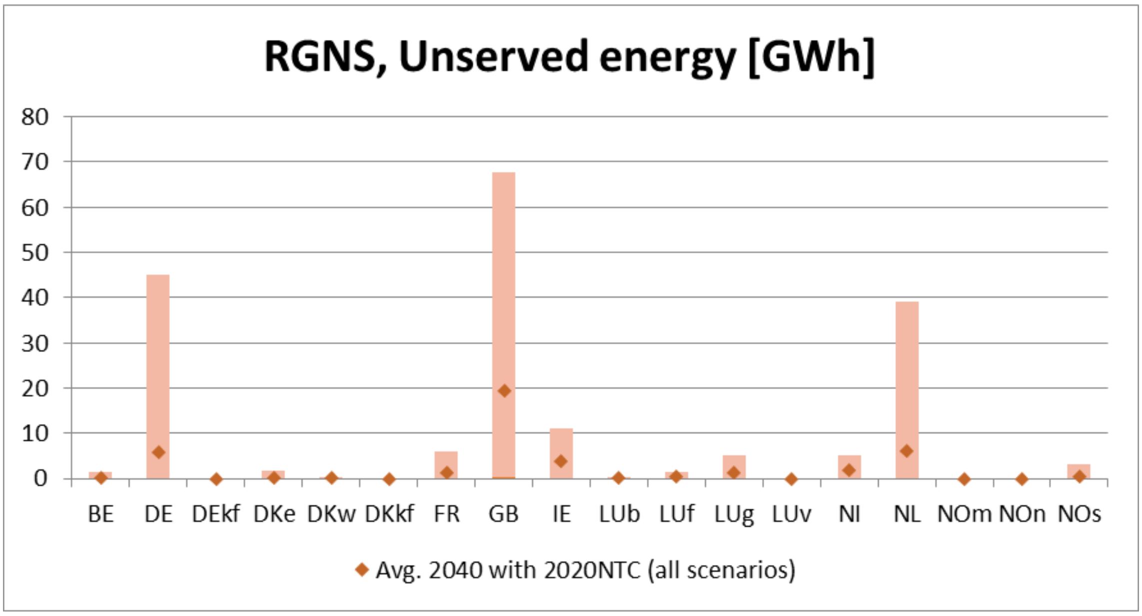

Figure 8-7: Unserved energy in the region

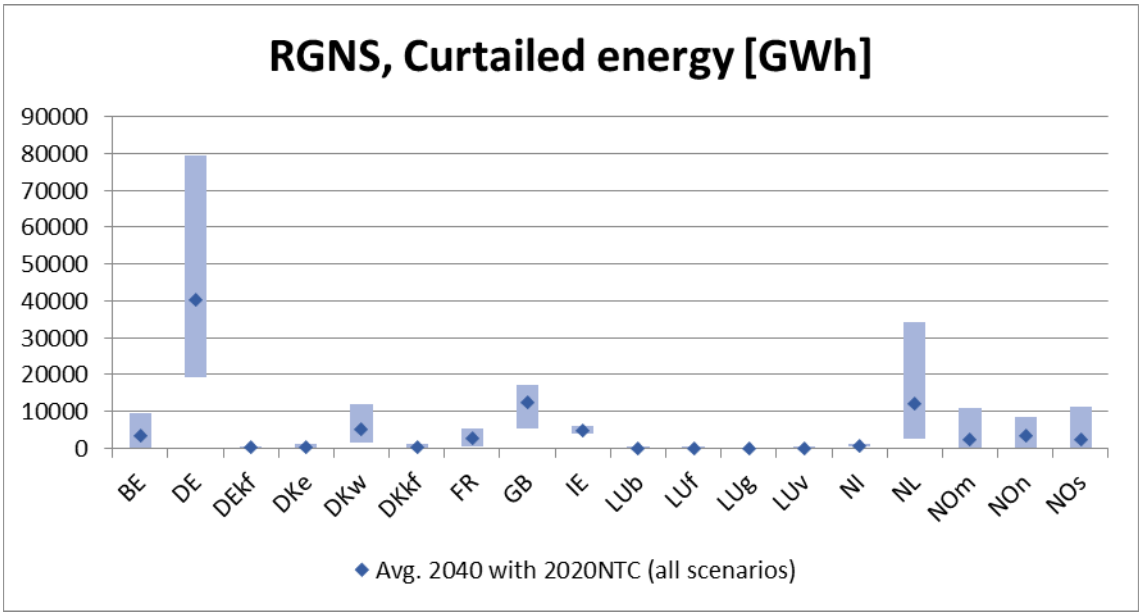

Figure 8-8: Curtailed energy in the region

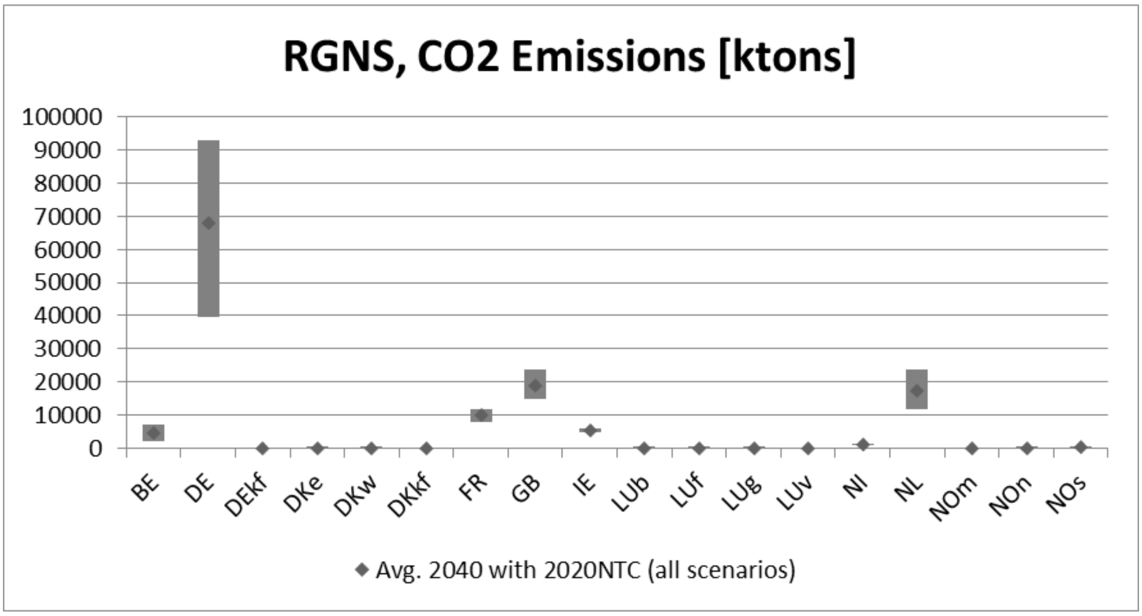

Figure 8-9: CO2 emissions in the region

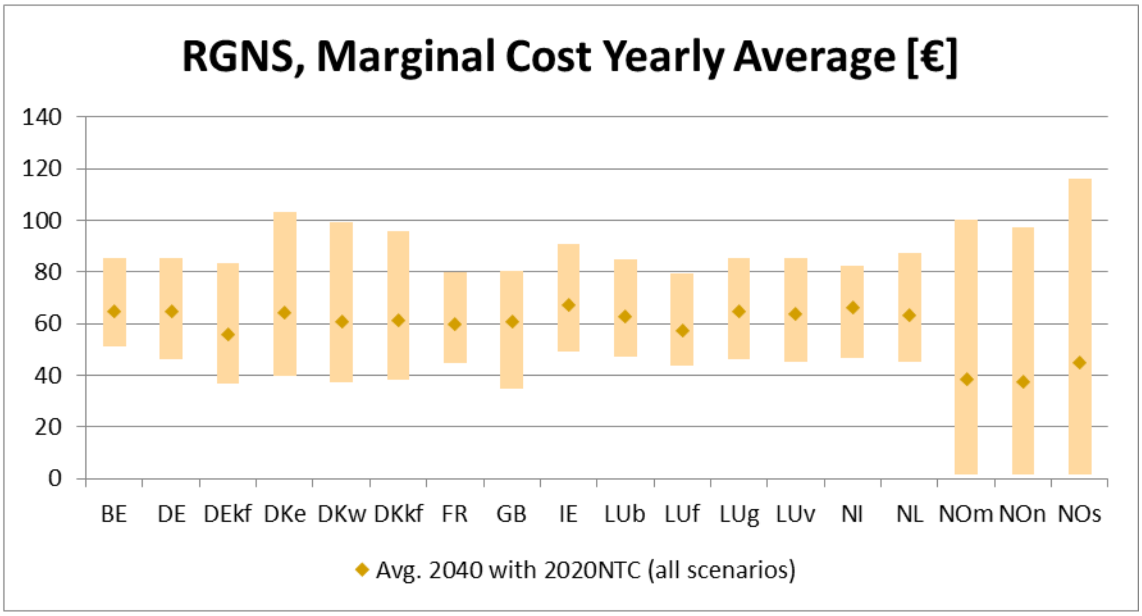

Figure 8-10: Average yearly marginal cost in the region

