European Network of
Transmission System Operators
for Electricity

Regional Investment Plan North Sea region

- Draft for consultation

24 June 2015

Contents

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1 EXECUTIVE SUMMARY

1.1 Regional investment plans as foundation for the TYNDP 2016

The TYNDP for Electricity is the most comprehensive and up-to-date planning reference for the pan-European transmission electricity network. It presents and assesses all relevant pan-European projects at a specific time horizon as defined by a set of scenarios. The TYNDP is a biennial report published every even year by ENTSO-E and acts as an essential basis to derive the next Projects of Common Interest (PCI) list, in line with the Regulation (EU) No. 347/2013 ("the Energy Infrastructure Regulation").

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.

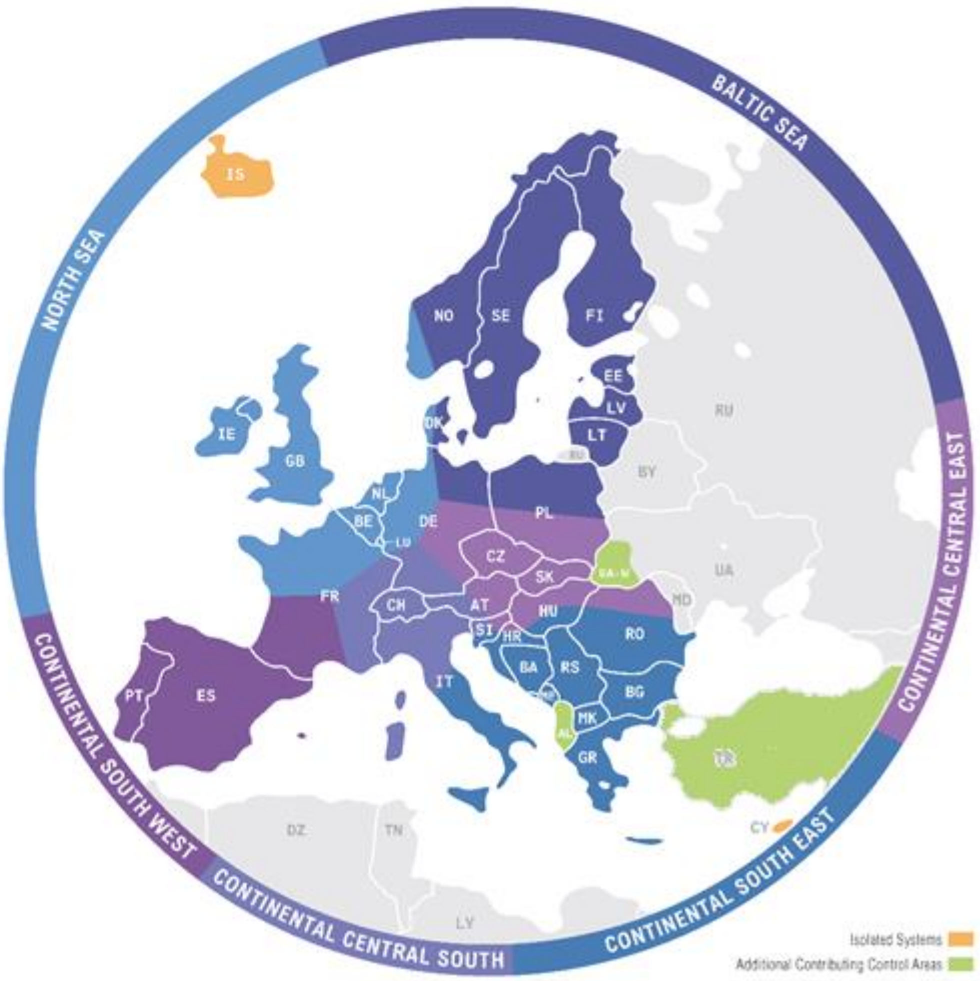

Figure 1-1 ENTSO-E System Development Regions

The TYNDP 2016 and the six Regional Investment Plans associated are supported by regional and pan-European analyses and take into account feedback received from institutions and stakeholder associations. The work of TYNDP 2016 has been split in two key phases:

- The first phase (summer 2014 to summer 2015) is devoted to common planning studies and results in the six Regional Investment Plans and the identification of a list of TYNDP2016 project candidates. During this phase also a set of TYNDP scenarios are developed.
- The second phase (summer 2015 to end 2016) will be dedicated to coordinated project assessments using the Cost Benefit Analysis Methodology (CBA) and based on common 2020/2030 scenarios. The results will be published in the TYNDP2016 report.

The common planning studies as basis of the Regional Investment Plans report are built on past TYNDP, on recent national plans, and follow a consolidated European network planning approach. It is worth noting that this is an intense and continuous work, where during the finalization of one TYNDP, the development of the next is already being initiated.

These common planning studies aim to identify the grid bottlenecks and potential investment solutions of pan-European significance for a 2030 time-horizon, in a robust, unified and consistent manner based on best available joint TSO expertise. Specifically, this report identifies cross-border and internal projects of regional and/or European significance, which allow the main European energy targets to be met with particular regard to the strengthening of the Internal Energy Market (IEM), the integration of Renewable Energy Sources (RES) and addressing security of supply (SoS) issues.

Proposed cross-border interconnections will also build on the reasonable needs of different system users, integrate long-term commitments from investors, and identify investment gaps.

The European Council has recently (October 2014 and March 2015) sent a strong signal that grid infrastructure development is an essential component of Europe's Energy Union goals, by confirming the need of an interconnection ratio of at least 10% of the installed generation capacity in every Member State by 2020. In addition, the Council also endorsed the objective of reaching a 15% level by 2030 "while taking into account the costs aspects and the potential of commercial exchanges", aiming at strengthening security of supply and facilitating cross-border trade and mandated the EC to report on their implementation. According to the Council, this is one of the pre-requisites to accomplish an effective internal market for electricity.

This panorama is one of the challenges for ENTSOE in order 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 Regional Group North Sea covers four separate synchronous power systems, which internally are linked by AC, and between the four systems by HVDC interconnectors. Regarding grid development and planning, the North Sea Region faces major challenges over the plan period, in determining the optimum solutions in facilitating an efficient European Energy market and in securing the European Network whilst accommodating connection of large volumes of renewable energy sources. These challenges lead the TSOs within the Region to evaluate, plan and conduct projects aiming at

1. maintaining the security of supply;
2. a higher integration of the European energy market ; and
3. increasing integration of renewable energy sources (wind, solar and hydro) and as a result a lower CO_2 emission.

Policies regarding the future energy mix in the region, especially regarding the future RES generation are heavily influencing the required need for additional grid infrastructure. These policies and their influence on the future energy-mix are crucial, and subject to change over the years. For instance, RES might "move

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around" in Europe, based on national policies, whilst still fulfilling the overall European targets but resulting in different interconnection needs. Therefore, several scenarios (Visions) with different amount of RES generation have been developed in order to simulate the possible consequences in a best possible way for meaningful and adequate additional grid expansion. These Visions have – especially for the high RES scenarios changed significantly between the TYNDP14 and this Common Planning Study.

Acknowledging this evolution and the related uncertainty on the adequate level of interconnection capacity, the projects resulting from this study are categorized into mid-term projects, long-term projects, future project candidates and long-term concepts (which might evolve differently over time).

Both non-ENTSO-E and ENTSO-E member projects are treated in the same way.

Investment needs – based on a generation mix shift

In general, the findings of the TYNDP14 are confirmed by the Common Planning Study. By 2030, the changes in the generation mix as described in the Visions project a significant increase in volumes of RES in the North Sea Region compared to today (especially for Visions 3 and 4)..

The additional interconnection capacity required to facilitate the envisioned RES integration whilst minimising their curtailment, would consequently result in increased power flows between the different synchronous areas and between the Member States within each synchronous area.

Although the Visions have changed, the main power flows during times of high RES infeed are still expected from EIR/UK to Continental Europe (West-East Power flow) and exchanges on the North - South axis of the Region (Norway/ NL/Denmark Germany).

The generation shift also requires a more flexible power system. The key characteristics are as follows:

a) A shift from thermal to renewable, including a nuclear phase out in Belgium , Germany and partially in France. Adding interconnectors to the system provides flexibility and avoids curtailment of variable renewable energy resources. This flexibility is required in order to integrate renewable whilst maintaining adequate power production to maintain security of supply.
b) A shift from coal to gas is expected .The analysis shows that new interconnectors between the different synchronous areas of the North Sea Region, leads to large reduction of regional CO_2-emissions.
c) Controllable fossil-fuel generation (gas, coal and to some extent nuclear) are expected to be decommissioned and replaced by less -controllable generation (wind and sun), which also requires more flexibility in system services for operations to maintain security of supply and (Regional) system adequacy.

Interconnectors will lead to increased Market and RES-integration and add flexibility to the system. Overall this supports a reduction of CO_2-emissions.

The interconnections across the Northern seas further facilitate the connection between the hydro-based Nordic system with seasonal patterns and the increasingly wind/solar –based UK and Continental systems with hourly patterns.

The development of interconnections facilitates cross-border support from areas with surplus capacities to areas facing from time to time security of supply challenges. (e.g. low wind, low solar, other meteorological events, outages etc.). As a result additional needs for higher interconnection-capacities and improved market cooperation between all the four synchronous power systems around the North Sea are foreseen. The four areas represent different but complementing skills (hydro, wind, sun, nuclear). Especially the improved cooperation between the Nordic system (mainly hydro-based) and the continental and UK system

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(wind, sun, thermal based) are contributing to required adequacy levels crucial for maintaining the security of supply in the broader European power system.

Foreseen market generation mix developments also create a need for higher integration and improved market design. The more RES based generation mix of the region North Sea will increase the need for additional market as well as grid capacity between the synchronous areas.

As the generation portfolio evolves, the opportunities of electricity trade between market players changes accordingly. The grid should be developed in order to support these new exchange possibilities, facilitating the access to the most economic energy mix, while minimizing grid congestions.

The North Seas Offshore infrastructure, both radial and coordinated connection of offshore wind parks and point to point interconnections to connect market areas both with AC and DC, is under development already. ENTSO-E strongly believes that the proposed solutions, given the current status of technology, should be seen as main facilitators of RES- and market integration and therefore will become part of an adequate and necessary North Seas offshore grid in the future.

Finally, related to the changing future energy mix in the region, it needs to be stated that market related volatility in location, timing and use of new generation (RES and Fossil generation) makes it necessary for TSOs to stay close to the market developments in order to facilitate the market developments with future grid extensions in an adequate way.

1.3 New project candidates identified in Common Planning Studies TYNDP 2016

The investment package proposed in TYNDP 2014 is the backbone of grid development in the region until 2030. The common planning studies for the regional investment plans 2015 were done to identify additional investment needs on top of previously proposed investments. The common planning studies were mainly done in a pan-European coordinated manner to find the additional investment needs in a scenario with a large amount of renewable. For this purpose Vision 4 from TYNDP 2014 was used. In addition, regional sensitivities relevant to the respective region were executed (mainly using the new developed Vision 3).

Table 1 below shows the future project candidates identified by a Common Planning Study. These cover 3 borders (BE-DE, GB-BE, FR-BE) for which first signals of capacity increase in high-RES conditions had been introduced in TYNDP14 as projects under consideration and 5 borders (GB-FR, GB-NL, DKW-NL, NL-DE, BE-NL) with capacity increases being new compared to the TYNDP14 project list.

North Sea studies did not investigate explicitly the border between Germany and France, on which more information can be found in the Regional Investment Plan of the Continental Central South region.

Beside these 8 borders, 14 more borders have been investigated, reconfirming the TYNDP14 project list.

Tableau 1-1 : Future project candidates identified by the Common Planning Studies

Borders	Current Capacity online in 2015 [MW]	Projects in TYNDP 2014 Starting point for Common Planning Studies [MW]	Future project candidates identified in RegIP 2015 [MW]	Total suggested Capacity 2030 “HIGH RES Target capacity” [MW]
BE-DE	0	1000	1000	2000
GB-BE	0	1000	1000	2000
FR-BE	3300/1800	1000	1000	5300/3800
GB- FR	2000	3400	1000	6400

GB-NL	1000	0	1000	2000
DKW-NL	0	700	700	1400
NL-DE	2500	1500 500 500	1000	6000
BE-NL	1400	1000	1000	3400

The gaps or the need for a longer term perspective (> 2030)
The TYNDP14 Vision 4 is used to produce a so-called High RES target capacity, i.e. the capacity proposed to support the assumed RES included in that particular Vision. However, for some countries (Great Britain) the new Vision 4 changed significantly compared to the TYNDP14 visions based e.g. on stakeholder comments. By nature, Visions always will evolve over time reflecting political developments.

Different views of the future result in different interconnection needs. The visions used have been translated into the projects above and some future term perspective. The exploration of the TYNDP 2014 Vision 4 scenario helps to inform higher RES settings in the light of meeting the more ambitious 2050 targets, and thus relates to longer term grid development beyond 2030. The scenario demonstrates there is potential for significant increase in market exchange capacity.

Given the uncertainties involved in the long-term development of the generation portfolio, the need to implement them must be carefully monitored in order to balance their timely delivery versus the inherent risk of stranded assets.

Furthermore, the Common Planning Study initiates the reflection upon novel grid development concepts like a West-East Corridor and a further development of the Northern Seas Offshore infrastructure. These potential developments might span multiple borders with potential multi-terminal solutions and require further detailed studies.

Non-nominated project candidates
The Common Planning Study also showed potential for a new interconnector between Norway and the Netherlands. The Norwegian TSO Statnett has already built and are planning to build several interconnectors out of southern and western part of Norway in a succession up until 2021: NorNed (2008), Skagerrak 4 (2014), NordLink (2020) and NSN (2021). Prior to the assessment of a further increase in capacity out of southern Norway, there is a strong need for Norwegian investigations of internal grid challenges when having implemented all these interconnectors. Therefore at this moment no nomination for a new interconnector between Norway and the Netherlands has been added as a new project-candidate, even though the Common Planning Studies show the potential benefits of such an additional interconnector.

All the nominated new project-candidates will, together with the re-confirmed TYNDP 2014-projects as well as non-ENTSO-E member projects, go into the CBA-assessment for the TYNDP 2016.

Figure 2 shows a synthesis of pan European cross borders projects. Much more details on the project list are given in chapter 5.

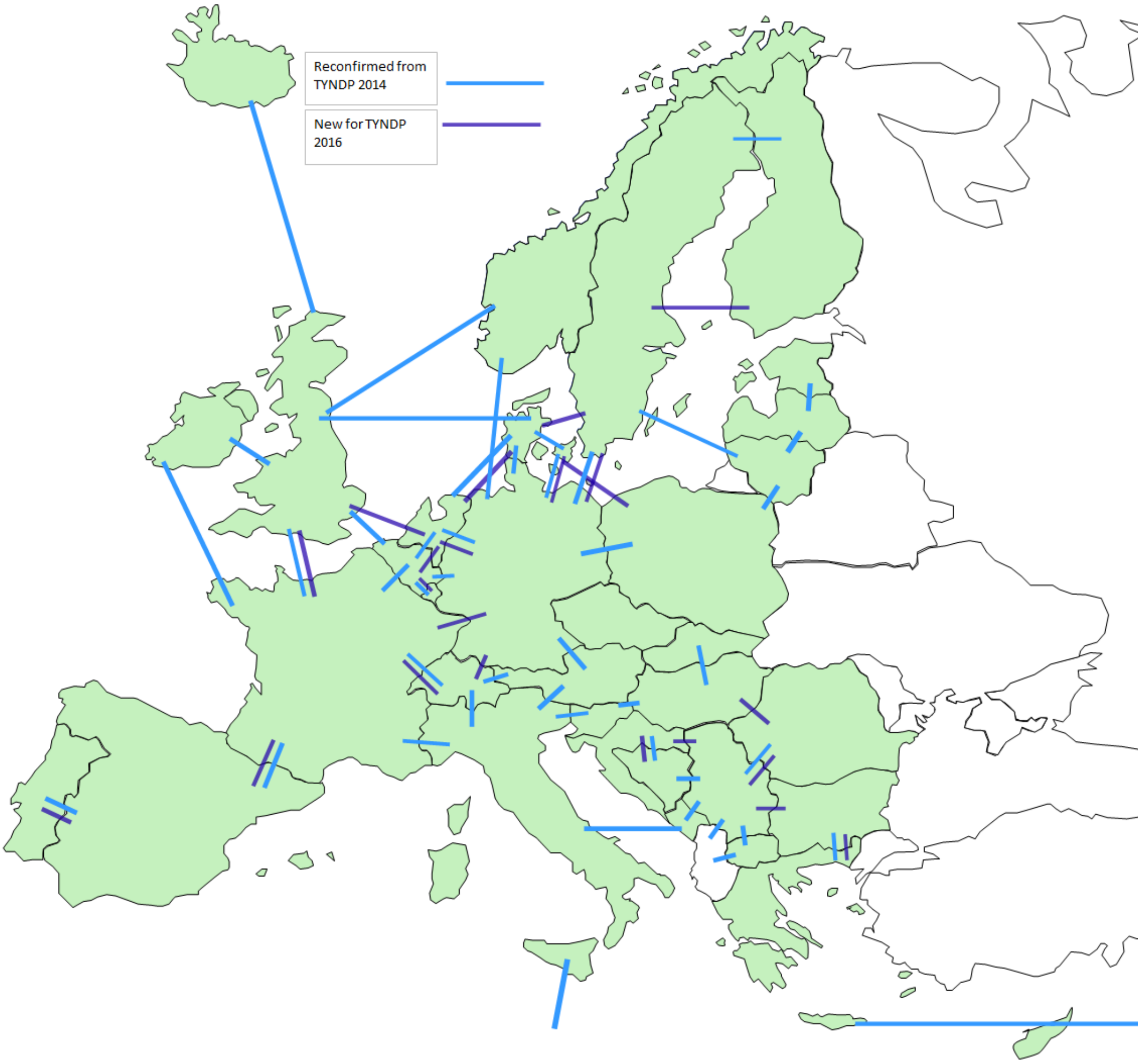

Figure 1-2 : Cross-border TYNDP 2016 project candidates

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2 INTRODUCTION

2.1 General and legal requirements

The TYNDP 2016 package, developed over the course of two years, will be composed of the following documents:

- The **TYNDP report** provides a helicopter view on the grid development in Europe, it shows where progress is made and where support is still needed, and it provides a standardized assessment of all projects of pan-European significance.
- The **six Regional Investment Plans** analyse the power system development from a regional perspective, based on common guidelines, and identify investment needs linked with a set of proposed projects.
- The **Scenario Development Report** sketches a set of possible futures, each with their own particular challenges, which the proposed TYNDP projects must address. All TYNDP projects are assessed in perspective of these scenarios.
- The **Scenario Outlook & Adequacy Forecast (SO&AF)** is delivered every year and assesses the adequacy of generation and demand in the ENTSOE interconnected power system on mid- and long-term time horizons.
- The **Cost Benefit Analysis Methodology (CBA)** as developed by ENTSO-E and adopted by the EC, allows the assessment of infrastructure projects in an objective, transparent and economically sound manner against a series of indicators which range from market integration, security of supply, integration of renewable energy sources (RES-E) to environmental impact.

The Regional Investment Plans are published in summer 2015 and focus on regional planning studies and the identification of the pan-European project candidates. It provides key information to understand the need for new projects, which are listed and published for public consultation until mid-September.

The Regional Investment Plans are complemented by a monitoring update of the TYNDP 2014 investments, providing insight in the changed status of these items and possible reasons.

The TYNDP report will be delivered by end of 2016 and will concentrate on individual project assessments based on common scenarios, data and CBA methodology.

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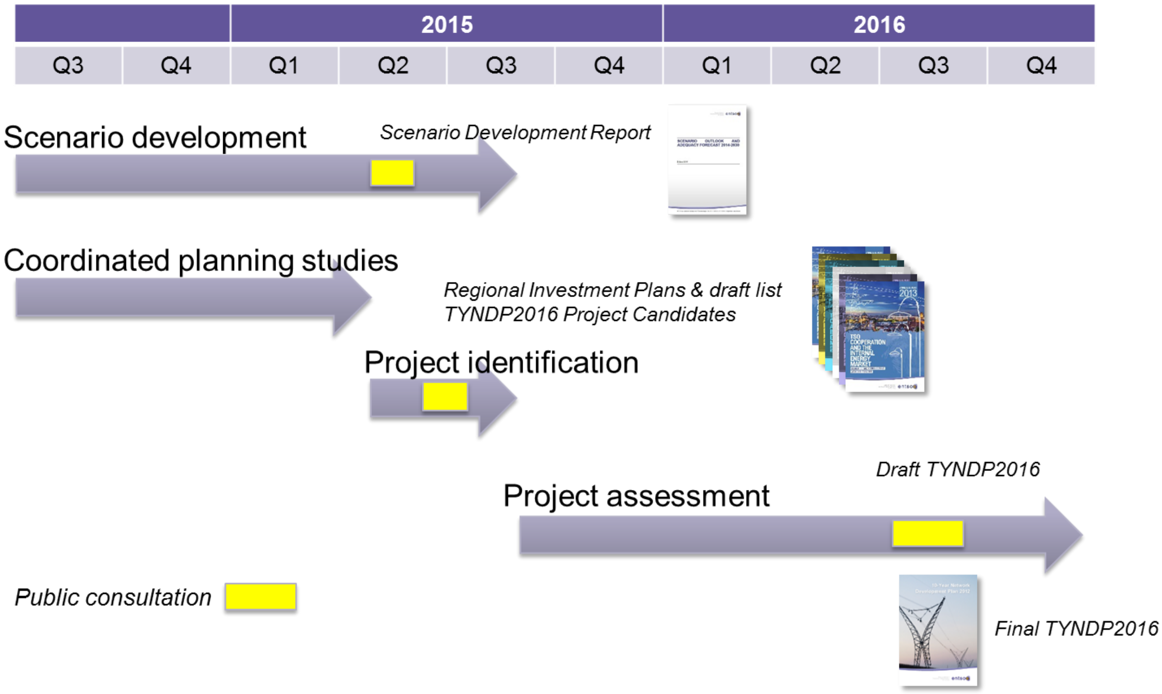

Figure 2-1 Overview of a two-year TYNDP process

The present publication complies with Regulation (EC) 714/2009 Article 12, where it is requested that TSOs shall establish regional cooperations within ENTSO-E and shall publish a regional investment plan every two years. TSOs may take investment decisions based on that regional investment plan. ENTSO-E shall provide a Community-wide ten-year network development plan which is built on national plans and reasonable needs of all system users, and identifies investment gaps.