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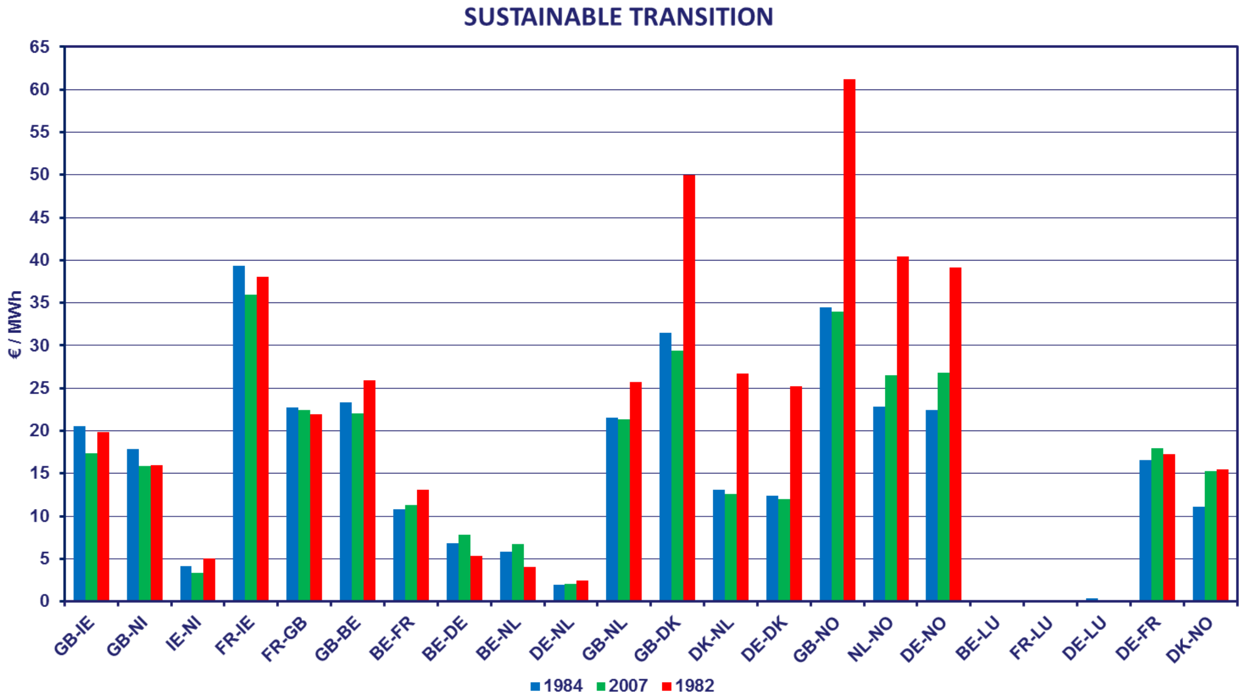


Figure 8-11: Average price differences 2040 scenarios with 2020 grid, Sustainable Transition

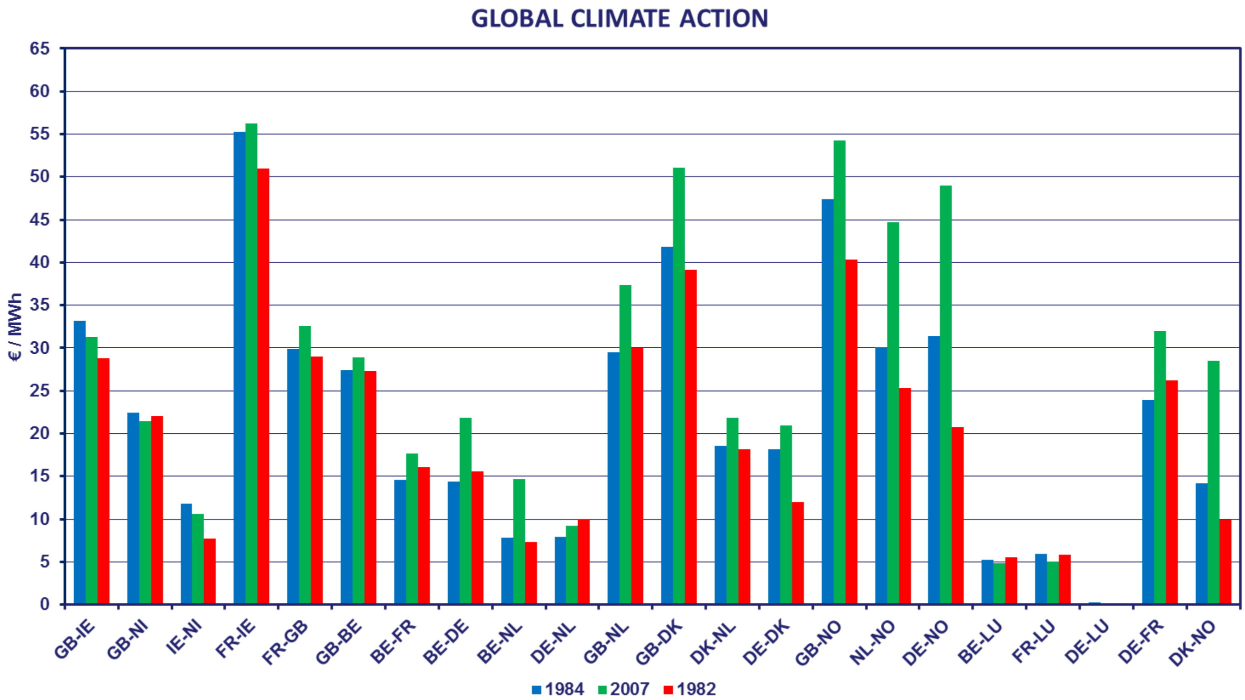


Figure 8-12: Average price differences 2040 scenarios with 2020 grid, Global Climate Action

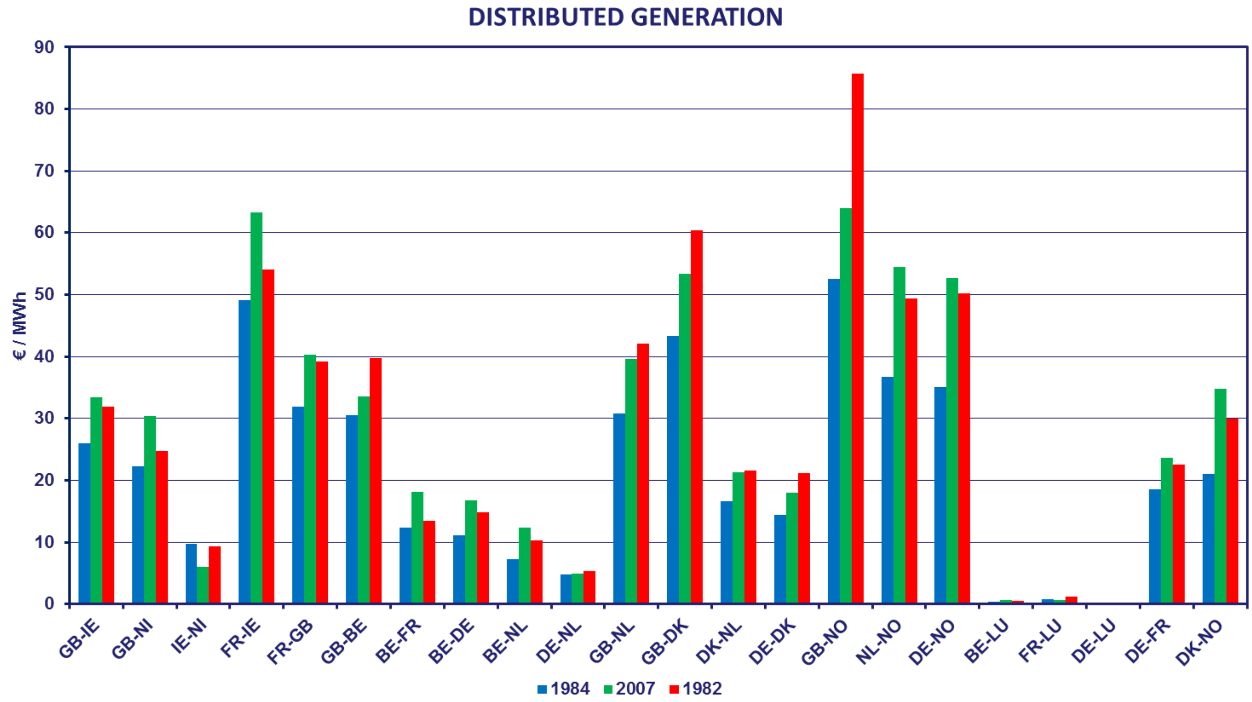


Figure 8-13: Average price differences 2040 scenarios with 2020 grid, Distributed Generation