As of 2016, the TYNDP package must also comply with Regulation (EU) 347/2013 ("the Energy Infrastructure Regulation"). This regulation organises a new European governance to foster transmission grid development. It establishes Projects of Common Interest (PCIs), foresees various tools (financial, permitting) to support the realisation of these PCIs, and makes the TYNDP the sole basis for identifying and assessing the PCIs according to a Cost-Benefit-Analysis (CBA) methodology. The ENTSO-E CBA methodology has been developed since 2012, based on stakeholder consultation, and the opinions of ACER, Member States and EC; it has been adopted by the EC in February 2015. Work continues to further improve the methodology

This Regional Investment Plan as such is to provide information on future European transmission needs and projects to a wide range of audiences:

- Agency for the Cooperation of Energy Regulators (ACER) who 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 in how various targets influence and complement each other;
- Energy industry, covering network asset owners (within ENTSO-E perimeter and the periphery) and system users (generators, demand facilities, and energy service companies);

- National regulatory authorities and ministries, to place national energy matters in an overall European common context;
- Organizations having a key function to disseminate energy related information (sector organizations, NGOs, press) for who this plan serves as a "communication tool-kit";
- The general public, to understand what drives infrastructure investments in the context of new energy goals (RES, market integration).

2.2 The scope of the report

The scope and focus of the present Regional Investment Plans has evolved as compared to the past editions of 2014. This Regional Investment Plan focuses on a set of common planning studies performed across ENTSO-E's regions with particular attention for the context of each individual region.

The Regional Investment Plan presents the methodologies used for these studies, relevant results and assumptions, and the resulting list of the project candidates as nominated by project promoters.

At present no detailed CBA analysis is provided in the Regional Investment Plan. This will be a key element of further studies leading to the final TYNDP2016 report to be released next year. This regional report takes the opportunity also to inform readers on regional context, studies and projects.

These studies re-confirm the main findings past TYNDP studies as well as others in terms of main corridors, general scenarios, and the key conclusion that an energy shift requires targeted future-proof infrastructure.

2.3 General methodology

This Regional Investment Plan 2015 builds on the conclusions of a Common Planning Study carried out jointly across the six regions of ENTSO-E's System Development Committee. The aim of this joint study is to identify investment needs triggered by market integration, security of supply, RES integration and interconnection targets, in a coordinated pan-European manner building on the expertise of all TSOs. These investment needs are translated to new project candidates where possible, and give in most cases a re-confirmation of past TYNDP2014 projects. This chapter explains the overall planning process of how project candidates have been identified by market studies, network studies and regional knowledge. More details about this process as well as regional intermediate steps can be found in Appendix 7.1 and 7.2.

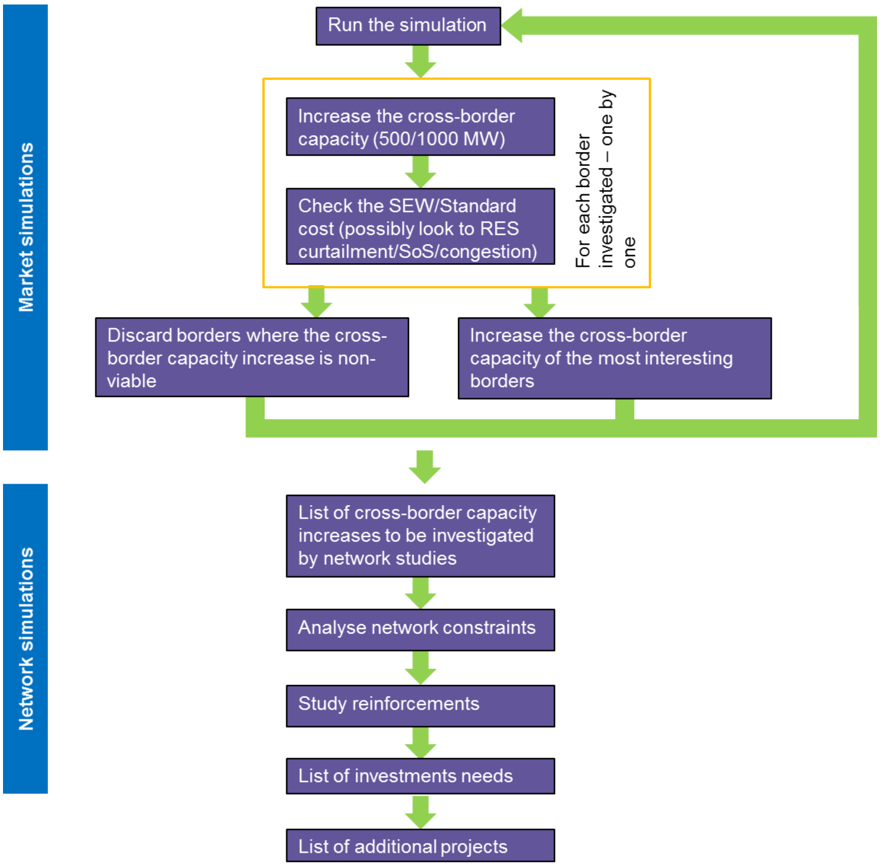

Figure 2-2 Common Planning Study workflow

Market Studies

All regions have jointly investigated all borders in order to identify the most beneficial ones based on a criteria of SEW/cost-ratio. The SEW indicator represents the socioeconomic welfare of a full-year market simulation. The cost indicator is an estimation of the capex of a potential cross-border capacity increase, including necessary internal reinforcements. Note that both indicators for a given capacity do not represent the same level of detail as the cost and SEW indicator retrieved in a CBA assessment for a specific project.

The analysis is carried out across the ENTSO-E perimeter in several iterations, each time increasing border capacities identified as being most valuable for the European system.

It is worth pointing out that this approach includes some simplifications. The most important one is that it simplifies the benefits just as SEW, without taking into account additional benefits, which are possibly more difficult to monetize than the savings in variable generation cost. Another one is the fact that the candidate projects are not yet defined by the time they are simulated. Therefore the expected GTC increase is a standard value (e.g. 1 GW) and the costs of the projects are assessed by expert view, taking into account the specificity of the area (e.g. mountain, sea). Cost of internal grid reinforcements considered as needed to get the expected GTC increase is also included in the cost of the candidate projects.

As a reference scenario the TYNDP2014 Vision 4 is taken, which represents the most challenging scenario coming from the present day situation and the most useful to identify new investment needs. Even if this scenario does not become reality by 2030, it can for the purpose of this planning study still be seen as a step between 2030 and 2050. In addition to the pan-European study iterations, regions repeated the exercise or performed a sensitivity analysis on the outcome to gain additional insight in relevant investment needs that trigger project candidates.

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Network Studies

Following these market simulations, network studies on detailed grid models show possible bottlenecks that would not allow the result from the market studies come true. This allows to explore reinforcements, to design suitable project candidates and update market-based target capacities resulting from the initial market study iterations. Depending on the models and tools used in a region, the translation from market to network studies can be done in two ways:

1. Select and study an adequate number of representative Points In Time (PiTs), based on the flow duration curves for the each studied border. Complemented this with a second analysis of the regional grid by means of a Power Transfer Distribution Factor (PTDF) matrix which gives approximate flows.
2. Compute all 8760 hours in a year with demand and generation dispatch profiles obtained from market studies in full DC load flow calculations.

These network analyses allow to test **project candidates**, as suitable grid reinforcements to eliminate bottlenecks.

Regional knowledge

Market studies focus primarily on SEW/cost-ratios. Network studies identify additional (internal) capacity needs. Sensitivity studies of market simulations (e.g. an extreme condition) and in particular network studies allow to capture additional views and model interpretations based on regional experts, and in many cases complementing the findings of national development plans and/or past studies.

2.4 Report overview

This chapter describes how the report is built up and the content of the different chapters.

Chapter 1 – Executive Summary

In this section the key take-aways of the region are presented and it is explained how the development of the report fits into the TYNDP2016 process.

Chapter 2 - Introduction

This chapter sets out in detail the general and legal basis of the TYNDP work, the overall scope of the report and its evolutions compared to the previous regional and TYNDP plans. The reader is presented with a short summary of the planning methodology used by all ENTSO-E regions.

Chapter 3 – Regional Context

This chapter describes the general characteristics of the region, in the as-is situation and in anticipated evolutions up to 2030 and beyond. It gives a general overview of TSO collaboration efforts in regional planning based on pan-European methodologies and coordination.

Chapter 4 – Regional results

It gives a synthetic overview of the basic scenarios and assumptions used in common planning and the overall results. The results are also placed in perspective of further ahead challenges and roadmaps leading up to 2050.

Chapter 5 – Project candidates

This chapter gives an overview of all projects proposed by promoters in the region, labelled as either TYNDP projects or projects of regional relevance. It links these projects to investment needs identified in ENTSOE joint TSO studies, clarifies possible barriers to address these system needs, and gives the baseline for future project CBA assessments (e.g. by means of boundary reference capacities).

Chapter 6 – Next steps

This chapter presents a look forward on how the TYNDP work will continue in the next year, leading to a full TYDNP2016 report.

Chapter 7 – Appendices

This chapter gives more insight in the used methodologies, as well conducted market and network studies.

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3 REGIONAL CONTEXT

The North Sea Regional Group (NS RG) under the scope of the ENTSO-E System Development Committee is among the 6 regional groups for grid planning and system development tasks. The countries belonging to each group are shown in Figure 3-1 below. NS RG itself consists of 10 countries, given in table 3-1 with the corresponding Transmission System Operator.

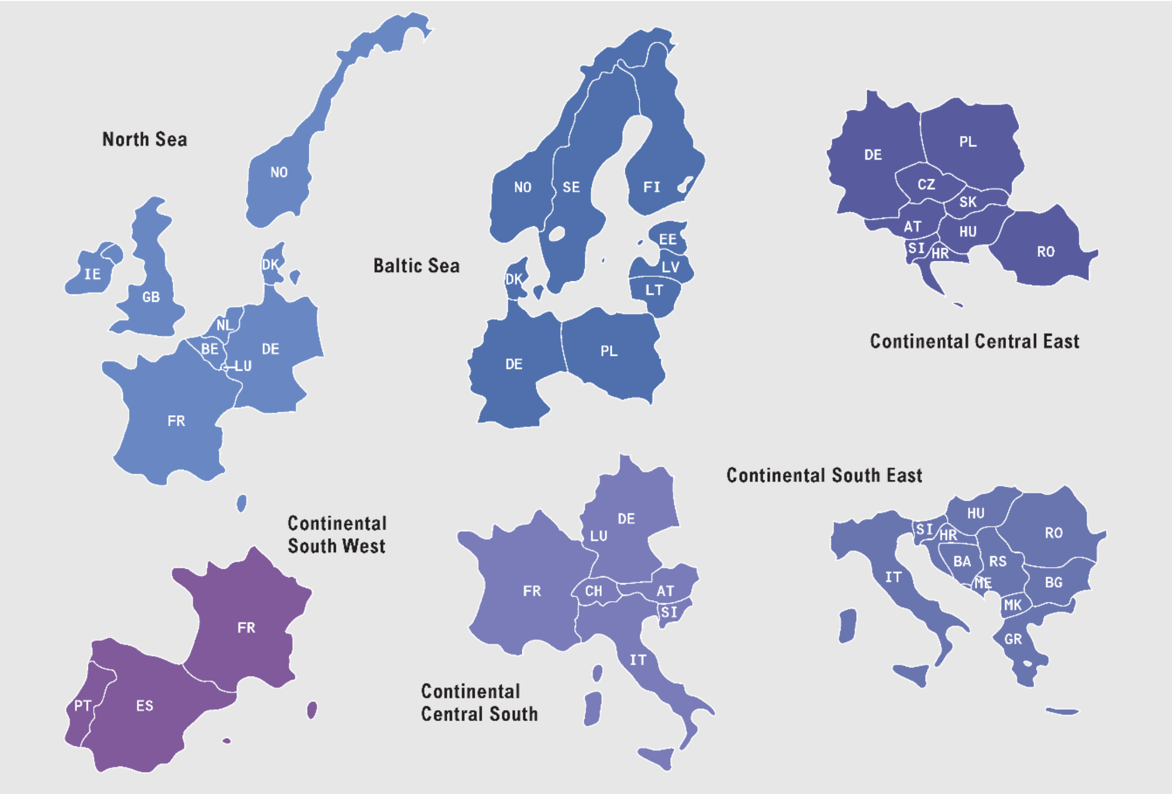

Figure 3-1 : ENTSO-E regions (System Development Committee)

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

Table 3-1: ENTSO-E Regional Group North Sea membership

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3.1 Present situation

The Regional Group North Sea covers four separate synchronous power systems (Figure 3-2), which internally are linked by AC, but between the four systems linked by HVDC interconnectors.

Figure 3-2: North Sea synchronous areas

Regarding grid development and planning, the North Sea Region faces major challenges over the plan period, in determining the optimum solutions in facilitating an efficient European Energy market and in securing the European Network whilst accommodating connection of large volumes of renewable energy sources. These challenges lead the TSOs within the Region to evaluate, plan and conduct projects aiming at (1) maintaining the security of supply, (2) a higher integration of the European energy market (3 (3) increasing integration of renewable energy sources (wind, solar and hydro) and as a result a lower CO_2 emission. Policies regarding the future energy mix in the region, especially regarding the future RES generation are heavily influencing the required need for additional grid infrastructure. These policies and their influence on the future energy-mix are crucial, and subject to change over the years. For instance, RES might “move around” in Europe, based on national policies, whilst still fulfilling the overall European targets but resulting in different interconnection needs. Therefore, several scenarios (Visions) with different amount of RES generation have been developed in order to simulate the possible consequences in a best possible way for meaningful and adequate additional grid expansion. These Visions have – especially for the high RES scenarios - changed significantly between the TYNDP14 and this Common Planning Study.

Acknowledging this evolution and the related uncertainty on the adequate level of interconnection capacity, the projects resulting from this study are categorized into mid-term projects, long-term projects, future project candidates and long-term concepts (which might evolve differently over time).

The generation mix and the annual generation and demand are given in figure 3-3 and 3-4 below.

Both non ENTSOE members and ENTSOE member’s projects are treated in the same way

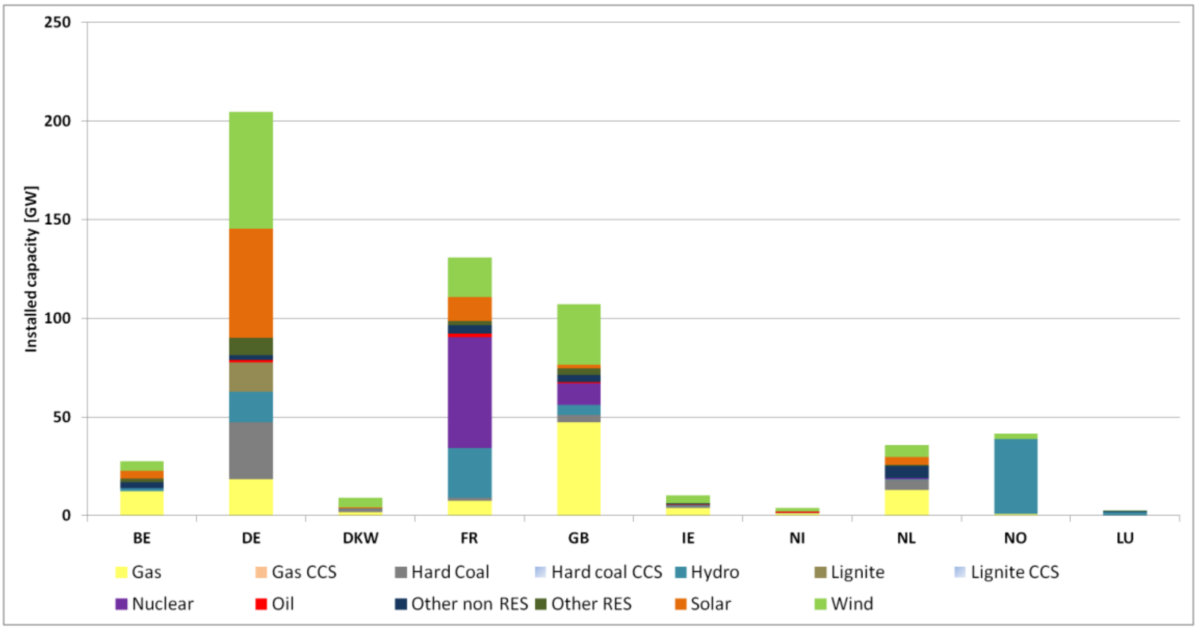

Figure 3-3: 2014 installed capacity per country within North Sea region (source ENTSO-E)

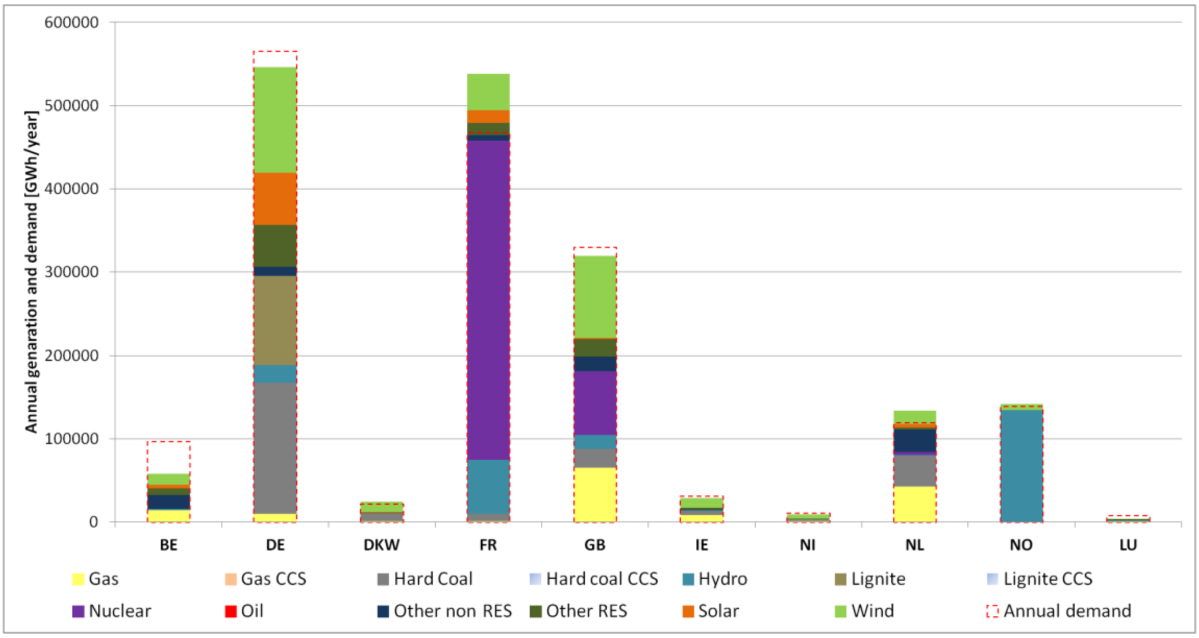

Figure 3-4: 2014 annual generation & demand per country within North Sea region (source ENTSO-E)

3.2 Main drivers

Investment needs – based on a generation mix shift
In general, the findings of the TYNDP14 are confirmed by the Common Planning Study. By 2030, the changes in the generation mix as described in the Visions project a significant increase in volumes of RES in the North Sea Region compared to today (especially for Visions 3 and 4)

The additional interconnection capacity required to facilitate the envisioned RES integration whilst minimising their curtailment, would consequently result in increased power flows between the different synchronous areas and between the Member States within each synchronous area.

Although the Visions have changed, the main power flows during times of high RES infeed are still expected from EIR/UK to Continental Europe (West-East Power flow) and exchanges on the North-South axis of the Region (Norway/ NL/Denmark Germany).