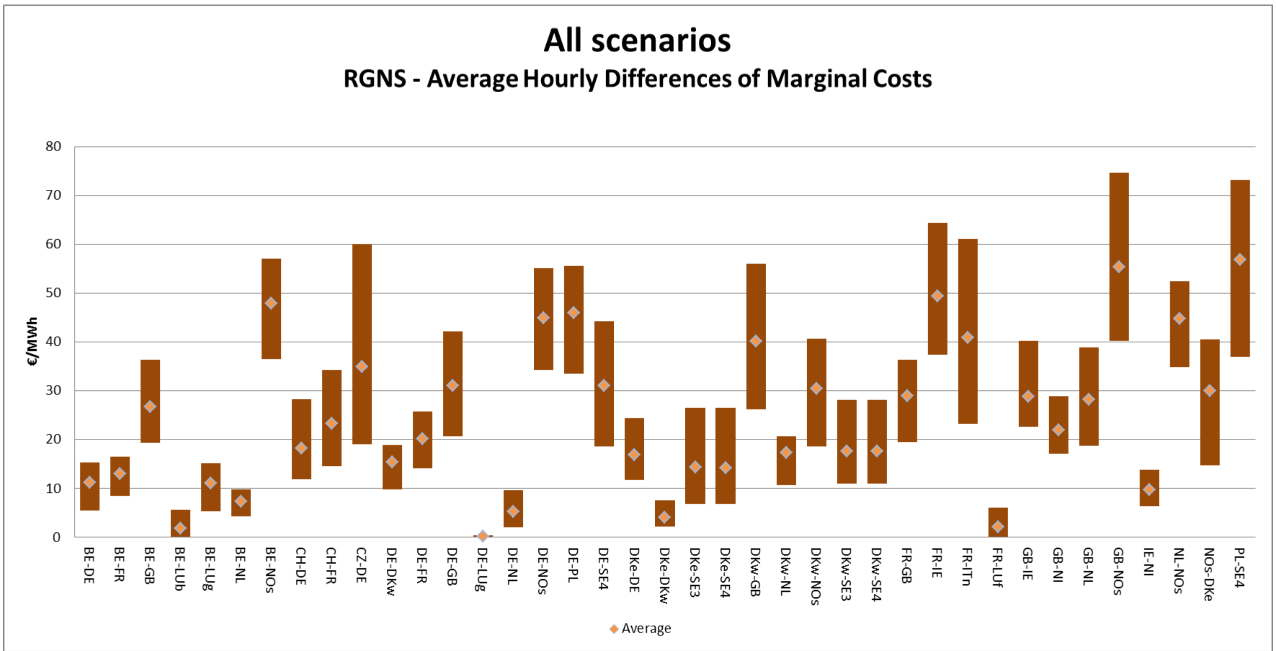


Figure 8-14: Average price differences, all scenarios

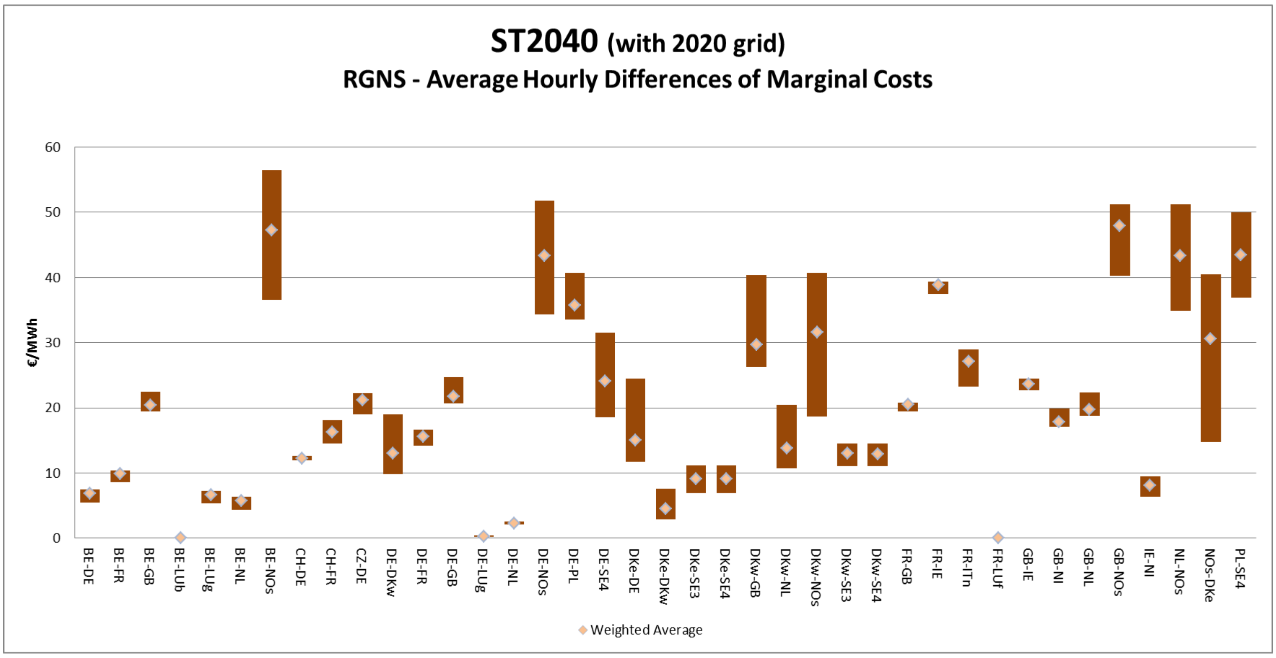


Figure 8-15: Average price differences, Sustainable Transition

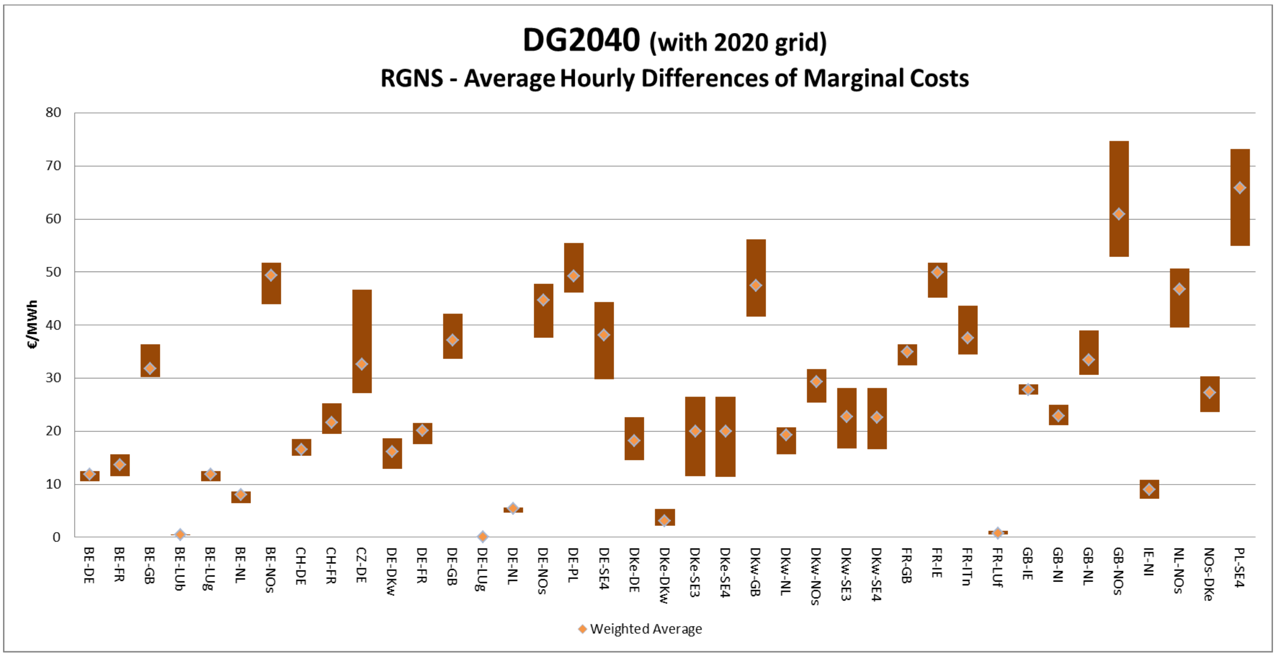


Figure 8-16: Average price differences, Distributed Generation

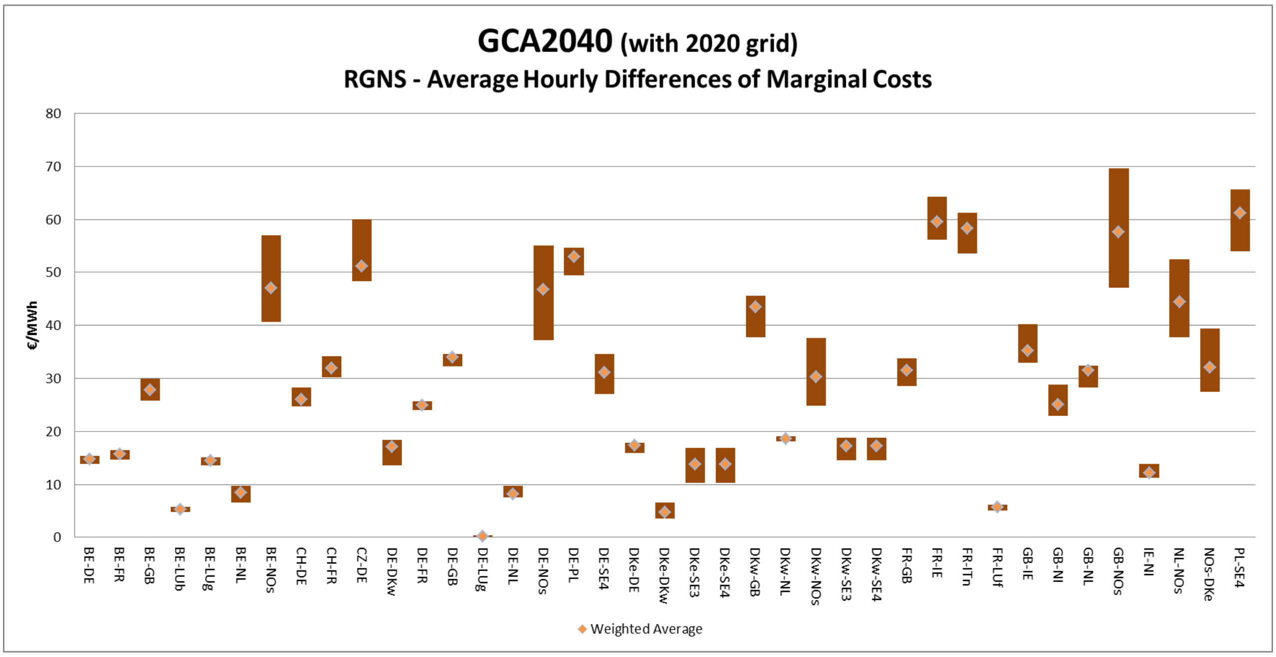
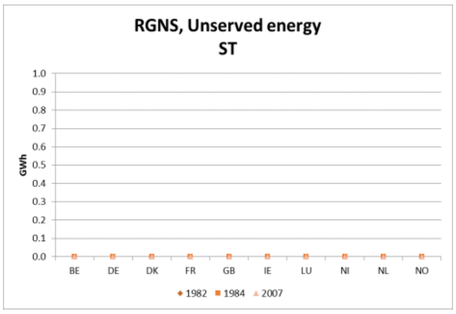
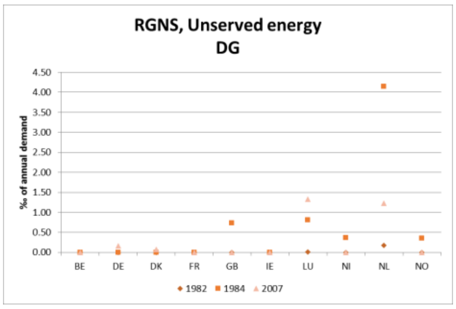
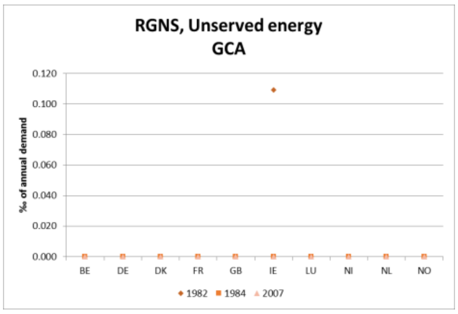
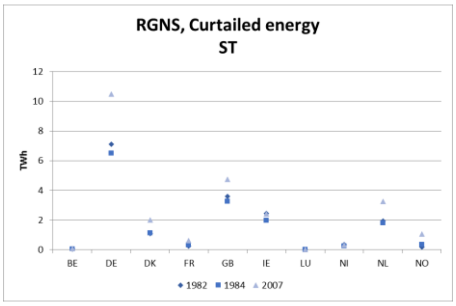