The generation shift also requires a more flexible power system. The key characteristics are as follows:

a) A shift from thermal to renewables, including a (partial) nuclear phase out in France, Belgium & and Germany. Adding interconnectors to the system provides flexibility and avoids curtailment of variable renewable energy resources. This flexibility is required in order to integrate renewables whilst maintaining adequate power production to maintain security of supply.
b) A shift from coal to gas is expected .The analysis shows that new interconnectors between the different synchronous areas of the North Sea Region, lead to large reductions of regional CO_2-emissions.
c) Controllable fossil-fuel generation (gas, coal and to some extent nuclear) are expected to be decommissioned and replaced by less -controllable generation (wind and sun), which also requires more flexibility in system services for operations to maintain security of supply and (Regional) system adequacy.

Interconnectors will generally lead to increased Market and RES-integration and adds flexibility to the system. Overall this supports a reduction of CO_2-emissions.
The interconnections across the Northern seas further facilitate the connection between the hydro-based Nordic system with seasonal patterns and the increasingly wind/solar –based UK and Continental systems with hourly patterns.

The development of interconnections facilitates cross-border support from areas with surplus capacities to areas facing from time to time security of supply challenges. (e.g. low wind, low solar, other meteorological events, outages etc.). As a result additional needs for higher interconnection-capacities and improved market cooperation between all the four synchronous power systems around the North Sea are foreseen. The four areas represent different but complementing skills (hydro, wind, sun, nuclear). Especially the improved cooperation between the Nordic system (mainly hydro-based) and the continental and UK system (wind, sun, thermal based) are contributing to required adequacy levels crucial for maintaining the security of supply in the broader European power system.

Foreseen market generation mix developments also create a need for higher integration and improved market design. The more RES based generation mix of the region North Sea will increase the need for additional market as well as grid capacity between the synchronous areas.

As the generation portfolio evolves, the opportunities of electricity trade between market players changes accordingly. The grid should be developed in order to support these new exchange possibilities, facilitating the access to the most economic energy mix, while minimizing grid congestions.

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The North Seas Offshore infrastructure, both radial and coordinated connection of offshore wind parks and point to point interconnections to connect market areas both with AC and DC, is under development already. ENTSO-E strongly believes that the proposed solutions, given the current status of technology, should be seen as main facilitators of RES- and market integration and therefore will become part of an adequate and necessary North Seas offshore grid in the future.

Regarding grid development and planning, the North Sea Region faces major challenges over the plan period, in determining the optimum solutions in facilitating an efficient European Energy market and in securing the European Network whilst accommodating connection of large volumes of renewable energy sources.

These challenges lead the TSOs within the Region to plan and conduct projects aiming at

1. Maintaining the security of supply,
2. A higher integration of the European energy market
3. Increasing integration of renewable energy sources (wind, solar and hydro) and as a result lowering CO_2 emission.

Finally, related to the changing future energy mix in the region, it needs to be stated that market related volatility in location, timing and use of new generation (RES and Fossil generation) makes it necessary for TSOs to stay close to the market developments in order to facilitate the market developments with future grid extensions in an adequate way.

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4 REGIONAL RESULTS

The Common Planning Studies are conducted to assess the potential opportunities for additional (referring to the TYNDP14 interconnection level) cross border capacities under a high RES scenario by also identifying internal bottlenecks. Within the North Sea region there are two main studies carried out.

The first study makes use of the Vision 4 generation portfolio from TYNDP 2014 Vision 4, as detailed in the Common Planning Studies methodology. This study is from here on referred to as the **TYNDP 2014 High RES scenario**. It should be noted that the outcomes based on the TYNDP 2014 High RES scenario are just an indication of the potential needs for one possible High RES future towards the 2050 time horizon.

Secondly, in the context of Common Planning Studies, a sensitivity analysis was performed upon the TYNDP 2016 high RES scenarios, where European RES targets are met in different ways, resulting into different potentials for target capacity increases and subsequent need for the development of grid capacity. The second study, based on the new TYNDP 2016 High RES scenarios was introduced because it was anticipated that these new scenarios would imply less potential for market capacity increase compared to the TYNDP 2014 High RES scenario. This second study makes use of the latest data prepared for the TYNDP 2016 process. From here on, this study is referred to as the **TYNDP 2016 scenario**.

Figure 4.1 below shows a number of countries' import and export market flows, and global balance, as an illustration of the difference between the **TYNDP 2014 High RES scenario** and the **TYNDP 2016 scenario**.

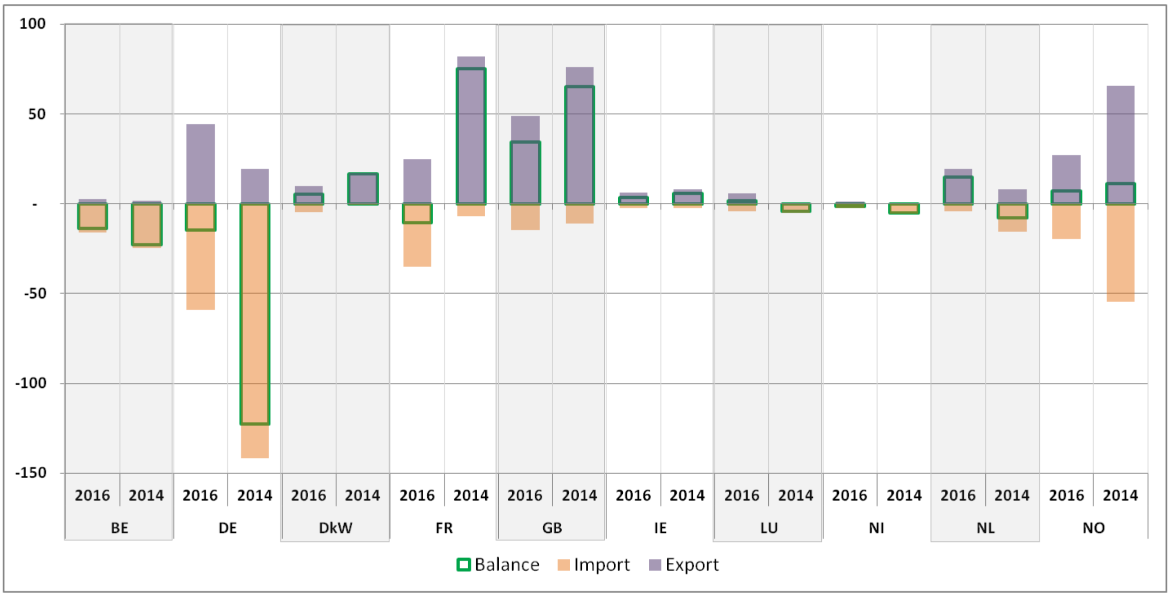

Figure 4-1 : North Sea countries power balances for High RES scenario in TYNDP 2016 & 2014

Table 4.2 gives the fuel prices taken into account to perform market studies on the different scenarios.

Fuel Type	Fuel Price (€/Net GJ)		
	High RES Scenario	TYNDP 2016 Vision 3	TYNDP 2016 Vision 4
Nuclear	0.377	0.46	0.46
Lignite	0.44	1.1	1.1
Hard Coal	2.21	2.8	2.19
Gas	7.91	7.23	7.23
Biofuel			

Light Oil	16.73	13.26	13.26
Heavy Oil	9.88	9.88	9.88
Oil Shale	2.3	2.3	2.3
CO_2 Price (€/ton)	**93**	**71**	**76**

Table 4.2: Fuel prices in both the High RES Scenario and the TYNDP 2016 Scenario

A complete description of the scenarios is available on the [Entsoe website].

The previous TYNDP 2014 Vision 4 interconnection cross border capacities are used in the reference case for all market studies in all six regions. In all regional studies, new potential interconnection projects are evaluated at each border using 0.5-1 GW increments, as set out in the Common Planning Studies methodology.

Figure 4.3 highlights the 22 borders within the North Sea Regional Group that are investigated during the Common Planning Studies. Please note that the French - German border was investigated and described in the CCS region. Please note that the Danish - Norwegian border was investigated and described in the Baltic Sea region.

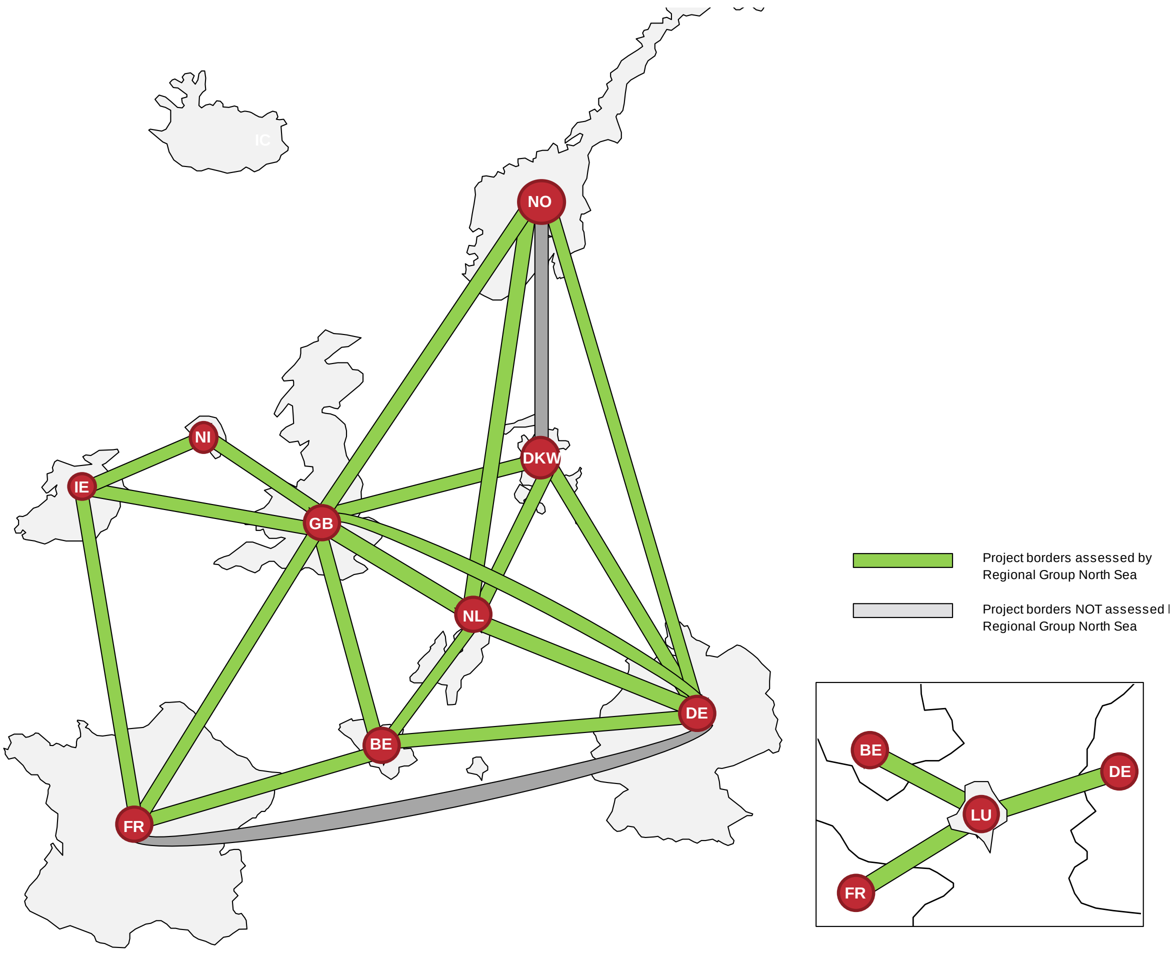

Figure 4.3: Common Planning Study, investigated borders additionally to TYNDP14 interconnection capacity level, North Sea Region

The Socio Economic Welfare output from the market model is compared with an estimate of the cost of the associated capital expenditures for each cross-border capacity increase between neighbouring countries (including estimate about the necessary internal grid reinforcements). This enables the selection or the rejection of potential interconnector project candidates.

After this selection, the impact of the generation dispatches resulting from the corresponding market run on the grid capacity is evaluated via a network study. The network model assumed for this study uses the TYNDP 2014 Vision 4 grid as a starting point. Onto this network, the new generation dispatches for the different synchronous areas are modelled; however, no additional network infrastructure is included. This allows for the identification of bottlenecks throughout the AC grids, in line with the corresponding power flows.

4.1 Target capacities in TYNDP 2014 high-RES scenario

The generation assumptions in the reference case of the Common Planning Studies are taken from TYNDP 2014 Vision 4, representative of a high level of RES integration. The results of these studies indicate a need for substantial additional transfer capacity between Great Britain and continental Europe. This need is primarily driven by high levels of renewable generation in Great Britain moving across the continent to cover high loads which would otherwise be supplied by more expensive conventional energy sources, notably coal or lignite.

Throughout the iterative process of the study, the majority of the transfer capacity increases are allocated to borders between Great Britain and continental Europe. However, it should be noted that as the transfer capacities between Great Britain and the continent continue to increase, so too does the need for internal reinforcements. As a result, other borders with favourable benefit ratios within continental Europe and to the Nordic area, not selected in the early iterations of the study, have also been allocated increased transfer capacity.

Figure 4.4 shows the standard cost and SEW after iteration 1.

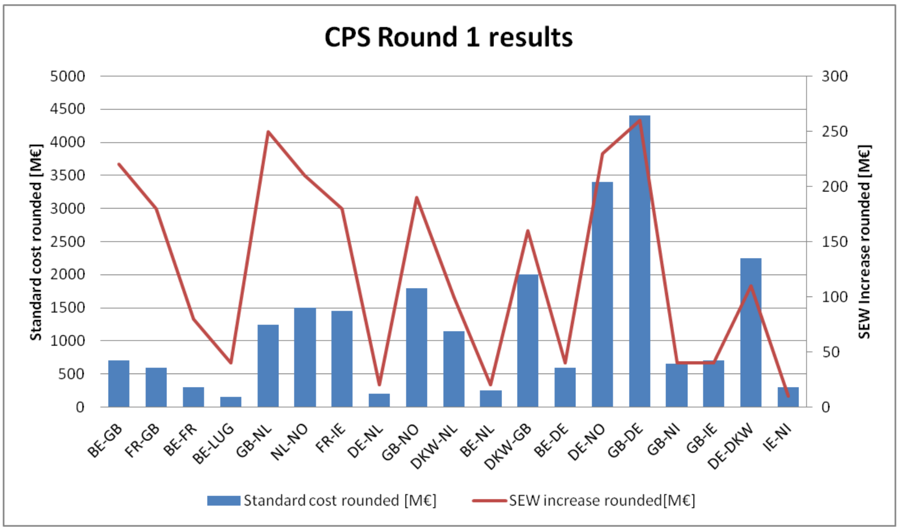

Figure 4.4: Standard cost and SEW after iteration 1 in Common Planning Studies

Figure 4.5 illustrates the cross border projects identified through the iteration process in the TYNDP 2014 Vision 4 market model. In total, 10 borders are identified as needing increases in cross border transfer capacity. The map shows that most of the additional market exchange capacity identified is required to enable the flow of energy from Great Britain to continental Europe.

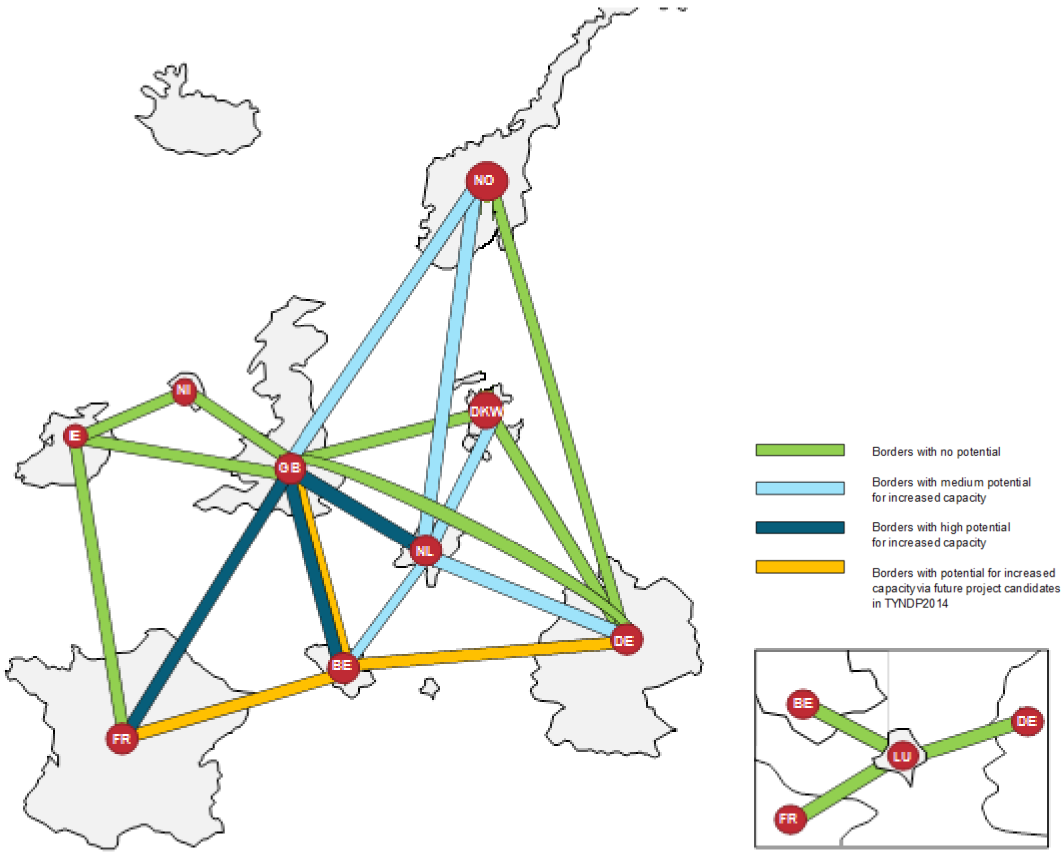

Figure 4.5: Transfer capacity increases resulting from market analysis

Starting from the TYNDP 2014, the potential for transfer capacity increases as indicated in the table below has been identified:

Border	Capacity increase
Great Britain – Continental Europe	7GW
Within Continental Europe	5GW
Great Britain – Norway	1GW
Norway – the Netherlands	1GW

Table 4.6: Transfer capacity increases resulting from market analysis

A part of these transfer capacity increases had already been identified in the TYNDP 2014 as future project candidates in a high RES scenario, and concerns capacity increases of 1 GW each between Great Britain and Belgium, Belgium and France, and Belgium and Germany (notably represented by the orange category on Figure 4.5).

Analysing these transfer capacity increases via a network study reveals that the North Sea region is characterized by significant power flows between the regions' synchronous areas - Great Britain, Ireland, Norway (as part of the Scandinavian area) and the Continent - and also throughout the continental AC grid.

Figure 4.6 depicts these power flows using the 5th and 95th percentile values of the year-round dataset, thus providing an indication of the magnitude of these power flows that can be expected for at least 5% for the time in each direction.

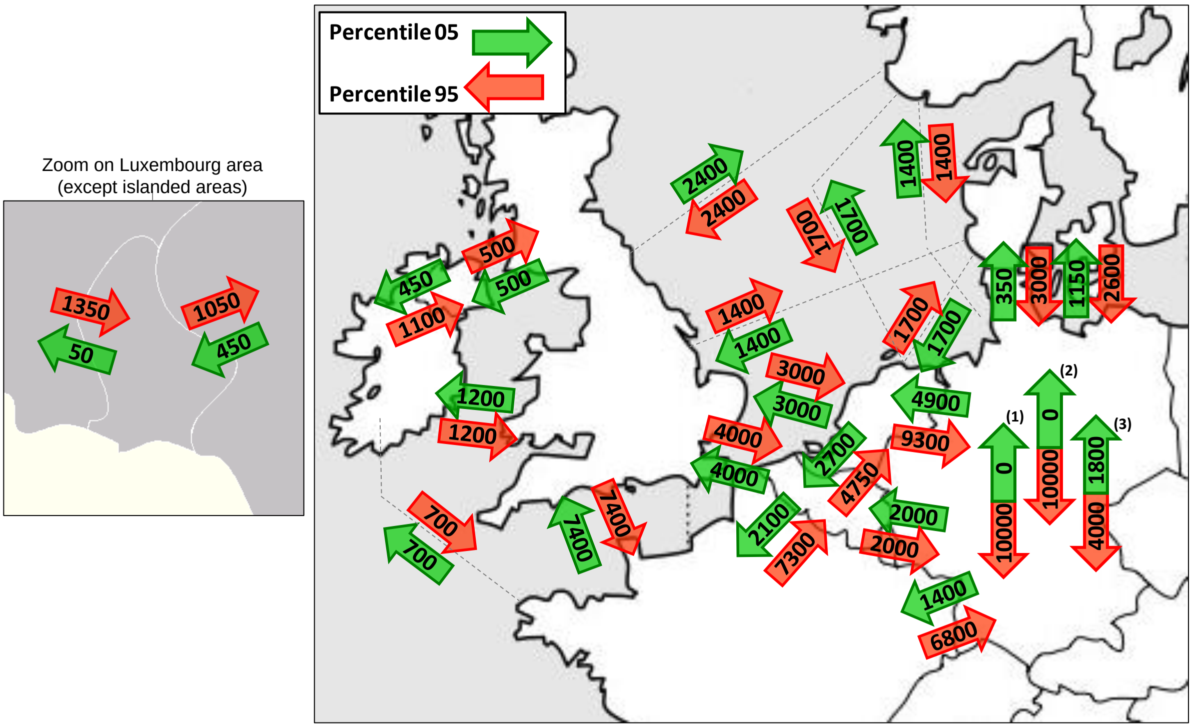

Figure 4.6: Bulk power flows – 5th (green) and 95th (red) percentiles resulting from the increased transfer capacities

This figure illustrates that the interconnectors between the synchronous areas are operating for at least 5% of the time in each direction at full capacity. This is explained by the fact that:

- During high RES generation conditions, there will be a need to export this generation from the islanded systems, in particular Great Britain, to the Continent;
- During low RES generation conditions, greater access to Great Britain from other regions will be beneficial for balancing, particularly from the northern part of the North Sea region, which is characterized by a combination of wind and hydro generation capacity;
- This significant quantity of wind and hydro generation in the northern region requires increased integration of the Norwegian and Danish systems and the Continent, allowing for more renewable energy to be exported south towards the larger demand areas in continental Europe.

It is also observed that the predominant power flows across the Continent are towards Germany, as a result of both the high demand in Germany and high fuel and CO_2-prices. Within Germany itself, the internal HVDC links [see (1), (2) and (3) in figure 4.5] are predominantly used to transport energy from North to South.

The flow duration curves illustrating the year-round power flows for the AC borders within Continental Europe are depicted in figure 4.7.

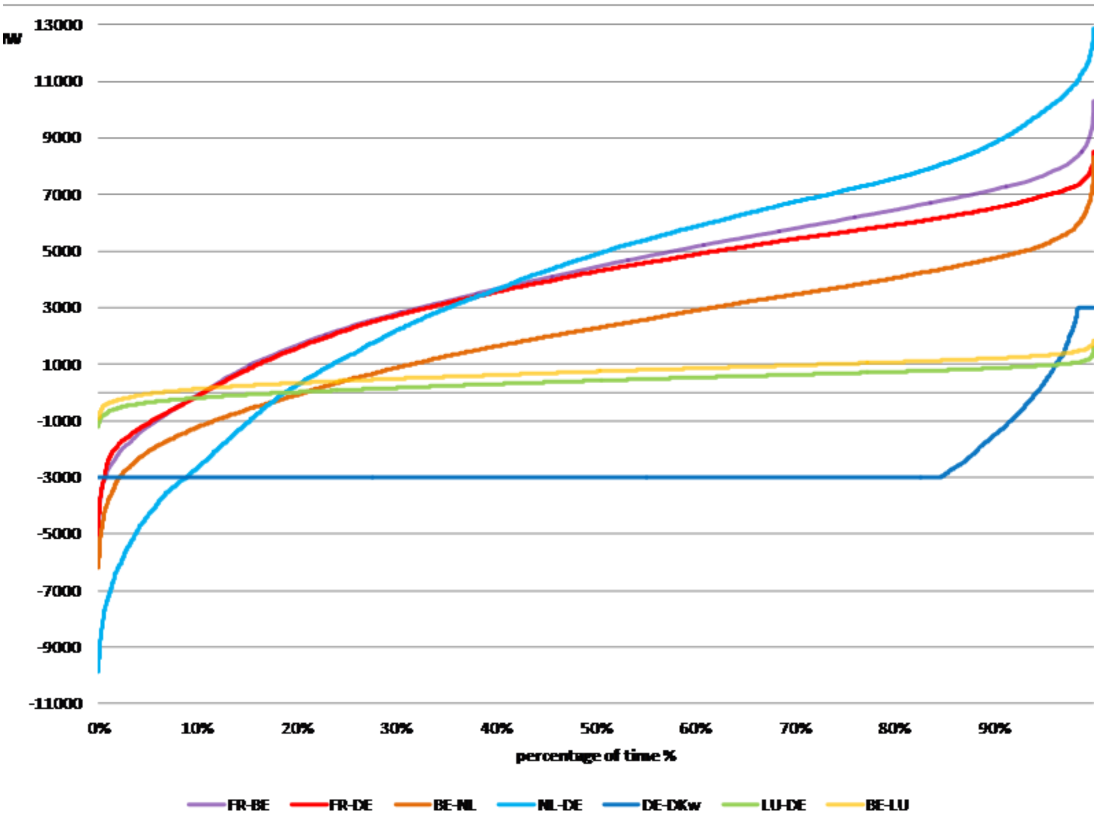

Figure 4.7: Power flow duration curves on the AC borders within the Continent[1]

This figure illustrates that the Central-West-European area covering the borders between France, Belgium, the Netherlands, Luxemburg and Germany is subject to very high power flows resulting from a combination of both West-East and South-North transits.

Sustaining this level of bulk power flow and thereby enabling the full market potential of RES would imply that the grid as planned in TYNDP 2014 is to be further reinforced. Figures 4.9 and 4.10 illustrate the subsequent bottlenecks in the grid, with the main areas of concern being the Greater London Area and the Central-West European area. The bottlenecks are also summarized in table 4.8 below.

(Please note that a more elaborated description of the bottlenecks, as well as the typical power flow pattern triggering these bottlenecks, can be found in **Appendix "Detailed regional walkthrough of the process"**.)

Further grid analysis need to be done for the Norwegian grid, to assess the capacity of the internal grid in case of adding new interconnectors.

[1] The DKW-DE duration curve is according to the market flows with a market exchange capacity of 3000 MW in both directions. It looks different compared to the other curves which are in the middle of a meshed system, while this line is highly affected by the strong – and controllable - HVDC connections to the Scandinavian system, which, in high RES Visions mostly are used to send energy southward. The network study did not reveal bottlenecks at this border. The border has been assessed in this Common Planning Study but did not result into an additional beneficial project candidate due to disproportional high capital expenditures related to internal grid reinforcements or potential components supporting voltage stability.

Table 4.8: Bottlenecks associated with the TYNDP 2014 High RES Scenario

Area	Severity	Origin
London	Bottleneck in N	Demand in London plus export across South Coast to continental Europe
Paris	Bottleneck in N	Demand in Paris plus west-east transit from UK and offshore wind
France-Belgium	Bottleneck in N on the eastern axis; bottleneck in N-1 on the western axis, where the bottleneck is of a more structural nature on the line Avelin-Avelgem compared to the line Avelin-Mastaing	South-North transit plus import Belgium
Belgium-Netherlands	Bottleneck in N on the eastern axis; structural bottleneck in N-1 on the western axis	Combination of South-North and West-East transit
Internal backbone in Belgium	Occasional bottleneck in N-1	Combination of South-North and West-East transit
France-Belgium-Luxemburg-Germany	Structural bottleneck in N for FR-BE-LU, occasional bottleneck in N-1 for LU-DE	West-East transit
France-Germany	Investigated in Continental Central South area	
Netherlands-Germany	Bottleneck in N on southern link, occasional bottleneck in N-1 on northern link	West-East transit plus high imports/exports Germany
North Netherlands	Structural bottleneck in N-1	New interconnections with Denmark and Norway
Ireland	Bottleneck in N-1 on network South-East of Dublin	Assumed connection of large quantity of offshore wind
Denmark on 400 kV backbone lines	Occasional bottleneck in N-1	Combination of high wind production and heavy north-to-south power transport through Denmark

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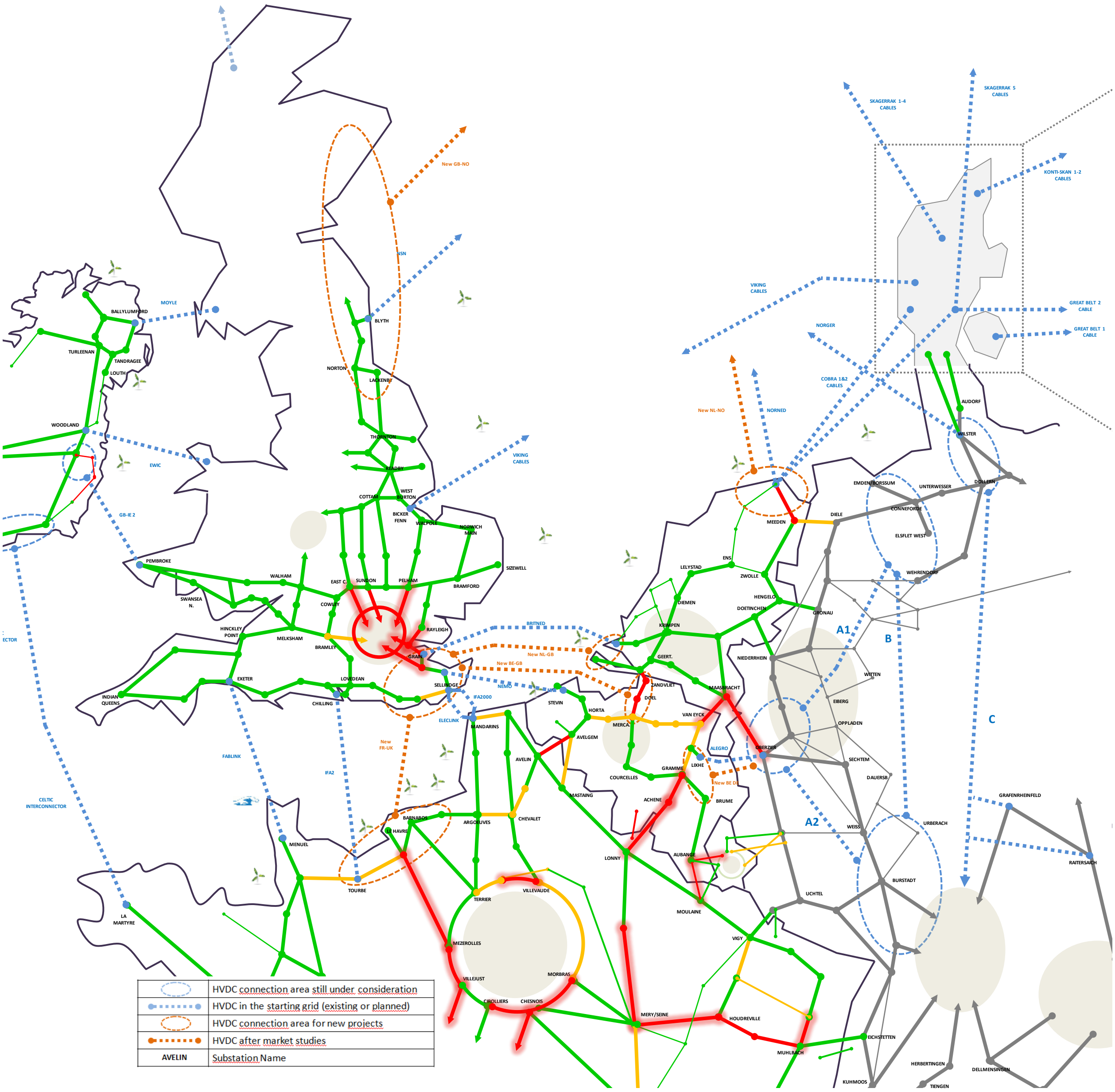


Figure 4.9: Bottlenecks across the Central West European area and Great Britain (Green when no bottleneck, yellow for occasional N-1 bottleneck, red for structural N-1 bottleneck, and highlighted red for bottleneck in N)[2]

The orange lines on Figure 4-9 conceptually represent the HVDC links that have been embedded into the network model. This in relation to the transfer capacity increases across the borders between different synchronous areas, and on the border between Belgium and Germany within the Central-West European area given its HVDC oriented nature as depicted already in TYNDP14. More specifically, these HVDC links entail the following capacities

- Between Great-Britain and the Netherlands: 2 GW
- Between Great-Britain and Belgium: 3 GW
- Between Great-Britain and France: 2 GW

[2] TYNDP focuses on the development of a European transmission system. Investigation of bottlenecks and grid reinforcements inside Germany are part of the German national grid development plan.

- Between Great-Britain and Norway: 1 GW
- Between Great-Britain and the Netherlands: 1 GW
- Between Belgium and Germany: 1 GW

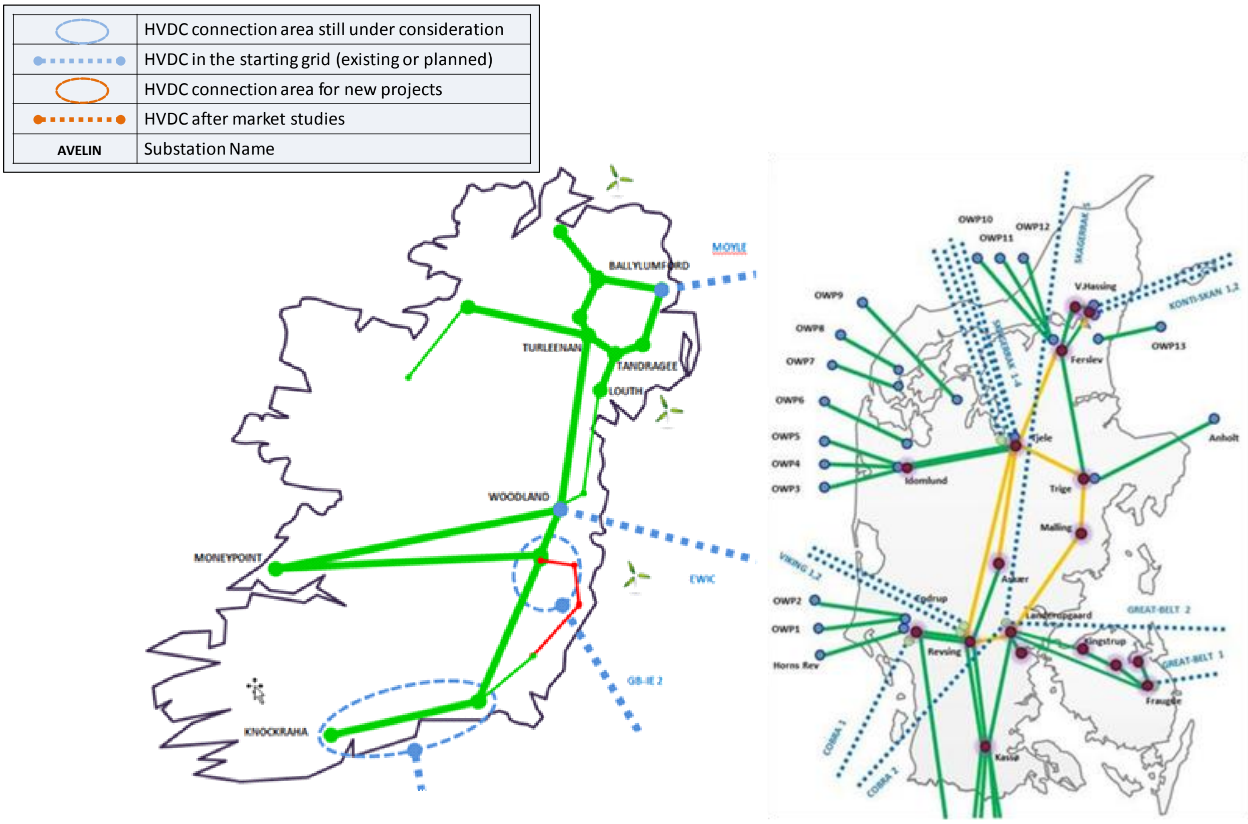


Figure 4.10: Bottlenecks within Ireland, Northern Ireland and Denmark (Green when no bottleneck, yellow for occasional N-1 bottleneck, red for structural N-1 bottleneck, and highlighted red for bottleneck in N)

4.2 Sensitivity analysis using TYNDP 2016 assumptions

As noted previously, there are significant differences between the generation portfolio from high RES scenarios in TYNDP 2014 and 2016. These differences are shown graphically in figures 4.11 and 4.12, but differences can differ significantly at national level.

More explanations on the differences between these scenarios are provided in chapter 7.2.

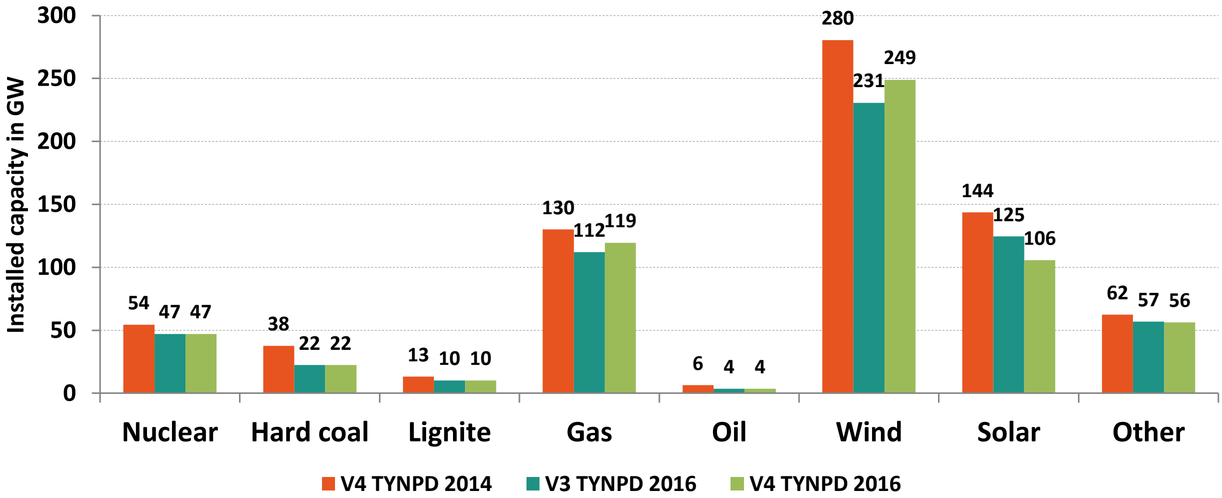
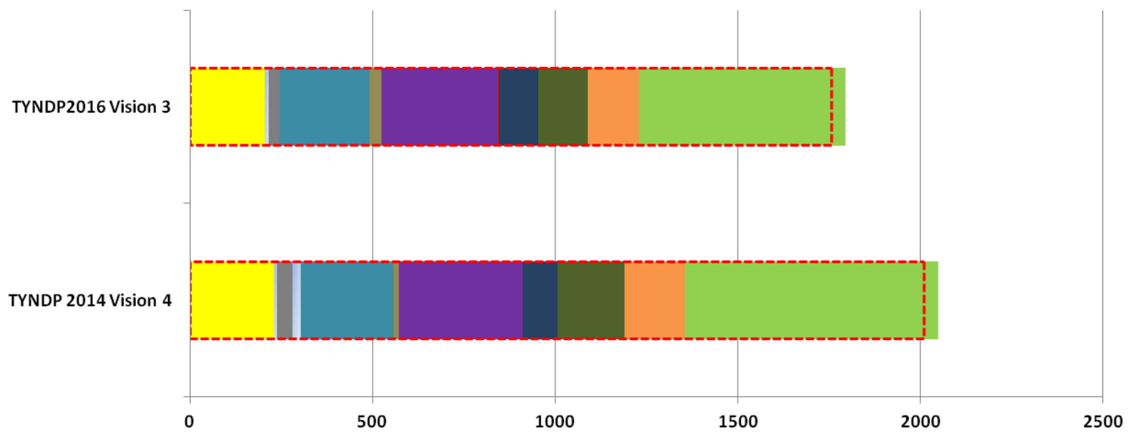


Figure 4.11: Installed capacity in GW in the North Sea Region



	TYNDP 2014 Vision 4	TYNDP2016 Vision 3
Gas	231	206
Gas CCS	7	10
Hard Coal	44	29
Hard coal CCS	22	0
Hydro	254	247
Lignite	15	32
Lignite CCS	0	0
Nuclear	339	320
Oil	0	1
Other non RES	96	108
Other RES	184	134
Solar	164	141
Wind	695	566
Annual demand	2013	1759

Figure 4.12: Annual generation and demand in TWh in the North Sea Region

As a result, two sets of additional studies are performed by the market modelling group, using Vision 3 and Vision 4 data from TYNDP 2016.

The first iteration of the study using the TYNDP 2016 Vision 3 data yields a single candidate border, Great Britain – France. Using the TYNDP 2016 Vision 4 data results in three borders are showing a benefit/cost ratio greater than one. These results of these first iterations are illustrated in figure 4.13 below. For comparison, the benefit/cost ratios for the equivalent borders from the **TYNDP 2014 High RES scenario** are also highlighted.

All of the candidate borders are between Great Britain and continental Europe. In all cases, the benefit/cost ratio is expected to be lower compared to those identified in the **TYNDP 2014 High RES scenario** study. This trend illustrates the value of the continuing re-evaluation of the need for these projects through subsequent studies.