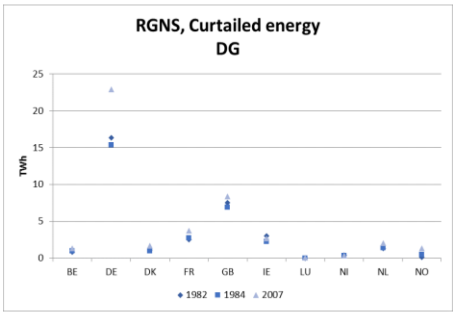
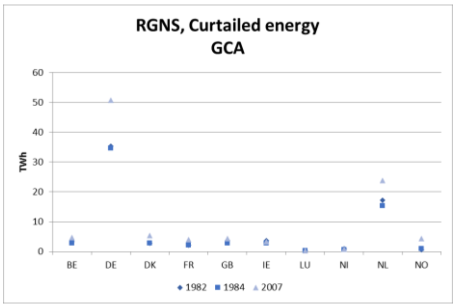
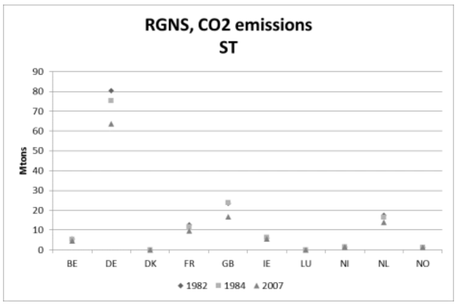
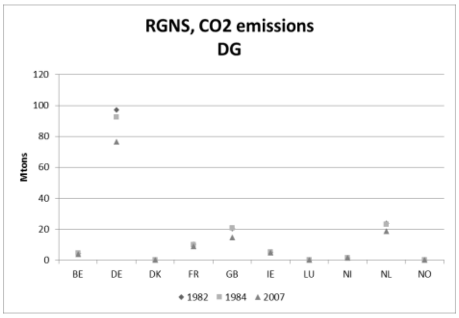
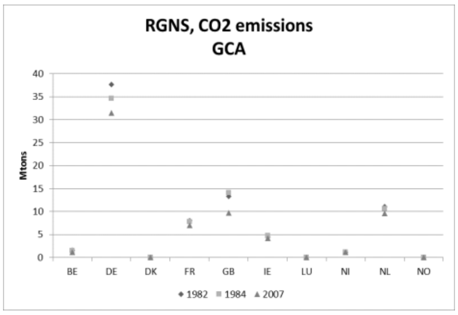
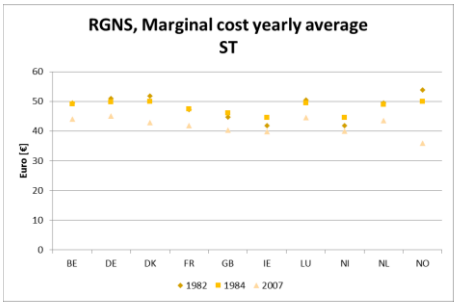
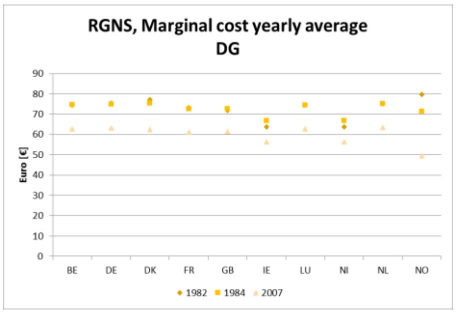
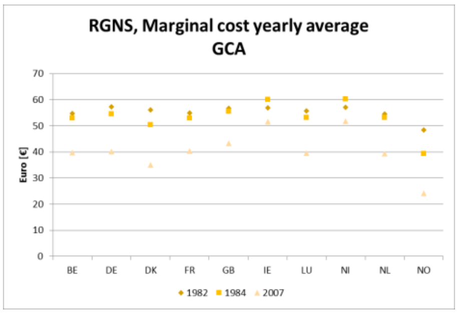


Figure 8-17: Average price differences, Global Climate Action

8.1.4 Market and network study results

Sustainable Transition 2040	Distributed Generation 2040	Global Climate Action 2040
		
		
		
		