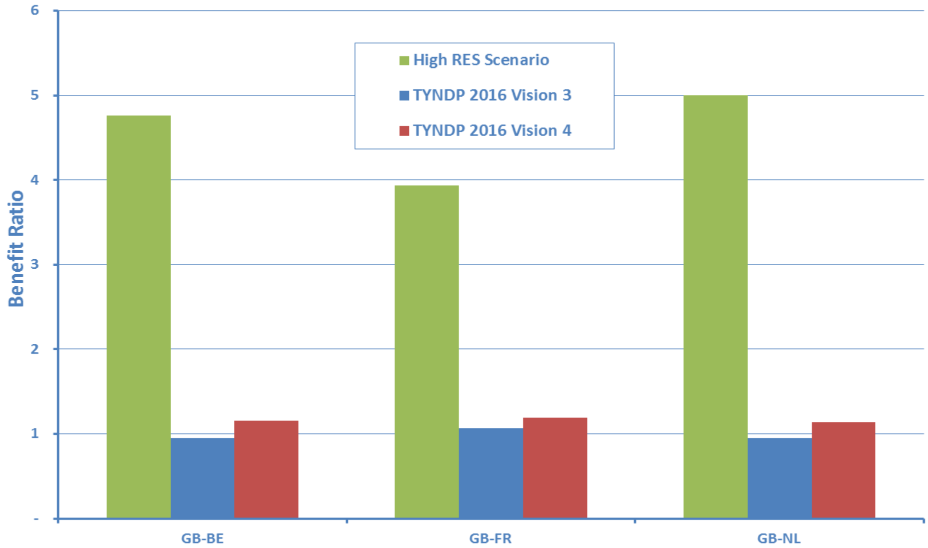


Figure 4.13: Benefit/Cost Ratios for trans-border capacity increases of 1 GW, for the study's first iteration

No further iteration of the Vision 3 data is required as only for one border (GB-FR) a benefit/cost ration of bigger than one is identified

However, a second iteration of studies using the data from Vision 4 TYNDP 2016 is performed. For this second iteration, the border with the highest benefit/cost ratio greater than one from the first iteration is incorporated into the market model, before the analysis is performed; i.e. the Great Britain – France border transfer capacity is increased by 1 GW. The results of the second iteration are shown in figure 4.14, and indicate that further transfer capacity could be beneficial, with an increase of 1 GW on the Great Britain – Netherlands border yielding the highest benefit ratio.

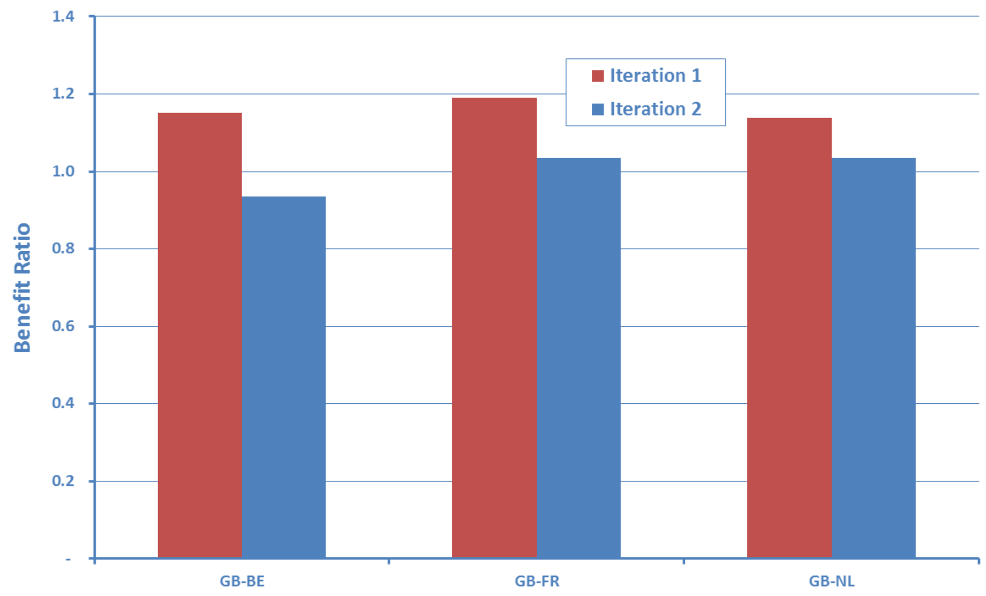


Figure 4.14: Benefit Ratios for both study iterations using the TYNDP 2016 Vision 4 data only

The analysis clearly demonstrates that the change in assumptions regarding the generation portfolio has a significant impact on the requirements for increased interconnection between Great Britain and continental Europe. The results of this analysis for the **TYNDP 2016 scenario** show that a maximum increase of 3 GW of transfer capacity from Great Britain to the continent would be sufficient, thus significantly lower than the 7 GW as identified in the TYNDP 2014 High RES scenario.

The finalised target capacities per border are given in figure 4.15 for the **TYNDP 2016 scenario**; for comparison, the transfer capacities for the **TYNDP 14 High RES scenario** are also provided.

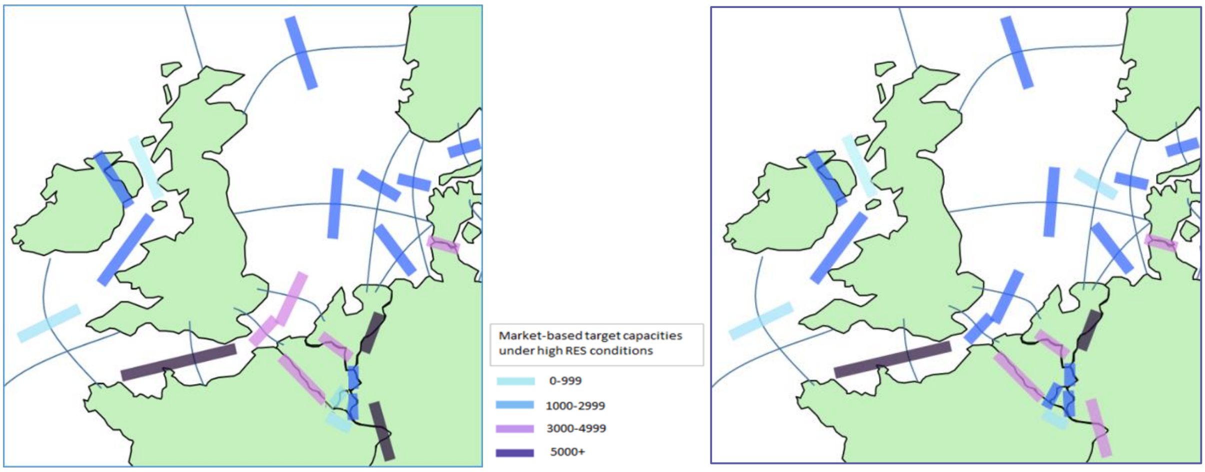


Figure 4.15: Target transfer capacities for TYNDP 14 High RES scenario (left) and TYNDP 2016 High RES scenario (right)

From a grid perspective, the lower level of transfer capacities in the TYNDP 2016 High RES scenario compared to the TYNDP 2014 High RES scenario is expected to imply less stress on the AC grid on the Continent.

The south-north (FR-BE-NL) and west-east (NL-DE and FR-DE) flows on the concerned AC borders are estimated to be less extreme. Figure 4.16 illustrates this effect.

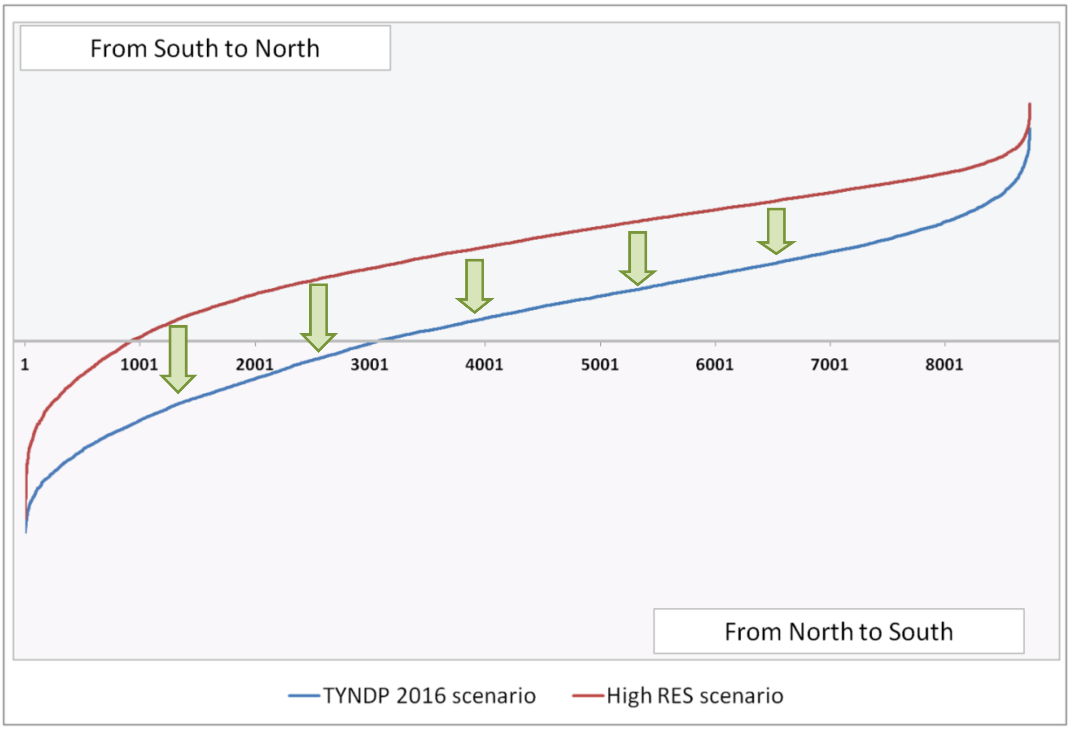


Fig. 4.16 – illustration of effect of lower level of transfer capacity on the duration curve of AC border in the Continent

Consequently, it is expected that the bottlenecks identified in the TYNDP 2014 High RES Scenario would partially disappear and/or be less severe from a year-round perspective:

4.3 Conclusion

The Common Planning Studies conducted for the North Sea region have considered two differing generation portfolios within a High RES setting, namely the TYNDP 2014 High RES scenario and the High RES TYNDP 2016 scenario.

The assessment has shown that the **potential** for market capacity increase with corresponding higher bulk power flows and consequent appearance of bottlenecks is **less pronounced in the TYNDP 2016 High RES scenario compared to the TYNDP 2014 High RES scenario,** hereby concluding that a **modular approach** is to be applied.

This modular approach introduces both new future project candidates related to increased market capacities towards 2030 as per the TYNDP 2016 scenario, as well as longer-term concepts related to the potential for further market capacity increase beyond 2030 as per the TYNDP 2014 High RES scenario.

New future project candidates
Within the TYNDP 2014 first signals for future project candidates in a High RES setting were given, cf. the projects under consideration on the Great Britain-Belgium, Belgium-Germany and French-Belgium borders. As a result of the performed study, these are complemented with new future project candidates on the Great Britain-France, Great-Britain-Netherlands, Belgium-Netherlands, Netherlands-Germany and Denmark-West-Netherlands borders, including the internal grid reinforcements deemed necessary to accommodate the resulting bulk power flows.

Longer-term concepts
The exploration of the TYNDP 2014 Vision 4 scenario helps to inform on higher RES settings in the light of meeting the more ambitious 2050 targets, and thus relates to longer term grid development beyond 2030. The scenario demonstrates there is potential for significant increase in market exchange capacity. Consequently there are very high West-to-East and South-to-North bulk power flows which result in numerous additional cross-border and internal bottlenecks in the grid.

The potential reinforcements to alleviate these bottlenecks are difficult to justify in the TYNDP 2016 scenario setting, given that these bottlenecks are less pronounced due to lower expected capacity increases compared to TYNDP 2014 vision 4 scenario. Given the uncertainties involved in the long-term development of the generation portfolio, the need to implement them must be carefully monitored in order to balance their timely delivery versus the inherent risk of stranded assets.

Furthermore, the Common Planning Study initiates the reflection that these potential reinforcements might involve novel grid development concepts like a West-East Corridors and a further development of the Northern Seas Offshore infrastructure. These potential developments might span multiple borders with potential multi-terminal solutions and require further detailed studies.

4.4 E-Highway2050 scenarios perspective

The e-Highway2050 project is supported by the EU Seventh Framework Programme and aims at developing a methodology to support the planning of the Pan-European Transmission Network. The study project started in September 2012 and will end in December 2015.
The main goal is to develop a top-down methodology for the expansion of the pan-European electricity grid from 2020 to 2050, with a view to meeting the EU energy policy objectives. Concretely, the methodology will ensure that future EU grids can host large quantities of electricity from renewable energy sources and transport it over long distances as well as foster market integration.
The e-Highway2050 project is based on five future power system scenarios (Example, see figure below), which are extreme but realistic for a 2050 perspective. The corridors identified provide a modular development plan for a possible long-term architecture. The five scenarios span uncertainties (technical, economics, political, social...) as well as different future choices (RES incentives, energy market integration, regulations, industry standards...).

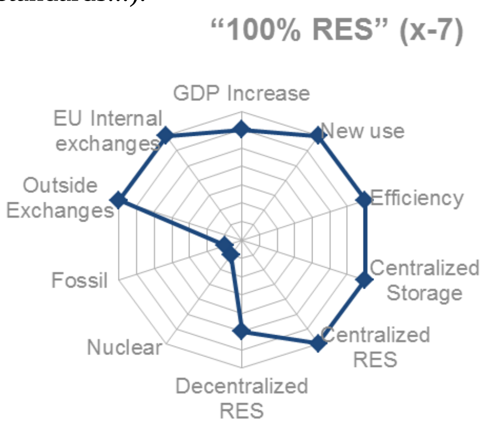


Figure 4-2 - Example of scenario characteristics

The methodology used in the e-Highway project, though different from the TYNDP planning, is still based on market and network studies. To focus on 2050 pan-European adequacy and efficiencies, it is based on stochastic analysis of unsupplied energy, energy spillage and thermal generation re-dispatching. The network model used is much simplified, based on a limited number of clusters all interconnected by equivalent impedance links (see figure below).

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Figure 4-3 - Reduced European grid

A comparison between 2030 and 2050 scenarios is subjective and in essence a fast evolving energy domain can always move from one 2030 Vision to any 2050 scenario. Therefore the four TYNDP Visions all show rather different ways to move forward to the 2050 goals. Regardless of the scenario perspective taken, it is important to see the TYNDP2016 projects as no-regret options across the common corridors identified in the e-Highway project, meaning that TYNDP2016 projects are the first steps to be considered by 2030 in order to match with 2050 very long term perspectives.

The regional results in this report provide further insight on this.

On the figure 4-3 below, the draft results for additional reinforcements throughout the five e-H2050 scenarios are displayed (colour code represents the number of appearances in the different scenarios).

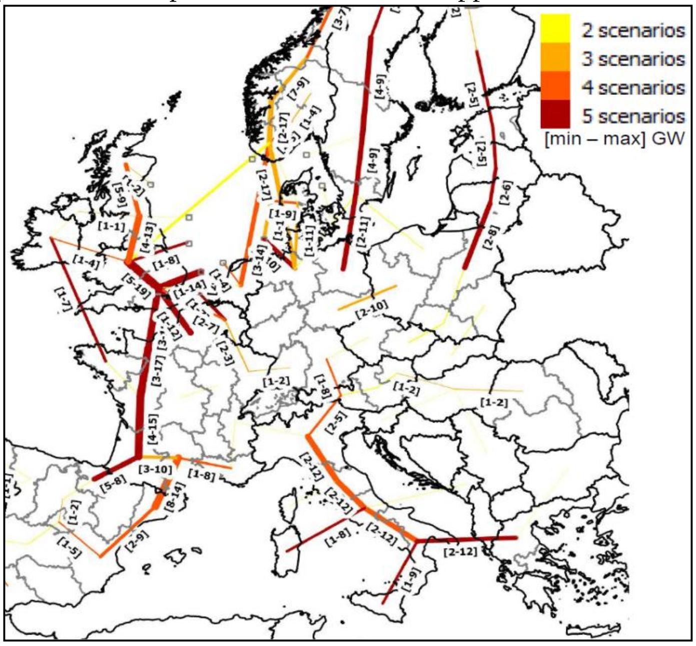

Figure 4-3: draft results of e-Highways project

If we focus on the North Sea region, we can see that e-H2050 draft results confirm the long term perspective of developing a West East axis, from Great Britain and Ireland to the continental Europe, as well as a North South corridor from Norway and Baltic system in general to the centre of Europe.

It should be noted that e-highways 2050 study did not specifically investigate the possible structure in which a North Seas offshore grid could be developed.

5 PROJECT CANDIDATES

5.1 Introduction

This chapter lists all TYNDP project candidates which after finalization of the list will be assessed by ENTSO-E as part of the TYNDP2016 process. In addition, projects that have impact on the region but are not of pan-European significance are also presented in this chapter; these are not part of the TYNDP list and will not be further assessed in the final TYNDP report.

A project is defined as the smallest set of assets that effectively add capacity to the transmission infrastructure that can be used to transmit electric power, such as a transformer + overhead line + transformer. In situations where multiple projects depend on each other to perform a single function (i.e. a single project cannot perform its function without a certain other project) they can be clustered in order to be assessed as a group providing that they achieve a common measurable goal.

TYNDP2016 projects as well as regional projects are based on earlier TYNDP2014 projects, result from recent common planning studies, and/or are driven by political targets.

TYNDP project candidates in this list are structured by

- **Boundary** – which can be a specific border, a combination of borders, or an internal boundary;
- **Maturity** – based on commissioning date and national approval projects are grouped as
  - Mid-term projects: Project to be commissioned by 2022 will be assessed by TOOT method against the expected 2020 network if is acknowledged in the latest national plans or is having intergovernmental agreement;
  - Long-term projects: Project to be commissioned by 2030 will be assessed by TOOT method against the expected 2030 network and PINT method against the expected 2020 network if the project is acknowledged in the latest national plans or is having intergovernmental agreement;
  - Future project candidates: All other projects which do not fall under the previous categories will be assessed with PINT method against the expected 2030 network.

The following map shows all cross-border projects to be analyzed during TYNDP2016. The projects are categorised by the following colour code:

- **Dark blue** – new TYNDP project candidates (among which the ones identified during the Common Planning Studies)
- **Light blue** – re-confirmed TYNDP2014 projects
- **Grey** – Regional projects (if specified)

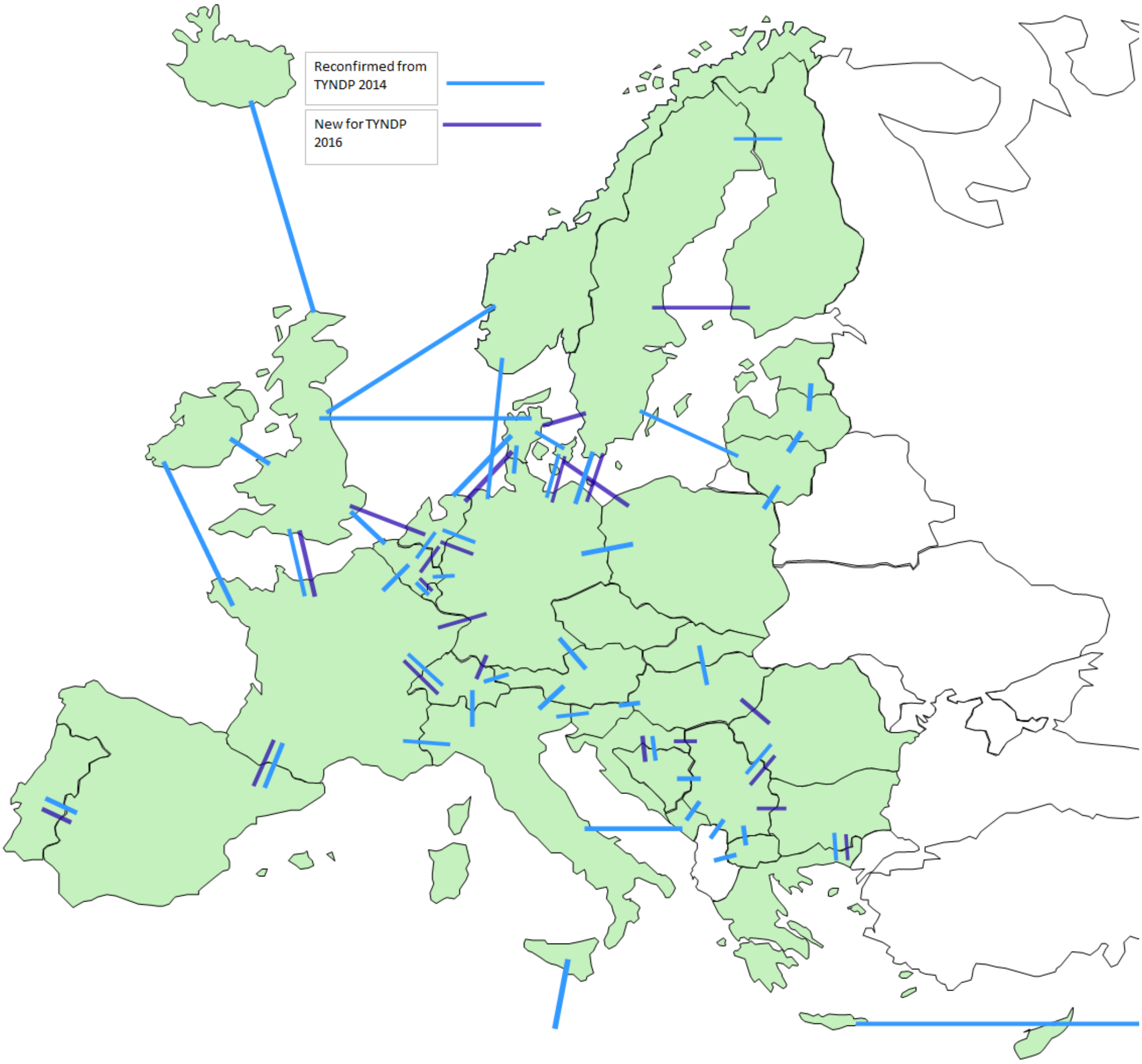

Figure 5-1: cross-border projects to be analysed during TYNDP16

After this first cross border overview, figures 5.2 and 5.3 below show with more details the candidate projects for the North Sea region. Internal projects are also described, except for Germany and Great Britain.

Figure 5.2: candidate projects for continental countries and Great Britain.

Note: Grey lines represent existing grid, light blue lines show TYNDP14 reconfirmed projects, and orange is applied for new TYNDP16 projects.

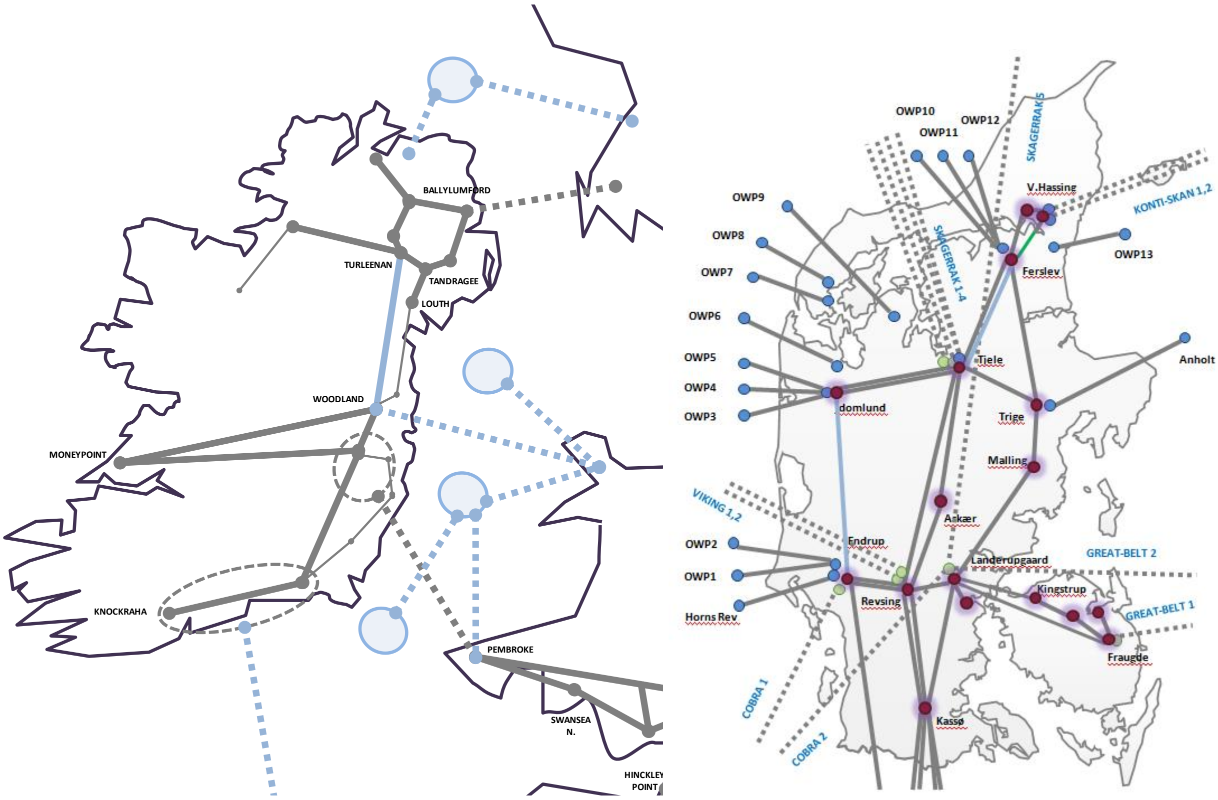

Figure 5.3: candidate projects for Ireland and Denmark (same legend as 5.2).

Note for figure 5.3: For simulation purposes, the connections to OWP1-12 are assumed to be built by 2030.

5.2 List of TYNDP2016 project candidates

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Belgium - Germany	**2nd interconnector Belgium - Germany**	This project considers the possibility of a second 1 GW HVDC interconnection between Belgium and Germany. The determination of the optimal capacity, location, technology, potentially needed internal grid reinforcements and possible synergies on the integration of this interconnector in relation to the long-term concept of a west-east corridor are subject of further studies..	1000	225	This is a conceptual project that could be considered as a long-term investment option, where preliminary analysis has shown the potential for further market integration triggered by high-RES scenarios.	2030	Future Project	AMPRION;ELIA

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Belgium - Germany	**ALEGrO**	This project involves the realization of a HVDC link with a bidirectional rated power of approximately 1.000 MW capacity, as the first interconnection between Belgium (Lixhe) and Germany (Oberzier). Internal reinforcements in AC grid in Belgium are amongst others needed to facilitate the integration of ALEGrO - creation of 380kV substation at Lixhe, including a 380/150kV transformer - creation of 380kV substation in Genk (André Dumont), including a 380/150 kV transformer - addition of a second circuit on line Lixhe-Herderen Additional potential reinforcements in the AC grid in Belgium are subject to monitoring the potential for new production units at Lixhe - creation of a second line between Lixhe & Herderen - installation of a second 380/150kV transformer in the Limburg area (substation André Dumont is reference)	1000	92	First of all, ALEGrO enhances the internal market integration by enabling direct power exchanges between these countries Secondly, the new interconnection will play a major role for the transition to a generation mix which is undergoing structural changes in the region (high penetration of RES, nuclear phase-out, commissioning and decommissioning of conventional power plants etc.). Given these major changes in the production mix, the new interconnection also contributes to the security of supply in facing the arising challenges for secure system operation.	2020	Mid-term Project	AMPRION;ELIA
Belgium - Great Britain	**Thames Estuary Cluster (NEMO)**	This projects envisions the realization of NEMO - the first interconnector between Great Britain and Belgium – as a 1 GW HVDC link with technical commissioning by 2018 and commercial operation in 2019, including a number of onshore UK reinforcements to facilitate this and other potential interconnector connections within the Thames Estuary region.	1000	74	NEMO enhances market integration, facilitates the penetration of renewable energy sources in the energy mix and contributes to security of supply since providing import capacity in a context of decommissioning of power plants.	2018	Mid-term Project	ELIA;NGT

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Belgium - Great Britain	**2nd interconncetor Belgium - UK**	This project considers the possibility of a second 1GW HVDC connection, between UK (Kemsley) and a Belgian 380kV substation in the Antwerp area (Doel, Zandvliet are indicative locations). The determination of the optimal capacity, location, technology, potentially needed internal grid reinforcements and possible synergies on the integration of this interconnector in relation to an offshore hub/grid or the concept of a "west-east corridor" are subject of further studies.	1000	121	This is a conceptual project that could be considered as a long-term investment option, where preliminary analysis has shown the potential for further market integration triggered by high-RES scenarios.	2030	Future Project	ELIA;NGT

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Belgium - Netherlands	**Belgium-Netherlands: further evolution**	A bilateral study is started to investigate the options for developing additional cross-border capacity between Belgium and The Netherlands (1000 MW), in addition to existing and planned projects. The reference solution envisions the reinforcement of the cross-border lines Zandvliet(BE)-Kreekrak(NL) and/or Van Eyck(BE)-Maasbracht(NL) with high performance conductors combined with the installation of additional phase shift transformers. The bilateral study will further evaluate the balancing of flux control measures between both x-border lines, hereby not excluding alternative solutions.	1000	A need has been identified to develop additional cross-border capacity between Belgium and The Netherlands, related to the security-of-supply perspective with planned nucleair phase out in Belgium. Market analysis (Common Planning Study) indicate that additional cross-border capacity is also necessary from market integration perspective. The timing of 2025 is indicative and the bilateral study will furhter evaluate the possibilities envisioning a shorter-term horizon.	Common Planning Studies & Internal Studies	2025	Future Project	Elia System Operator;TenneT TSO
Countries around the Northern Seas	**Long term conceptual North Seas Offshore grid infrastructure**	Potential synergies to be further studied given the preliminary ideas on a global scheme for offshore infrastructure in the North Seas, complemented with the long term perspective for further market integration as per analysed TYNDP2014 vision 4 scenario.	TBD	RES integration and increase the integration level between countries, including necessary onshore reinforcements	Common Planning Studies	Beyond 2030	Future Project	EirGrid;Elia System Operator;Energinet.dk.dk;Creos Luxembourg;National Grid;RTE;TenneT TSO GmbH;SONI;Statnett;TenneT TSO

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Denmark-West - Great Britain	**Viking DKW-GB**	This project, known as Viking Link and under development by National Grid Interconnector Holdings Limited and Energinet.dk, investigates a 600-700 km connection between Denmark West and Great Britain by two parallel HVDC subsea cables and related substations on both ends.	1400	167	The project adds cross-border transmission capacity between both countries, thereby facilitating integration of the energy markets and the incorporation of more RES, as the wind is not correlated between both markets.	2020	Mid-term Project	Energinet.dk;NGT
Denmark-East - Germany	**Kriegers Flak CGS**	The Combined Grid Solution (CGS) is new a DC offshore connection between Denmark and Germany. The project is a combined grid connection of the offshore wind farms Kriegers Flak, Baltic 1 and 2 and an interconnection between both countries.	400	36	The project facilitates RES connection and increased cross border trade of electricity (market integration).	2018	Mid-term Project	50HERTZ;Energinet.dk
Denmark-West - Denmark-East	**Great Belt II**	This project candidate includes an HVDC connector between Denmark-West (DKW) and Denmark-East (DKE). The connector is called Great Belt-2. It could among other variants be located between the 400 kV substation Malling in DKW and the reconstructed 400 kV substation Kyndby in DKE.	600	175	The main purpose of this project is to incorporate more RES into the Danish system by sharing reserves between both systems and improve market integration.	2030	Future Project	Energinet.dk
Denmark-West - Germany	**DKW-DE, Westcoast**	The project consists of a new 400 kV line from Endrup (Denmark) to Niebüll (Germany), adding more transfer capacity at the West Coast between these countries. On the Danish side, this project includes the establishment a 400 kV AC underground cable system from the existing 400 kV substation Endrup to the border, from where the interconnector continues to Niebüll. The project is labelled by the EC as project of common interest (PCI 1.3.1).	500	183	The project helps to integrate RES and to strenghten the connection between the Scandinavian and Continental market.	2022	Mid-term Project	Energinet.dk;TENNET-DE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Denmark-West - Germany	**DKW-DE, step 3**	This project is the third phase in the Danish-German agreement to upgrade the transfer capacity between Denmark West and Germany. The third-phase project consists of a new 400 kV line from Kassoe (Denmark) to Audorf (Germany). It mainly follows the trace of an existing 220 kV line, which will be substituted by the higher voltage line. The project is labelled by the EC as project of common interest (PCI 1.4.1).	Direction A: 720 - Direction B: 1000	39	The project helps to integrate RES and to strenghten the connection between the Scandinavian and Continental market.	2020	Mid-term Project	Energinet.dk;TENNET-DE
Denmark-West - Netherlands	**COBRA cable**	'The project is an interconnection between Endrup (Denmark) and Eemshaven (The Netherlands). The project consists of a 320 kV DC subsea cable and related substations on both ends, 320-350 km apart, applying VSC DC technology. The project is supported by the European Energy Programme for Recovery (EEPR) and is labelled by the EC as project of common interest (PCI 1.5).	700	71	The purpose is to incorporate more renewable energy into both the Dutch and the Danish power systems and to improve the security of supply. Moreover, the cable will help to intensify competition on the northwest European electricity markets.	2019	Mid-term Project	Energinet.dk;TENNET-NL
Denmark-West - Netherlands	**COBRA-2**	The second HVDC connector between Denmark-West and The Netherlands.	700	Market integration, RES connection	Common Planning Studies 2015 with the preliminary market transport capacity 1000 MW (additional).	>2030	Future Project	Energinet.dk.dk;TenneT TSO
East-West	**East Coast Cluster**	A very high level indication of the works required for GB East Coast. In detail the projects will consist of multiple offshore HVDC and AC circuits and connecting platforms joining to multiple onshore connection points with their own reinforcement requirements.	3000	86	A very high level indication of the works required for GB East Coast. In detail the projects will consist of multiple offshore HVDC and AC circuits and connecting platforms joining to multiple onshore connection points with their own reinforcement requirements.	2026	Future Project	NGT

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
France - Belgium	**FR-BE phase 2**	The option that will be evaluated envisions the replacement of the current conductors on the axis Lonny-Achène-Gramme with high performance conductors.The integration of complementary flux control measures is subject to further studies depicting the interaction with the 225kV axis Aubange-Moulaine. Hereby not excluding alternative / complementary solutions (new HVDC corridor, upgrade 225kV to 380kV,...) as per the framework of the long-term concepts of an offshore grid & west-east corridor.	1000-1400	173	The project aims at sustaining further market integration within the long-term perspective of the energy transition and subsequent need to balance the transit flux between the 225kV and 380kV grids at the east side of the border.	2030	Future Project	ELIA;RTE
France - Belgium	**France-Belgium Phase 1**	The project consists in reconductoring the existing double-circuit 400-kV cross-border line between Lille(Avelin/Mastaing, FR) - Avelgem (BE) - Zomergem (Horta, BE) with High Temperature Low Sag conductors to increase its thermal capacity.	600-1300	23	The project aims at ensuring reliable grid operation to cope with more volatile south-north flows, and at increasing the exchange capacities between France & Belgium to sustain an adequate level of market integration.	2022	Mid-term Project	ELIA;RTE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
France - Great Britain	**ElecLink**	Eleclink is a new FR – UK interconnection cablewith 1000 MW capacity though the channel Tunnel between Sellindge (UK) and Mandarins (FR). Converter stations will be located on Eurotunnel concession at Folkestone and Coquelles. This HVDC interconnection is a PCI project (Project of Common Interest) no. 1.7.3.	1000	1005	Following the completion of initial studies which confirmed that the development of an interconnector in the Tunnel is technically possible and economically viable, ElecLink is now completing the development work to bring the project to Financial Close. ElecLink has submitted and received its regulatory exemption from the UK and FR regulators, signed grid connection agreements for access to the national transmission systems in the UK and FR, obtained its electricity interconnector licence in the UK, carried out its public consultation for the project works in the UK, received conditional approvals for the converter stations in the UK and FR, and has invited market participants to register their interest in contracting interconnector capacity.	2018	Mid-term project	ElecLink
France - Great Britain	**France-Alderney-Britain**	France-Alderney-Britain (FAB) is a new HVDC subsea interconnector between Exeter (UK) and Cotentin Nord (France) with 1,4 GW capacity. The investment has been selected as PCI 1.7.1 in the NSCOG corridor.	1400	153	The project will not only increase the interconnection between Great Britain and continent but also integrate additional RES (especially RES in Great Britain). 2,8 GW of future tidal generation could also be connected to this link when it develops off the Cotentin Coasts.	2022	Mid-term Project	RTE and FABLINK limited

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
France - Great Britain	**IFA2**	IFA2 is a new HVDC VSC subsea interconnector that will develop between Tourbe (area of Caen) in France and the Chilling (region of Southampton) in Great Britain. It has been selected as PCI 1.7.2 in the NSCOG corridor on 14/10/13.	1000	25	The objective is to increase the interconnection capacity between Great Britain and Continent and to integrate RES generation, especially wind in Great Britain.	2020	Mid-term Project	NGT;RTE
France - Great Britain	**New Great Britain France interconnector**	New HVDC link between France (connection area in Normandy) and Great Britain (South East area)	1000	RES connection, Market integration	Common Planning Studies	2030	Future Project	National Grid;RTE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
France - Great Britain	**AQUIND Interconnector**	The Project is to develop a high voltage direct current subsea interconnector power transmission cable between the United Kingdom and France with the total capacity of up to 2000MW and other associated installations as explained herein. The interconnector will land and connect to the United Kingdom grid in the South East of England. The connection point in France will be on the Normandy Coast.	2000	To generate revenues for the energy generator, for traders using the link, and for the owner of the interconnector.To reduce the consumer cost of energy for the nation in receipt of the energy.To potentially reduce the CO2 content in the UK energy mix.To aid in the creation of a single European energy market.To improve security of supply for each of the interconnected networks.To act as a balancing mechanism for networks with a high penetration of intermittent renewable energy sourcesTo provide a sustainable and reliable source of energy import and export for both of the interconnected networks.To support the target of achieving 10% interconnectivity for the GB network, relative to its peak capacity, by 2020.	(tbc)	2020	Future project	Aquind Limited

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
France - Ireland	**Celtic Interconnector**	Celtic Interconnector will be the first interconnection between Ireland and France. This HVDC (VSC) link with 700 MW capacity is presently being surveyed from Cork harbour (Ireland) to La Martyre (Finistère) in France. The project has been selected as PCI 1.6 in the NSOG corridor on 14/10/13	700	107	The project will not only create a direct link between the French and Irish markets but also increase RES integration, especially wind in Ireland. it will also allow mutual support between Ireland and Brittany.	2025	Long-term Project	EIRGRID;RTE
Germany - Netherlands	**Long-term conceptual interconnector DE-NL**	Market analysis revealed the need for additional cross-border capacity between Germany and The Netherlands. Therefore a bilateral study is started to investigate options for a further increase, in addition to existing and planned interconnections, of the cross border capacity Germany and The Netherlands.	1000	Market integration leads to high social economic welfare increase in extremely high RES scenario planning studies	Common Planning Studies based on TYNDP2014 Vision 4	beyond 2030	Future Project	Amprion;TenneT TSO

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Germany - Norway	**Norway - Germany, NordLink**	NordLink: a new HVDC connection between Southern Norway and Northern Germany. Estimated subsea cable length: 514km. Capacity: 1400 MW.	1400	37	A 514 km long subsea interconnector between Norway and Germany is planned to be realized in 2020. The main driver for the project is to integrate the hydro-based Norwegian system with the thermal/wind/solar-based Continental system. The interconnector will improve security of supply both in Norway in dry years and in Germany in periods with negative power balance (low wind, low solar, high demand etc.). Additional the interconnector will be positive both for the European market integration, for facilitating renewable energy and also for preparing for a power system with lower CO2-emission. The interconnector is planned to be a 500 kV 1400 MW HVDC subsea interconnector between southern Norway and northern Germany.	2020	Mid-term Project	STATNETT;TENNET-DE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Great Britain - Central Europe	**Long-term conceptual "West-East corridor" in North Sea**	Potential synergies between interconnectors and internal grid reinforcements, enabling further market integration between Great Britain and Central Europe, is to be further studied within the concept of a "west-east corridor"	TBD	Long-term perspective as per the analyzed TYNDP14 Vision 4 scenario induces reflection upon a corridor from Great Britain to Central Europe, with possible multi-terminal take-off points in Benelux, France and Germany	Common Planning Study	Beyond 2030	Future Project	Amprion;Creos Luxembourg;Elia System Operator;National Grid;RTE;TenneT TSO
Great Britain - Netherlands	**New Great Britain - Netherlands Interconnector**	Indentified through RES studies. HVDC link between South East coast of Great Britain and the Netherlands	1000	RES connection integration	Common Planning Studies	2030	Future Project	National Grid;TenneT TSO GmbH

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Great Britain Norway	**Norway-Great Britain NSN**	NSN, 1400 MW interconnector Norway and England.	1400	110	A 720 km long subsea interconnector between Norway and England is planned to be realized in 2021. When realized it will be the world's longest. The main driver for the project is to integrate the hydro-based Norwegian system with the thermal/nuclear/wind-based British system. The interconnector will improve security of supply both in Norway in dry years and in Great Britain in periods with negative power balance (low wind, high demand etc.). Additional the interconnector will be positive both for the European market integration, for facilitating renewable energy and also for preparing for a power system with lower CO2-emission. The interconnector is planned to be a 500 kV 1400 MW HVDC subsea interconnector between western Norway and eastern England.	2021	Mid-term Project	NGT;STATNETT
Great Britain - Norway	**NorthConnect**	A 650 km long subsea interconnector between Norway and Scotland is planned to be realized in 2022. The interconnector is planned to be a 500 kV, 1400 MW HVDC subsea interconnector between western Norway (Simadalen) and eastern Scotland (Peterhead), UK.	1400	190	tbc	2022	Mid-term project	NorthConnect