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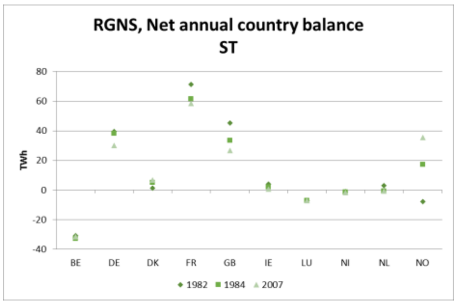
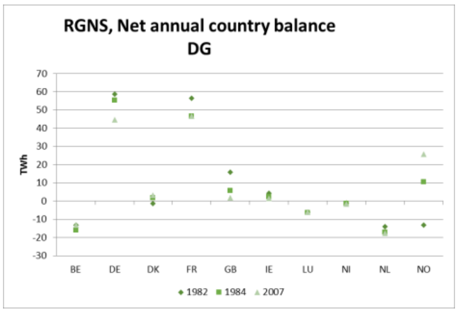
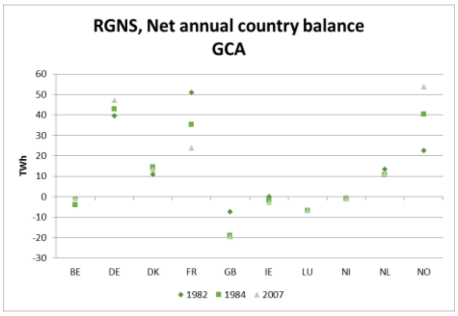
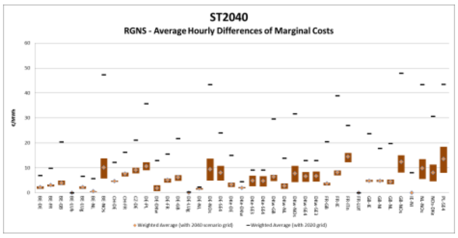
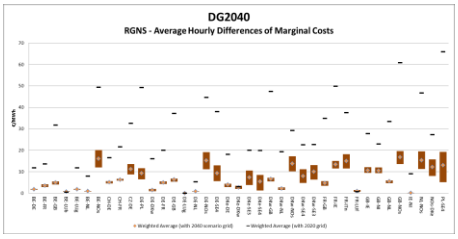
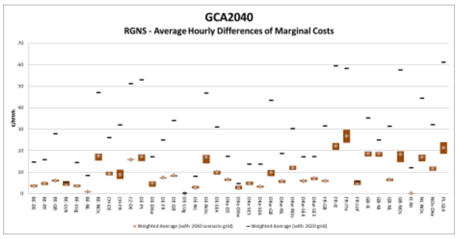
Sustainable Transition 2040	Distributed Generation 2040	Global Climate Action 2040
		
		

Figure 8-18: Detailed scenario results

8.1.5 Standard cost map

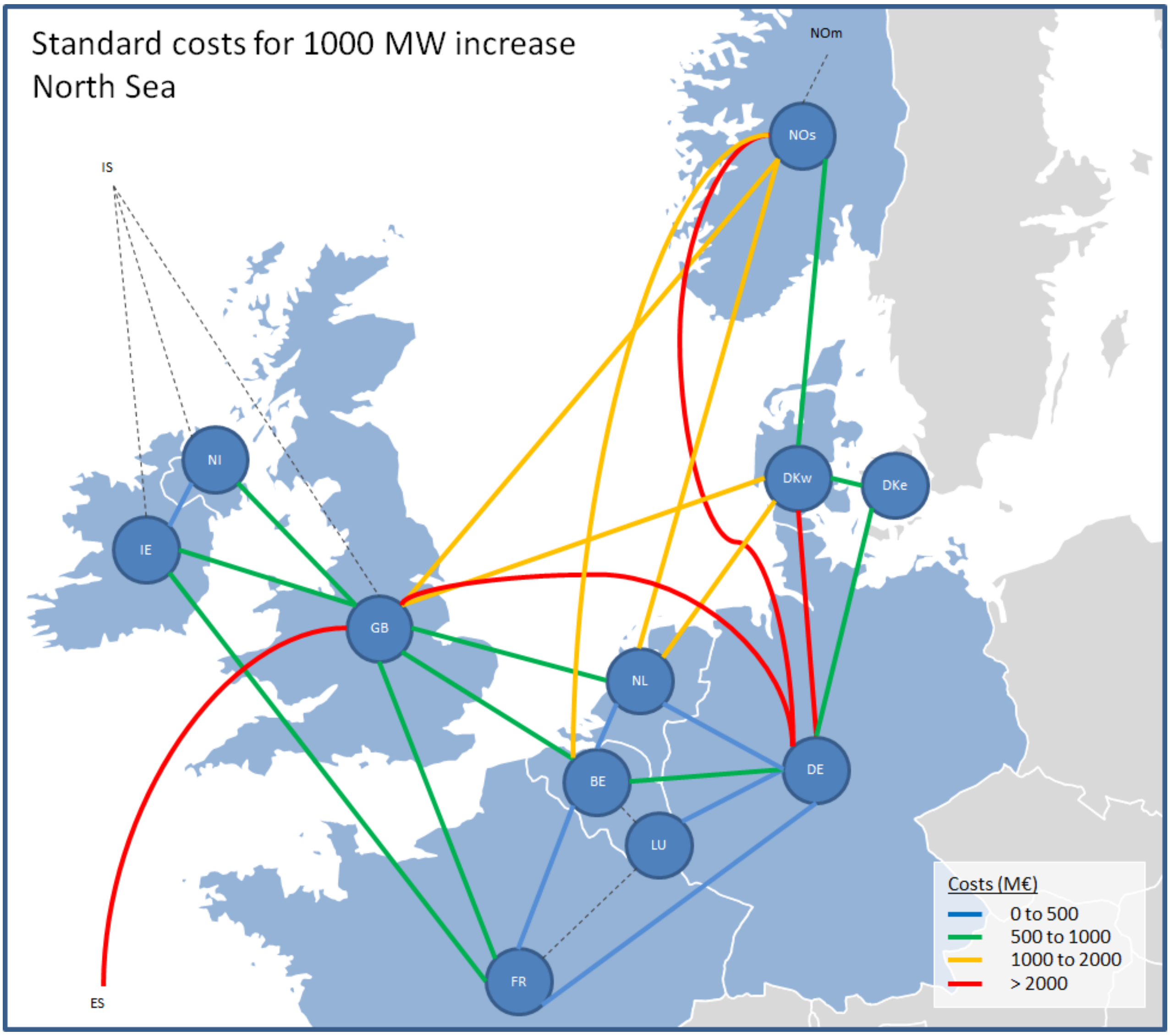


Figure 8-19: Standard cost map

8.1.6 Illustration of power flows

The graphs below illustrate the power flows resulting from the 2040 scenario capacities.