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Iceland - Great Britain	**Interco Iceland-UK**	Interconnector (Sea cable) between Iceland and Great Britain. The Cable is DC with 800-1200 MW capacity and over 1.000 km long. 99.98% of the generation in Iceland is RES. Icelands hydro generation is highly flexible and ideal for complementing intermittency of GB's growing wind sector.	1000	214			Future Project	LANDSNET;NGT
inside-DE	**OWP Northsea TenneT Part 4**	Connection of offshore wind parks in the North Sea to Germany. Mainly subsea DC cable. The OWP will help to reach the Eropean goal of CO2 reduction and RES integration	3600	129		2031	Future Project	TENNET-DE
inside-DE	**OWP TenneT Northsea Part 2**	Connection of offshore wind parks in the North Sea to Germany. Mainly subsea DC cable. The OWP will help to reach the Eropean goal of CO2 reduction and RES integration	5400	191		2022	Mid-term Project	TENNET-DE
inside-DE	**OWP Northsea TenneT Part 3**	Connection of offshore wind parks in the North Sea to Germany. Mainly subsea DC cable. The OWP will help to reach the Eropean goal of CO2 reduction and RES integration	4500	192		2027	Future Project	TENNET-DE
inside-downstream	**East Anglia Cluster**	This investment is internal to the NGET TSO. This group of investments are in response to an expected growth in offshore wind and nuclear generation in and around the area at stake and is located north and east to London.	3600	69	To facilitate Offshore and nuclear developments	2023	Future Project	NGT
inside-inside	**Reinforcement Northwestern DE**	Integration of on- and offshore RES in Lower Saxony	5500	207		2024	Long-term Project	50HERTZ;AMPRION;TENNET-DE
inside-inside	**N-S Western DE_section North_1**	Integration of on- and offshore RES in Lower Saxony	5500	208			Mid-term Project	50HERTZ;AMPRION;TENNET-DE
inside-inside	**Reinforcement Northeastern DE**	New 380-kV-lines in the area of Schleswig-Holstein mainly for integration of Onshore-Wind.	12000	209			Mid-term Project	50HERTZ;AMPRION;TENNET-DE
inside-inside	**N-S transmission DE_par_line_2**	new 380-kV-OHL between Thuringa and Bavaria due to increase of RES in Northen Germany	11800	204		2024	Long-term Project	50HERTZ;TENNET-DE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
inside-inside	**N-S transmission DE_par_line_1**	new 380-kV-OHL between Thuringa and Bavaria due to increase of RES in Northern Germany	11800	205		2015	Mid-term Project	50HERTZ;TENNET-DE
inside-inside	**N-S Eastern DE_central section**	North-South transmission in Germany. AC links from Northern Germany towards the load centers of Bavaria and Baden-Württemberg.	11800	164		2022	Mid-term Project	AMPRION;TENNET-DE
inside-inside	**Reinforcement Southern DE**	"AC-busbar" in Southern Germany for energy dispatching within Bavaria and Baden-Württemberg and gathering solar energy.	11800	206		2024	Long-term Project	TENNET-DE;TRANSNET-BW
Internal Belgian Backbone East	**Internal Belgian Backbone East**	In a first step (2015) the axis Gramme-Van Eyck is reinforced via the realization of a second 380kV circuit involving the creation of a substation 380 at Van Eyck as well as the installation of a new 380kV circuit in high performance conductors over a distance of about 30km between Van Eyck & Zutendaal. In a latter step (2020-2025) the 'full upgrade' to high-perfomance conductors is envisioned between Gramme & Van Eyck, combined with the installation of a second 380kV circuit between Meerhout & Van Eyck. The need for this latter step is subject to further monitoring of the evolution of the (transit)flux and the potential of new production units that could be deployed within the area.	1400	This project englobes the development of the internal backbone at the east side of Belgium to accommodate the potential new production units in the area and to sustain the development of cross-border capacity.	TYNDP14 - reclustering of project # 24: Belgian North Border	2020	Mid-term Project	Elia System Operator

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Internal Belgian Backbone West	**Internal Belgian Backbone West**	Upgrade consists of replacing the current double circuit 380kV conductors between Horta and Mercator with high performance conductors allowing to double the transport capacity of the axis. The line currently passing Mercator going to Doel will be integrated into Mercator substation to obtain a better flux balance and avoid an upgrade between Mercator & Doel at this stage.	1500	This project covers the development of the internal backbone at the west side of Belgium, which needs to be upgraded in order to transport higher fluxes between France, Stevin & the Netherlands. Furthermore, the upgrade facilitates connection of possible new generation.	TYNDP14 - reclustering of project # 24: Belgian North Border	2019	Mid-term Project	Elia System Operator
Internal Belgium	**Belgian North Border (BRABO)**	Reinforcements are grouped in a modular way into "BRABO" project: - BRABO I (2016): integration of 4th PST on Belgian North Border combined with second 380kV line between Doel & Zandvliet - BRABO II (2020) + BRABO III (2023): realization of a new 380kV AC connection Zandvliet-Lillo-Mercator, including a new 380kV substation at Lillo	1000	24	The need to reinforce the Belgian North Border is driven by a congruation of factors - ensuring reliable grid cooperation in a context of increasing & more volatile international fluxes on Belgian's which could cause internal congestions and negatively effect market capacity - desire to further develop market capacity between Belgium & the Netherlands with +- 1000 MW - possible connection of new central production units - increasing industrial demand around Antwerp harbour area	2020	Mid-term Project	ELIA

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Internal boundary in Germany	**HVDC Brunsbüttel/Wilster to Großgartach/Grafenrheinfeld**	4 GW HVDC connection from Northern Germany (areas of Brunsbüttel/Wilster) to Bavaria / Baden-Württemberg (areas of Großgartach/Grafenrheinfeld)	4000	Integration of RES and security of supply of Southern Germany	NEP (German NDP)	2022	Mid-term Project	TenneT TSO;TransnetBW
Internal Boundary in North-East Germany	**380-kV-grid enhancement between Area Güstrow/Bentwisch and Wolmirstedt**	380-kV-grid enhancement between the areas Güstrow/Bentwisch and Wolmirstedt.	1500	This Project will help to transport the expected amount of RES to the South of Germany. It will also help to increase the technical possibility in this area to integrate the expected new Interconnectors to Scandinavia (e.g. Hansa Power Bridge or Kontek 2).	NEP (German NDP)	2020	Mid-term Project	50Hertz Transmission
Internal Boundary in North-East Germany	**Offshore Wind Baltic Sea (I)**	AC grid connections connecting Offshore Wind Farms in Cluster 1 of the Baltic Sea (see German Offshore Grid Development Plan). Cluster 1 is located north east of Rügen in the German Exclusive Economic Zone.	750	RES connection	German Offshore Grid Development Plan	2018	Mid-term Project	50Hertz Transmission
Internal Boundary in North-East Germany	**Offshore Wind Baltic Sea (II)**	AC grid connections connecting Offshore Wind Farms in Cluster 1, 2 or 4 of the Baltic Sea (see German Offshore Grid Development Plan). Clusters are located north east of Rügen mainly in the German Exclusive Economic Zone.	500	RES connection	German Offshore Grid Development Plan	2026	Long-term Project	50Hertz Transmission
Internal Boundary in West-Germany	**Ultranet**	2 GW HVDC-connection from the Region of Osterath (Rhineland) to the Region of Philippsburg (Baden-Württemberg). New circuit on an existing route on the same pylons as AC lines.	2000	Integration of RES and security of supply of South-Germany.	NEP (German NDP)	2019	Mid-term Project	Amprion;TransnetBW

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Ireland - Great Britain	**Ireland GB Interconnector**	EWIC HVDC interconnector between National Grid and EirGrid	700	106	Connection now connected and operational	2012	Mid-term Project	EIRGRID;NGT
Ireland - Northern Ireland	**North South Interconnector**	A new 400 kV interconnector between Woodland in Ireland and Turleenan in Northern Ireland.	800	81		2019	Mid-term Project	EIRGRID;SONI
Ireland - Northern Ireland	**RIDP I**	The infrastructure development is required to facilitate connection of renewable generation in the North and West of the Island. It will further integrate the Ireland and Northern Ireland transmission systems and provide capacity for substantial demand growth in the area.	570	82		2030	Future Project	EIRGRID;SONI
Luxembourg - Belgium	**Luxembourg-Belgium Interco**	First a phase-shift transformer is integrated at Schifflange (LU) in order to control the transit flows from Germany to Belgium, hereby enabling the line Aubange (BE) - Schifflange (LU) to figure as interconnector. Furthermore, the Luxembourg network is being reinforced by creating a loop around Luxembourg city, including substations for in feed in lower voltage levels.On a longer-term perspective, the further development of interconnection capacity between Belgium & Luxemburg via two cables between Aubange (BE) & Bascharage (LU) is being studied.	700	40	The project envisions the realization of an interconnection between Luxembourg and Belgium allowing to increase the transfer capability between LU, DE, BE and FR and contributing to the security of supply of both countries.	2017	Future Project	AMPRION;CREOS;ELIA;RTE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Netherlands - Germany	**Reinforcements Ring NL**	The project reinforces the Dutch grid to accommodate new conventional and renewable generation, to handle new flow patterns and to facilitate the cross-border capacity increase with neighbouring countries. The project investments are spanning overall from 2019 to 2024. Project 168 "Spaak" is closely related to this project, as ithas the same drivers and benefits as project 103 and can be seen as a long term investment of project 103.The two projects have been assessed as a whole and share the same common assessment.	300	103	Accommodate new conventional and renewable generation, to handle new flow patterns and to facilitate the cross-border capacity increase with neighbouring countries.	2030	Long-term Project	TENNET-NL
Netherlands - Germany	**Doetinchem - Niederrhein**	This new AC 400-kV double circuit overhead line will interconnect The Netherlands and Germany (Ruhr-Rhein area). Upon realization of the project, the border between The Netherlands and Germany will consist of four double circuit interconnections in total. The project will increase the cross border capacity and will facilitate the further integration of the European Energy market especially in Central West Europe.	1500	113		2017	Mid-term Project	AMPRION;TENNET-NL

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Netherlands - Germany	**Spaak NL**	Project 168 "Spaak" associates to project 103 the "Dutch ring"as a second phase long term investment , to be commissioned in 2030. Both projects reinforce the Dutch grid to accommodate new conventional and renewable generation, to handle new flow patterns and to facilitate the cross-border capacity increase with neighbouring countries. The two projects have been assessed as a whole and share the same common assessment.	250	168	Accommodate new conventional and renewable generation, to handle new flow patterns and to facilitate the cross-border capacity increase with neighbouring countries.	2025	Future Project	TENNET-NL
Netherlands - Germany	**201 Upgrade Meeden - Diele**	Increase of the interconnection capacity between The Netherlands and Germany by approximately 500 MW by adding two new phase shifting transformers and upgrade of an existing 400 kV double circuit tie line between Meeden and Diele. The project will increase the cross border capacity and hence increase the market capacity between the two countries. This will lead to better price convergence in the region. Furthermore the energy from RES sources can better be integrated in the Dutch and German system, avoiding spillage and in extreme cases the increase of the interconnection capacity and controllability helps in securing the system.	500	Market integration, RES integration, security of supply		2018	Mid-term project	TenneT TSO;TenneT TSO GmbH

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
North-South	**BOG & Stevin**	STEVIN extends the 380kV backbone to the coastal area, via the construction of a new +-50km (40km OHL; 10km cable) double-circuit between Zomergem and Zeebrugge, including the construction of a new substation in Zeebrugge and transition stations for the cable-line transitions. BOG considers the eruption of an offshore hub connected to the onshore grid (at Zeebrugge) via AC underground cables, including the necessary reactive compensation for these cables.	Direction A: 3000 - Direction B: 0	75	This project facilitates the integration of up to 2,3 GW of offshore capacity into the Belgian grid via the modular development of an offshore hub (BOG: Belgian Offshore Grid project) and the extension of the 380kV backbone to the coastal area (STEVIN project) The final design as well as the legal, ownership & regulatory framework for BOG is being defined in concertation with the stakeholders (wind farm developers,...). BOG is presented here into the extent that it would be considered as regulated infrastructure. Note that the STEVIN project is also required for the integration of the NEMO interconnector (BE-UK).	2018	Mid-term Project	ELIA
North-South	**Anglo-Scottish Cluster**	These projects facilitate the connection of RES and the connection of the remote Scottish Islands.	4200	77	These projects facilitate the connection of RES and the connection of the remote Scottish Islands.	2023	Future Project	NGT;SHETL
North-South	**Offshore Wind Baltic Sea**	Grid connections of offshore wind farms (AC), connecting offshore wind farms in the Baltic Sea to the German transmission grid in Bentwisch, Lüdershagen and Lubmin.	4500	46			Future Project	50HERTZ
North-South	**HVDC Wolmirstedt to area Gundremmingen**	2 GW HVDC-connection from Wolmirstedt to the area of Gundremmingen. Capacity extension to 4 GW is under investigation.	2000	130			Mid-term Project	50HERTZ;AMPRION

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
North-South	**Longterm German RES**	internal German DC-Link for RES integration	18000	133	This project becomes necessary in case of further long-term strong increase in RES generation like in Vision 3 and 4. The project is not in Vision 1 and 2. It connects areas with high installed capacities of RES and areas with high consumption and storage capabilities. For this reason the development of new North-South and Northeast- Southwest electricity transmission capacity in Germany is necessary. This project begins in the North and North-East of Germany, areas with high RES generation (planned and existing) and connections with Scandinavia (planed and existing).The project ends in the South of Germany, an area with high consumptions and connections to Austria and Switzerland (transit to Italy and pump storage in the Alps).	2034	Future Project	50HERTZ;AMPRION;TENNET-DE;TRANSNET-BW
North-South	**N-S Western DE_parallel lines**	Grid reinforcement between North-West-Germany and South-West-Germany to integrate RES.	5500	135	RES integration and system stability.	2022	Mid-term Project	AMPRION
North-South	**N-S Western DE_section North_2**	New 380-kV-OHL and one DC-Link in North-West Germany for integration of RES, mainly on- and offshore wind.	5500	132		2022	Mid-term Project	AMPRION;TENNET-DE

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
North-South	**N-S Western DE_section South**	North-South transmission Western Germany - AC reinforcements and upgrades towards the load centers of Baden-Württemberg and Switzerland	5500	134	RES integration and system stability	2021	Mid-term Project	AMPRION;TRANSNET-BW
North-South	**OWP TenneT Northsea part 1**	Connection of offshore wind parks in the North Sea to Germany. Mainly subsea DC cable. The OWP will help to reach the Eropean goal of CO2 reduction and RES integration	5750	42		2017	Mid-term Project	TENNET-DE
outside-inside	**2nd Offshore-Onshore Corridor (Belgium)**	To evacuate up to 3.3 GW wind, thus 1 GW more than currently planned, preliminary studies indicated that this corridor could consists of a 1 GW DC connection from an offshore platform or nearby Stevin substation in Zeebrugge towards the Antwerp Area (substation Doel could be a possible location) Additional solutions are needed on top op the 1 GW connection to the Antwerp area to integrate the full potential of 4 GW offshore wind. This could take the form of a complementary connection towards Izegem or Brussels, as well as a larger dimensioning of the connection to the Antwerp area. The determination of optimal location/route, technology and the integration of this corridor in relation to an eventual offshore hub/grid are subject of further studies.	1700	120	This is a conceptual project that could be considered as a long-term investment option, triggered by high-RES scenarios where up to 4GW of offshore capacity is envisioned in the Belgian part of the North Sea (note that this 4 GW is not ensured in official government plans). Compared to the current forecast of 2,3 GW of offshore capacity as to which Elia's portfolio is designed, it implies an additional reinforcement under the form a second offshore-onshore corridor. Preliminary analysis indicates that this corridor could consist of multiple reinforcements to different inland locations.	2030	Future Project	ELIA

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
UK - Ireland	**Irish Scottish Links on Energy Study (ISLES)**	ISLES consists of a coordinated offshore grid in the Irish sea and west of Scotland, providing market-to-market interconnection and connection to renewable generation functionalities. The concept ISLES 'zones' consist of a number of complementary multi-terminal HVDC connections that can be operated without the need for DC breakers and without breaching existing onshore loss of in feed limits but which can be reconfigured post-fault to re-establish power transfer paths. The benefits of the design would be that offshore wind or tidal power can be brought to either of two shores, there would be reduced redundancy in connections and, in particular, interconnection capacity would be provided between the GB market and the Single Electricity Market on the island of Ireland. Thus while not 'dedicated to security of supply', realising the ISLES vision would make a significant contribution towards it. Two 'Zones' have been identified:Northern ISLES Corridor (PCI 1.9.2)Southern ISLES Corridor (PCI 1.9.3)"	1000	189	The project partners secured additional INTERREG IVA funding for a second phase of ISLES in 2013. Entitled 'Towards Implementation' it includes three distinct work-streams: ISLES Spatial Plan Network Regulation and Market Alignment Study Business Plan Consultants have been procured to deliver these work-streams and the outputs will begin to emerge May 2015, after a period of extensive stakeholder consultation and engagement. The outputs and recommendations will be disseminated via a number of channels including publications on our website, stakeholder events and final conference events in the summer of 2015.	2020-2030	Future Project	the Department of Enterprise, Trade and Investment in Northern Ireland, the Department of Communications, Energy and Natural Resources in Ireland, and the Scottish Government
West-East	**South West Cluster**	Project needed for renewables off of the South West peninsula, the replanting of Hinkley Point nuclear power station and further CCGT at Seabank.	3200	78	Project needed for renewables off of the South West peninsula, the replanting of Hinkley Point nuclear power station and further CCGT at Seabank.	2022	Future Project	NGT
West-East	**Wales Cluster**	Reinforcement of the internal grid to facilitate the integration of nuclear plant and RES.	2000	79	Reinforcement of the internal grid to facilitate the integration of nuclear plant and RES.	2024	Future Project	NGT

Boundary	Project name	Description	Provisional GTC [MW]	TYNDP2014 reference (if applicable) or motivation for new project candidates	Detailed studies	Expected Commissioning Year	Classification	Project promoter(s)
Inside Germany	**Westcoast line**	New 380-kV-line Brunsbüttel – Niebül inside Schleswig – Holstein. Main focus of the project is the integration of onshore-RES – mainly wind – in Western Schleswig-Holstein. The project is labeled as PCI 1.3.2. It is the southbound connection of PCI 1.3.1. and is necessary to increase the GTC between Dänemark/West and Germany by 500 MW.	3000			2018	Mid-term Project	Tennet-DE
Inside Germany	**Audorf-Dollern**	New 380-kV-line Audorf – Hamburg/Nord – Dollern" in existing 220-kV-corridor. Main focus of the project is the integration of onshore-RES – mainly wind – in Schleswig-Holstein. The project is labeled as PCI 1.4.2. and 1.4.2. It is the southbound connection of PCI 1.4.1. and is necessary to increase the GTC between Dänemark/West and Germany by 720/1000 MW.	3000			2017	Mid-term Project	Tennet-DE

In addition, the following storage projects have been promoted as TYNDP2016 project candidate

Name of the project	Country	Type of storage	Maximum active power [MW]	Total storage capacity [GWh][3]	Expected commissioning date
Cruachan II	UK - Scotland	Pump Storage	600	7,2	2025
MAREX storage	Ireland	PHES pure pumping	1500	6,0	2020
iLand	Belgium	Pumped Hydro - Offshore	550	2,0	2021
CAES Larne, Northern Ireland	Northern Ireland	Compressed air energy storage	330	2,0	2020
Coire Glas	UK	Hydro Pumped Storage	600	30,0	2023

[3] defined as total energy delivered to the grid when reservoir is totally emptied, starting at reservoir full condition

5.3 List of projects of regional significance

Please find below France and Germany projects of regional significance. Note that for Belgium, Luxemburg and the Netherlands, the projects relevant for European grid development all qualify as projects of pan-European significance and as such no projects appear in the list of projects of regional significance.