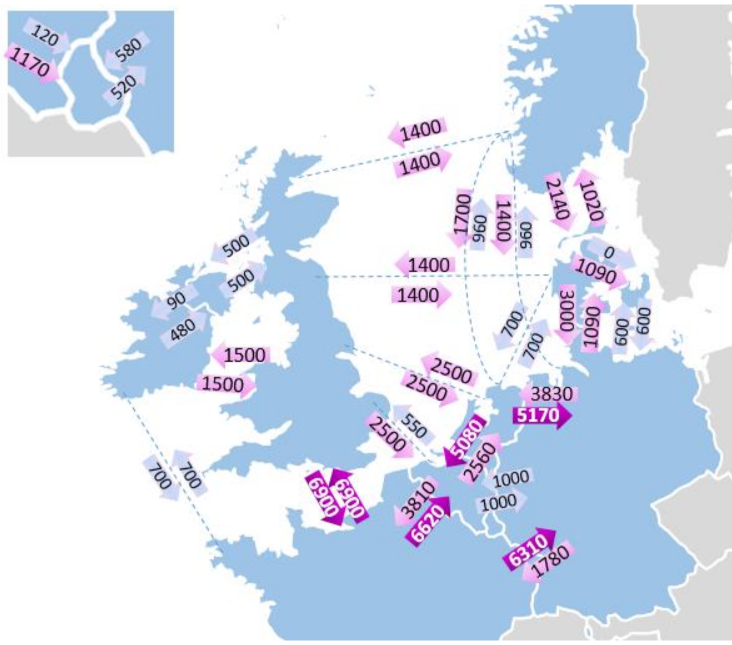


Figure 8-20: Bulk power flows (ST2040) – 5th percentile (for both directions) resulting from the 2040 scenario capacities

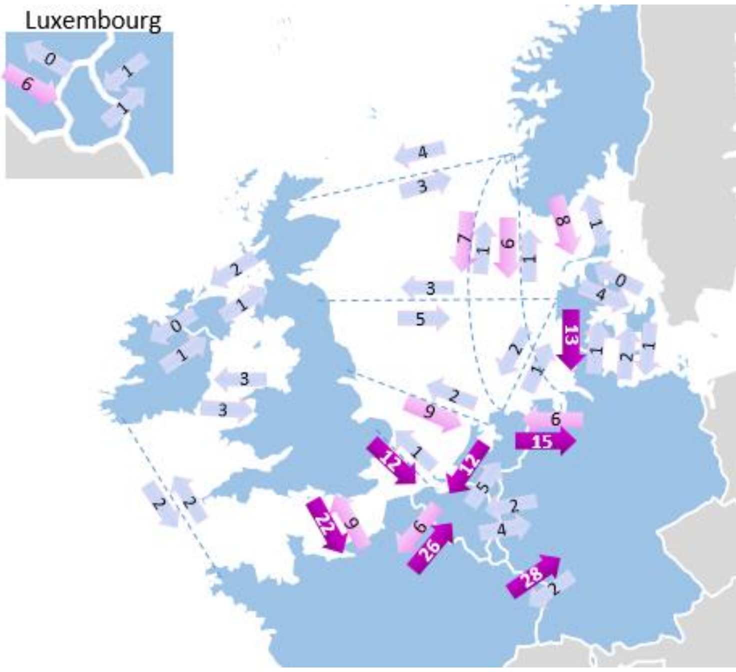


Figure 8-21: Bulk power flows (ST2040) – Yearly energy transfer (sum of physical flows, TWh) resulting from the 2040 scenario capacities

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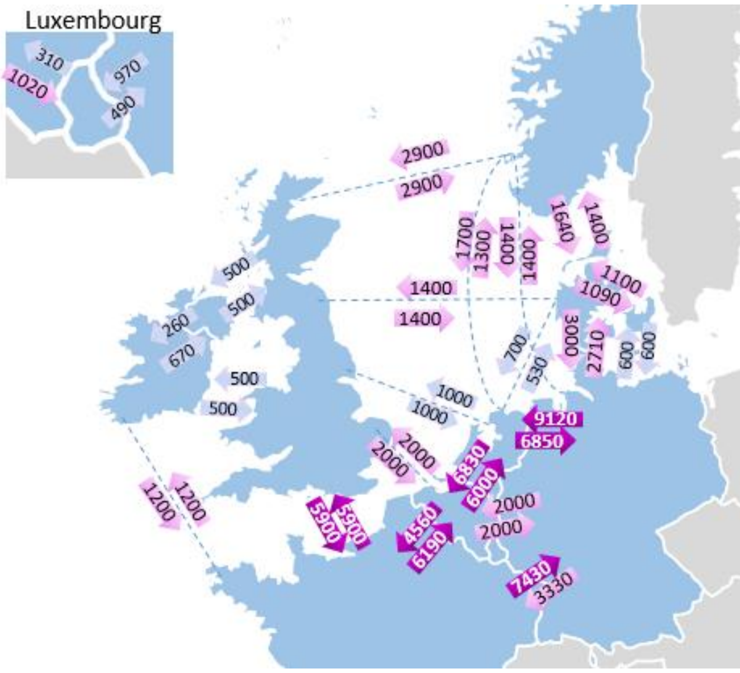

Figure 8-22: Bulk power flows (DG 2040) – 5th percentile (for both directions) resulting from the 2040 scenario capacities

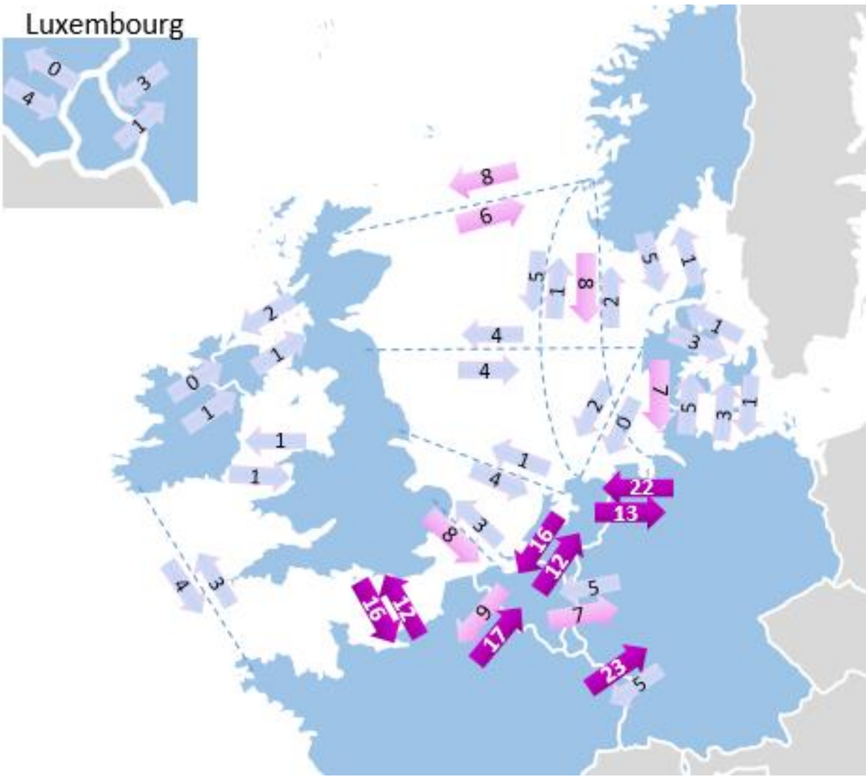

Figure 8-23: Bulk power flows (DG2040) – Yearly energy transfer (sum of physical flows, TWh) resulting from the 2040 scenario capacities

8.1.7 Illustration of congestions

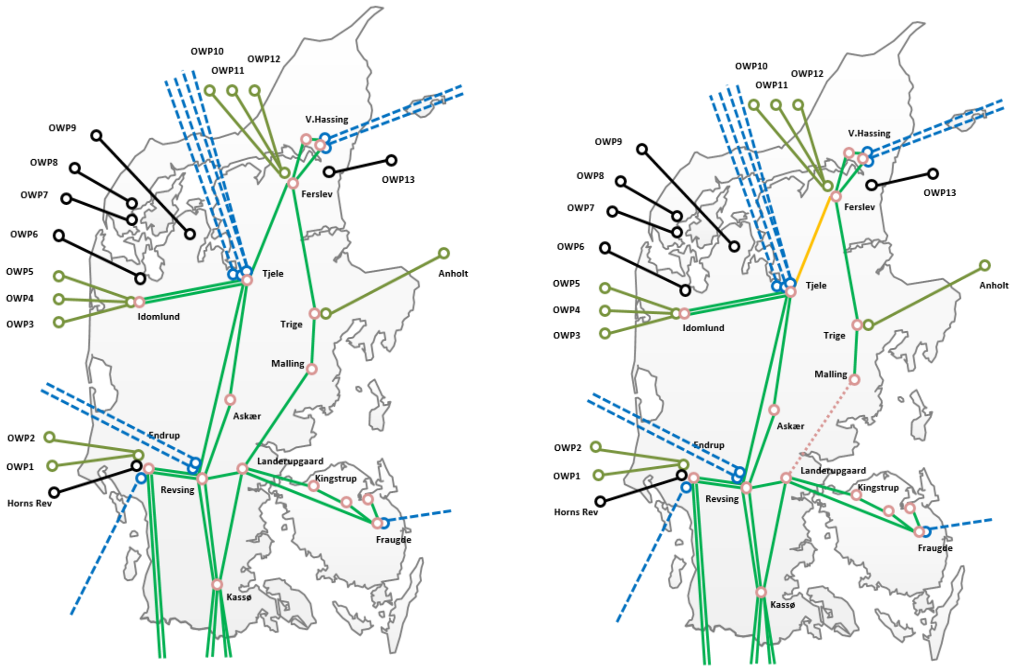

Figure 8-24: Congestions in Danish grid in N state (left) and N-1 state (right) for the power flows resulting from the DG 2040 scenario capacities

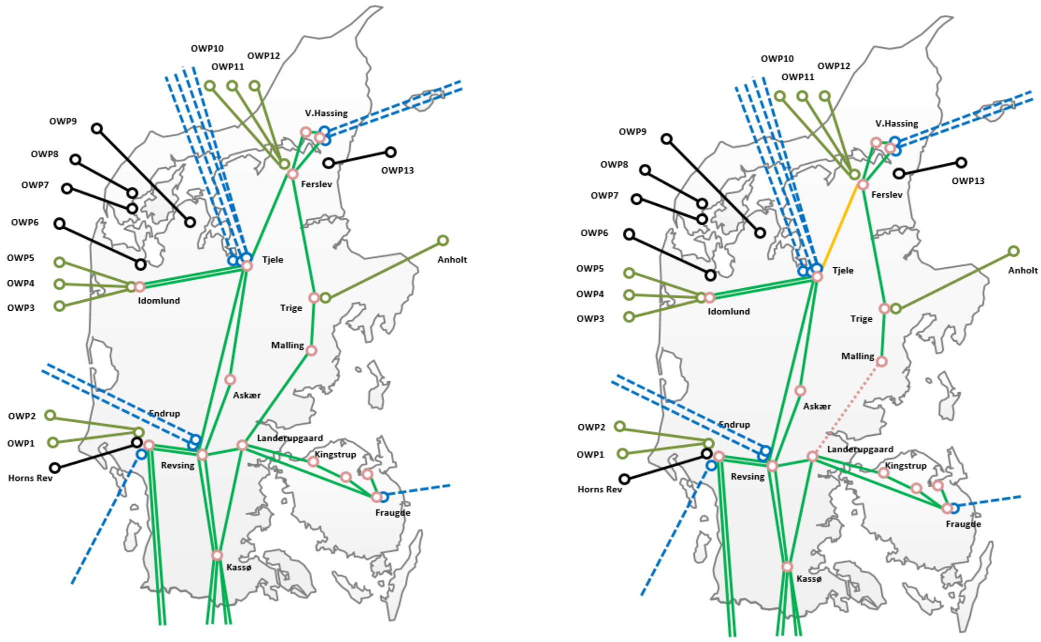

Figure 8-25: Congestions in Danish grid in N state (left) and N-1 state (right) for the power flows resulting from the GCA 2040 scenario capacities

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
- KPI Key Performance Indicator
- IEM Internal Energy Market
- 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 the Time
- PST Phase Shifting Transformer
- RegIP Regional Investment Plan

- RES Renewable Energy Sources
- RG BS Regional Group Baltic Sea
- RG CCE Regional Group Continental Central East
- RG CCS Regional Group Continental Central South
- RG CSE Regional Group Continental South East
- RG CSW Regional Group Continental South West
- RG NS Regional Group North Sea
- RoCoF Rate of Change of Frequency
- SEM Single Electricity Market (Ireland and Northern Ireland = Island of Ireland)
- SEW Socio-Economic Welfare
- SOAF Scenario Outlook & Adequacy Forecast
- SoS Security of Supply
- SNSP System Non-Synchronous Penetration: relation (RES + DC import) / total synchronous generation
- TEN-E Trans-European Energy Networks
- TOOT Take Out One at the Time
- TSO Transmission System Operator
- TWh Terawatt hour
- TYNDP Ten-Year Network Development Plan
- VOLL Value of Lost Load
- VSC Voltage Source Converter

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 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, however, 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 must 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 – 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 CO2 prices) per technology. In the real electricity market, not only the offers from generators units are considered, but taxes and other services such as ancillary services take part as well (reserves, regulation up and down…), which introduce changes in the final electricity price.

Net Transfer Capacity (NTC) – The maximum total exchange program between two adjacent control areas compatible with security standards applicable in all control areas of the synchronous area, 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 Article 4 of the TEN-E Regulation and which has been granted the label of PCI Project according to the provisions of the TEN-E Regulation.

Put IN one at the Time (PINT) – Methodology that considers each new network investment/project (line, substation, PST or other transmission network device) on the given network structure one-by-one and evaluates the load flows over the lines with and without the examined network reinforcement.

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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 (also called Total Transfer Capacity) – The maximum transmission of active power in accordance with the system security criteria that is permitted in transmission cross-sections between the subsystems/areas or individual installations.

Take Out One at the Time (TOOT) – Methodology that consists of excluding investment items (line, substation, PST or other transmission network device) or complete projects from the forecasted network structure on a one-by-one basis to evaluate the load flows over the lines with and without the examined network reinforcement.

Ten-Year Network Development Plan (TYNDP) – The Union-wide report carried out by ENTSO-E every other year as 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 wide-ranging possible alternatives.

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