Country	Project Name	Investment		Description	Main drivers	Included in RgIP 2014?	Monitoring		
		From	To				Commissioning date and status		Evolution drivers
							RgIP 2015	RgIP 2014	
France	Lille - Arras	Avelin	Gavrelle	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	2018	2017	Validation of the least impact corridor took more time than initially planned due to longer than expected consultation in part of the route.
France		Avelin	Mastaing	Operation at 400 kV of existing line currently operated at 220 kV		Yes	2023	2017	Permitting issues and investment needs posponed; hence the investment is postponed.
France	FR offshore wind connection	Several substations on the West coast		AC 225-kV subsea cables and substations works for connecting to shore French offshore windfarms in order to comply with the 2020 objective.	RES integration Integration of new offshore wind generation	Yes	2020	2020	Investment will develop step by step according to the pace of offshore wind generation installation; two calls for tenders have already been issued.
France	Britanny “safety net”	Calan	Plaine Haute	New 80km single circuit 220kV underground cable between existing stations Calan and Plaine Haute, with T-connection in Mur de Bretagne (existing HV substation where 220-kV voltage will be implemented)	SoS The project aims at ensuring the security of supply in Brittany, and is part of the "Pacte Electrique Breton" which also includes demand side management and new generation in the area	Yes	2017	2017	
France		PST in Mur de Bretagne		New 220 kV phase shifter in Mur de Bretagne		Yes	2017	2017	
France		PST in Brenillis		New 220 kV phase shifter in Brennilis		Yes	2015	2014	The investment will be commissioned

									with a few months delay due to technical issues during the construction phase.
France		New AT in Plaine Haute		New transformer 400/220kV in existing substation		Yes	2015	2015	
France	Ouest Amienois	New substation in Limeux		New 400-kV substation connected to existing 400-kV network and equipped with transformers to 220 kV or high voltage networks in order to connect new on-shore wind generation.	RES integration New substation to ensure the integration of wind generation	Yes	2015	2015	
France	Grid adaptation in Alsace following Fessenheim shutdown	PST in Muhlbach		Two 400 kV phase-shifters will be installed in an existing substation in order to mitigate the flows when decommissioning Fessenheim nuclear power station.	SoS Following Fessenheim nuclear plant shutdown, the grid in Alsace has to be adapted in order to secure voltage control and mitigate increased power flows through the area	Yes	2016	2016	
France		MVARs in Alsace		Installation of 320 MVARs of capacitors and 2 reactances of 64-MVAR in Alsace for voltage support after decommissioning Fessenheim nuclear power station.		Yes	2016	2016	
France		Scheer		in-out connection of Scheer 400kV existing substation to the existing line Bezaumont-Muhlbach. This investment is needed for securing the area after the decomissioning of Fessenheim power station.		Yes	2016	2017	This investment is needed after Fessenheim nuclear power station decommisioning.
France		Muhlbach	Scheer	Ampacity increase of existing 400 kV Muhlbach-Scheer line		Yes	2016	2016	
France	Long term perspective in Eastern France	Muhlbach	Scheer	New 400kV line substituting to existing 225kV line in Alsace area. Several solutions are under consideration and some restructuration of the 225 kV grid may be needed in the area. This investment is only needed in vision 4.	Market integration, RES integration Long term reinforcements package needed in case of high development of RES generation in Northern part of Europe	Yes	2030	2030	This investment is needed only in long term high RES scenario; triggered by high north-west to south-east flows in eastern France (from Lorraine and northern border to Alsace, southern Germany and Switzerland)
France		Vigy	Marlenheim	Operation at 400kV of the second circuit of a 112-km		Yes	2030	2030	This investment is needed only in long

				existing 400 kV line currently operated at 225kV, with some restructuration of the 225-kV grid in the area.					term high RES scenario; triggered by high north-west to south-east flows in eastern France (from Lorraine and northern border to Alsace, southern Germany and Switzerland)
France		Vigy	Bezaumont	Operation at 400 kV of the second circuit of a 40-km existing 400 kV line currently operated at 225 kV.		Yes	2030	2030	This investment is needed only in long term high RES scenario; triggered by high north-west to south-east flows in eastern France (from Lorraine and northern border to Alsace, southern Germany and Switzerland)
France		Mery	Creney	Reconductoring an existing 25-km single circuit 400 kV line in Bourgogne area.		Yes	2030	2030	Accurate scope of the investment to be defined taking into account congestion in specific long term high RES scenario and refurbishment needed on existing asset.
France		Creney	Vielmoulin	Upgrade of an existing single-circuit 400 kV line in Bourgogne. Accurate scope of the investment should be defined taking into account congestion in specific scenarios (visions 3 & 4) and refurbishment needed on existing assets in the area.		Yes	2030	2030	Increase of grid capacity is needed only in long term high RES scenario, triggered by high north-west to south-east flows in eastern France; also possible needs for refurbishment of existing assets in the area.
France	Long term perspective	Rossignol substation		New 400kV substation east of Paris and associated	SoS, RES, Market integration	Yes	2030	2030	This investment is needed in the long

	Haute-Normandy - southern Paris area			connections to existing grid.	Development of new RES generation, as well as new FR GB interconnection capacities, lead to increase flows from West of France to East through Paris Area.				run for high RES scenario to balance flows on the north-eastern Paris 400-kV ring.
France		Chesnois	Cirolliers	Reconductoring Chesnoy-Cirolliers existing 400kV OHL with high temperature conductors in order to strengthen the south-western part of Paris 400-kV ring.		Yes	2030	2030	This long term investment is needed only in long term high RES scenario in order to strengthen the south-western part of Paris 400-kV ring.
France		Chaingy	Dambron	New 26-km double circuit 400kV line in Loiret department, substituting to two existing 225kV lines. This investment is needed in order to cope with south-north flows to Paris area.		Yes	2030	2030	Recent studies for long term high RES scenarios showed the need to strengthen the grid in the area in order to cope with south-north flows to Paris area.
France		Southern Paris		Restructuration/development of the 400kV grid south of Paris area, needed for long term high RES scenarios. Several solutions are under consideration inlvolving either new axis or reconductoring of existing assets.		Yes	2030	2030	Recent studies for long term high RES scenarios have shown the need for strengthening the southern part of the Paris 400 kV ring, either by creating a new line or by increasing the capacity of the existing assets.
France	Lonny – Vesle	Lonny	Vesle	Reconstruction of the existing 70km single circuit 400kV OHL as double circuit OHL.	SoS, RES integration Projet needed to cope with more volatile power flows through Champagne, triggered by the development of new generation sources that would naturally flow to consumptions areas (Paris, Reims...)	Yes	2016	2016	
France	Havre - Rougemont	Havre	Rougemontier	Reconductoring of existing 54km double circuit 400kV OHL to increase its capacity in	New conventional generation integration	Yes	2018	2018	the investment progresses according to the pace of new

	ier			order to integrate new generation.	Integration of new conventional generation in Le Havre area				generation installation in the area.
France	Cergy – Persan	Cergy	Persan	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 integration, RES Project triggered by larger and more volatile power flow from new generation, and by new FR GB interconnection projects	Yes	2018	2018	
Germany	182	Kriftel (DE)	Obererlenbach (DE)	New 400 kV double circuits OHL Kriftel - Obererlebenbach in existing OHL corridor.		Yes	2016	2015	
Germany	185	Hanekenfähr (DE) and Ibbenbüren (DE)	Uentrop (DE)	In order to facilitate the integration of RES (especially wind) several grid reinforcements in the area of Münsterland/Westphalia are needed. This project will affect mainly the following substations: Hanekenfähr, Uentrop, Gütersloh, Wehrendorf, Lüstringen, Westerkappeln and Ibbenbüren. Within this area new lines and installation of additional circuits are planned. In addition the necessity for extension of existing and erection of several 380/110kV-substations is given.		Yes	2020	2020	
Germany	186	Gütersloh (DE)	Bechterdissen (DE)	New lines and installation of additional circuits, extension of existing and erection of 380/110kV-substation.		Yes	2014	2014	Commissioned
Germany	187	Utfort (DE)	Rommerskirchen (DE)	New lines and installation of additional circuits, extension of existing and erection of several 380/110kV-substations.		Yes	2018	2018	
Germany	190	St. Barbara (DE)	Mittelbexbach (DE)	New lines, extension of existing and erection of several 380/110kV-substations		Yes	2016	2014	
Germany	672	Area of West		Installation of reactive power compensation (eg. MSCDN,		Yes	2018	2016	Delays in planning process

		Germany (DE)		SVC, phase shifter). Devices are planned in Kusenhorst, Büscherhof, Weißenthurm and Kriftel. Additional reactive power devices will be evaluated.					
Germany	673	Pkt. Metternich (DE)	Niederstedem (DE)	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.		Yes	2021	2021	
Germany	678	Hamm/Uentrop (DE)	Kruckel (DE)	Extension of existing line to a 400 kV single circuit OHL Hamm/Uentrop - Kruckel and extension of existing substations.		Yes	2018	2018	
Germany	681	Bürstadt (DE)	BASF (DE)	New line and extension of existing line to 400 kV double circuit OHL Bürstadt - BASF including extension of existing substations.		Yes	2021	2024	
Germany	1088	Mengede (DE)	Wanne (DE)	Reconductering of existing 380kV line Mengede - Herne - Wanne.		Yes	2016	2014	Delays due to private law negotiation
Germany	1089	Point Ackerstraße	Point Mattlerbusch	Reconductering of existing 380kV line between Point Ackerstraße-Mattlerbusch		Yes	2017	2014	Delays due to costumer power supply
Germany	1090	Niederhein (DE)	Utfort (DE)	New lines and installation of additional circuits, extension of existing and erection of several 380/110kV-substations.		Yes	2018	2018	
Germany	1091	Günnigfeld (DE)	Wanne (DE)	Additional 380kV circuit. Connection of power plant.		Yes	2018	2018	
Germany	1092	Landesbergen (DE)	Wehrendorf (DE)	Installation of an additional 380-kV circuit between Landesbergen and Wehrendorf		Yes	2022	2023	
Germany	1093	Point Okriftel (DE)	Obererlenbach (DE)	Upgrade of existing 380kV lines. Furthermore will the 220kV substation Farbwerke Höchst-Süd be upgraded to 380kV.		Yes	2021	2022	

Germany	1094	Several		This investment includes new 380/220kV transformes in Walsum, Sechtem, Siegburg, Mettmann and Brauweiler.		Yes	2019	2024	
Germany	1095	Lippe (DE)	Mengede (DE)	Reconductering of existing 380kV line between Lippe and Mengede.		Yes	2025	2024	
Germany	1096	Lüstringen (DE)	Gütersloh (DE)	Additional 380kV circuit between Lüstringen and Gütersloh and reinforcement of the substations Lüstringen and Gütersloh.		Yes	2020	2024	
Germany	1097	Several		This investment includes several new 380/110kV transformers in order to integrate RES in Erbach, Gusenburg, Kottigerhook, Mettmann, Niederstedem, Öchtel, Prüm and Wadern. In addition a new 380kV substation and transformers in Krefeld Uerdingen are included.		Yes	2019	2019	
Germany	1100	Herbertingen (DE)	point Neuravensburg (DE)	Between the 380-kv-station Herbertingen and point Neuravensburg a new line with a significantly higher transmission capacity will be constructed (Grid enhancement).		Yes	2023	2034	
Germany	191	Neuenhagen (DE)	Vierraden (DE)	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).		Yes	2017	2016	Longer than expected permitting procedure
Germany	197	Neuenhagen (DE)	Wustermark (DE)	Construction of new 380kV double-circuit OHL between the substations Wustermark-Neuenhagen with 75km length. Support of RES and conventional generation integration, maintaining of security of supply and support		Yes	2018	2018	

				of market development.					
Germany	199	Pasewalk (DE)	Bertikow (DE)	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.		Yes	2018	2018	
Germany	202	Bärwalde (DE)	Schmölln (DE)	Upgrading existing double-circuit 380kV OHL in the South-Eastern part of the control area of 50Hertz Transmission. Bärwalde-Schmölln length approx. 50km. Support of RES and conventional generation integration in North-Eastern Germany, maintaining of security of supply and support of market development.		Yes	2014	2015	Already in commission
Germany	206	Röhrsdorf (DE)	Remptendorf (DE)	Construction of new double-circuit 380-kV-overhead line in existing corridor Röhrsdorf-Remptendorf (103 km)		Yes	2021	2020	Rescheduled
Germany	959	Lubmin (DE)	Güstrow (DE)	380-kV-grid enhancement and structural change Lubmin-Lüdershagen-Bentwisch-Güstrow		Yes	2024	2030	Rescheduled
Germany	960	Lubmin (DE)	Pasewalk (DE)	380-kV-grid enhancement and structural change area Lubmin-Iven-Pasewalk.		Yes	2024	2030	Rescheduled
Germany	993	Röhrsdorf (DE)		Installation of new PSTs in Röhrsdorf		Yes	2023	2016	Rescheduled
Germany	1067	Klosterman sfeld (DE)	Lauchstädt (DE)	Upgrade of existing 380kV line		Yes	2024	2020	Rescheduled
Germany	208	Pulgar (DE)	Vieselbach (DE)	Construction of new 380kV double-circuit OHL in existing corridor Pulgar-Vieselbach (103 km) Support of RES and		Yes	2024	2024	

				conventional generation integration, maintaining of security of supply and support of market development.					
Germany	965	Hamburg/Nord (DE)	Hamburg/Ost (DE)	AC Enhancement Hamburg		Yes	2024	2023	Rescheduled
Germany	966	Krümmel (DE)	Hamburg/Nord (DE)	AC Enhancement Krümmel		Yes	2024	2023	Rescheduled
Germany	967	control area 50Hertz		Contructions of new substations, Var-compensation and extension of existing substations for integration of newly build power plants and RES in 50HzT control area		Yes	2024	2023	Rescheduled
Germany		Gießen/Nord	Karben	new 380-kV-line Gießen/Nord - Karben in existing corridor for RES integration		No	2025	New investment	
Germany	683	Wolmirstedt (DE)	Wahle (DE)	New double circuit OHL 380 kV; Line length 111 km		Yes	2022	2022	
Germany	684	Vieselbach (DE)	Mecklar (DE)	New double circuit OHL 400 kV line in existing OHL corridor . (129 km)		Yes	2022	2022	
Germany	974	Elsfleht/West	Ganderkesee	new 380 kV OHL in existing corridor for RES integration between Elsfleth/West, Niedervieland and Ganderkesee		Yes	2021	2030	
Germany	975	Irsching	Ottenhofen	new 380-kV-OHL in existing corridor between Irsching and Ottenhofen		Yes	2030	2030	
Germany	976	Dollern	Alfstedt	new 380-kV-OHL in existing corridor in Northern Lower Saxony for RES integration		Yes	2024	2030	
Germany	977	Unterweser	Elsfleth/West	new 380-kV-OHL in existing corridor for RES integration in Lower Saxony		Yes	2024	2030	
Germany	978	Conneforde	Unterweser	new 380-kV-OHL in existing corridor for RES integration in Lower Saxony		Yes	2024	2030	
Germany	1092	Landesbergen (DE)	Wehrendorf (DE)	Installation of an additional 380-kV circuit between Landesbergen and Wehrendorf		Yes	2023	2023	
Germany	1101	Büttel	Wilster	new 380-kV-line in extisting corridor in Schleswig - Holstein for integration of RES		Yes	2021	2019	

				especially wind on- and offshore					
Germany	1102	junction Mehrum	Mehrum	new 380-kV-line junction Mehrum (line Wahle - Grohnde) - Mehrum including a 380/220-kV-transformer in Mehrum		Yes	2019	2019	
Germany	1103	Borken	Mecklar	new 380-kV-line Borken - Mecklar in existing corridor for RES integration		Yes	2021	2021	
Germany	1104	Borken	Gießen	new 380-kV-line Borken - Gießen in existing corridor for RES integration		Yes	2022	2022	
Germany	1105	Borken	Twistetal	new 380-kV-line Borken - Twistetal in existing corridor for RES integration		Yes	2021	2021	
Germany	1106	Wahle	Klein Ilsede	new 380-kV-line Wahle - Klein Ilsede in existing corridor for RES integration		Yes	2018	2018	
Germany	168	Goldshöfe (DE)	Dellmensigen (DE)	Upgrade the line Goldshöfe - Dellmensigen from 220kV to 380kV . Line length:114km. Included in the investment : 3x 380kV substations, 2 transformers.		Yes	2015	2014	
Germany	170	Großgartac h (DE)	Hüffenhardt (DE)	New 380kV OHL Großgartach Hüffenhardt. Length: 23km. Included in the project : 1 new 380kV substation, 2 transformers.		Yes	2014	2013	
Germany	172	Mühlhause n (DE)	Großgartach (DE)	Upgrade of the line Mühlhausen-Großgartach from 220kV to 380kV. Length: 45km.		Yes	2015	2014	
Germany	173	Hoheneck (DE)	Endersbach (DE)	Upgrade of the line Hoheneck-Endersbach from 220kV to 380kV. Length:20km.		Yes	2015	2014	
Germany	174	Bruchsal Kändelweg (DE)	Ubstadt (DE)	A new 380kV OHL Bruchsal Kändelweg - Ubstadt. Length:6km.		Yes	2014	2014	
Germany	175	Birkenfeld (DE)	Ötisheim (DE)	A new 380kV OHL Birkenfeld-Ötisheim (Mast 115A). Length:11km.		Yes	2019	2020	
Germany	178	Goldshöffe and		Installation of 2x250 MVAr 380kV capacitance banks (1x250 MVar Goldshöfe and		Yes	2014	2014	

		Engstlatt		1x250MVar Engstlatt).					
Germany	1108	Metzingen-Oberjettingen	Oberjettingen-Engstlatt	New 380kV OHL Metzingen-Oberjettingen (32 km) and new 380kV OHL Oberjettingen-Engstlatt (34 km)		Yes	2020	2020	
Germany	1109	Großgartach	Pulverdingen	New circuit 380kV OHL Großgartach-Pulverdingen (30 km) combined with reconductering existing circuit 380kV OHL Großgartach-Pulverdingen (30 km)		Yes	2024	2024	
		Stalldorf		New 380 kV substation between Kupferzell and Grafenrheinfeld		No	2016		
		Höpfingen/ Kupferzell		New transformers 380/110 kV in existing stations		No	2019		
		Heidelberg Nord		New 380 kV substation including 380/110 kV transformer		No	2018		

5.4 Reference capacities

Reference capacities should not be confused with market based target capacities under a high RES scenario. These capacities were a result of the Common Planning Studies of TYNDP2014 vision 4 and they were one basis for promoted TYNDP2016 project candidates.
The aim of the reference capacities however, is to give a common ground for comparison and assessing benefits of the different projects. Reference capacities are formed by taking into account today's capacities and the capacity increases on the borders by taking into account mid- and long-term projects as described in chapter 5.1. Projects will be assessed based on either TOOT- or PINT-methodology and a detailed description of how this will be done with respect to the reference capacities, will be provided in the TYNDP-report.

	Reference Capacities (including present situation, Mid-term and Long-Term projects but not including future projects) (MW)	
Border	**2020 Expected Progress**	**2030 Visions**
BE-DE	1000	1000
BE-FR	2800	2800
BE-GB	1000	1000
BE-LUB	380	380
BE-LUG	700	700
BE-NL	2400	2400
DE-BE	1000	1000
DE-DKW	3000	3000
DE-LUG	2300	2300
DE-NL	4450	5000
DE-NO	1400	1400
DKW-DE	3000	3000
DKW-GB	1400	1400
DKW-NL	700	700
FR-BE	4300	4300
FR-GB	5400	5400
FR-IE	0	700
FR-LUF	380	380
GB-BE	1000	1000
GB-DKW	1400	1400
GB-FR	5400	5400
GB-IE	500	500
GB-IS	0	0
GB-NI	500	500
GB-NL	1000	1000
GB-NO	1400	1400
IE-FR	0	700
IE-GB	500	500
IE-NI	1100	1100
IS-GB	0	0
LUB-BE	0	0
LUF-FR	0	0
LUG-BE	700	700
LUG-DE	2300	2300
NI-GB	80	500
NI-IE	1100	1100
NL-BE	2400	2400
NL-DE	4450	5000
NL-DKW	700	700
NL-GB	1000	1000
NL-NO	700	700

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NO-DE	1400	1400
NO-GB	1400	1400
NO-NL	700	700

Figure 5-1 Reference cross-border capacities for the Assessment phase, 2020 and 2030

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5.5 Interconnection ratios

The following figures show the interconnection ratios based on the draft TYDNP2016 scenarios for 2020 (Expected Progress) and 2030 (four Visions)[4].

The objective set by the European Council is to reach 10% for all Member States in 2020 and to aim at 15% for 2030 "while taking into account the costs aspects and the potential of commercial exchanges".

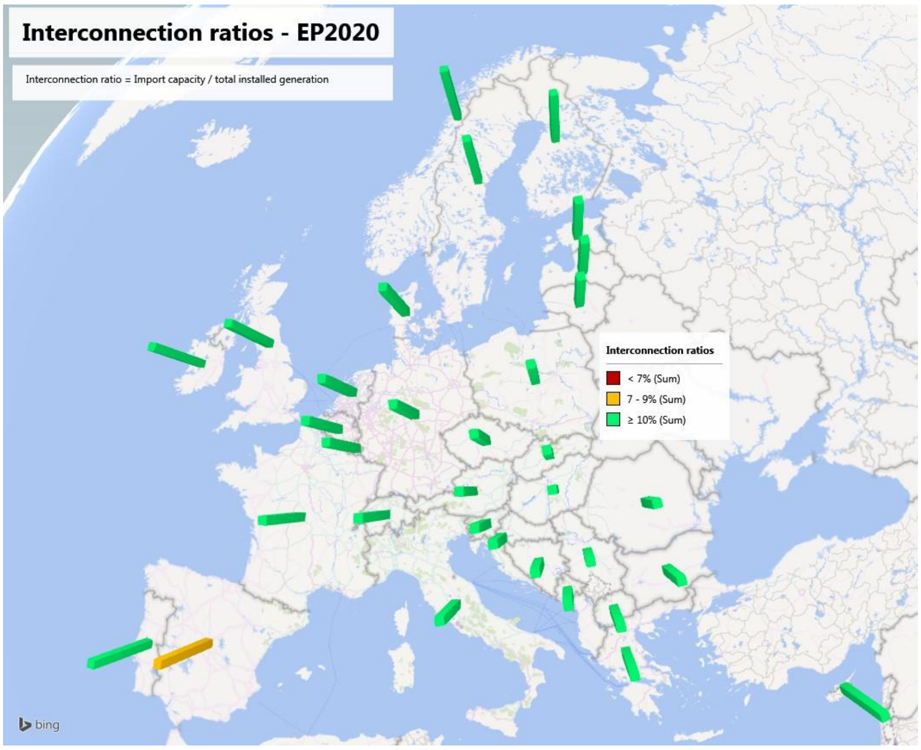

Figure 5-2 EP2020 Interconnection ratio

4 https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/150521_TYNDP2016_Scenario_Development_Report_for_consultationv2.pdf

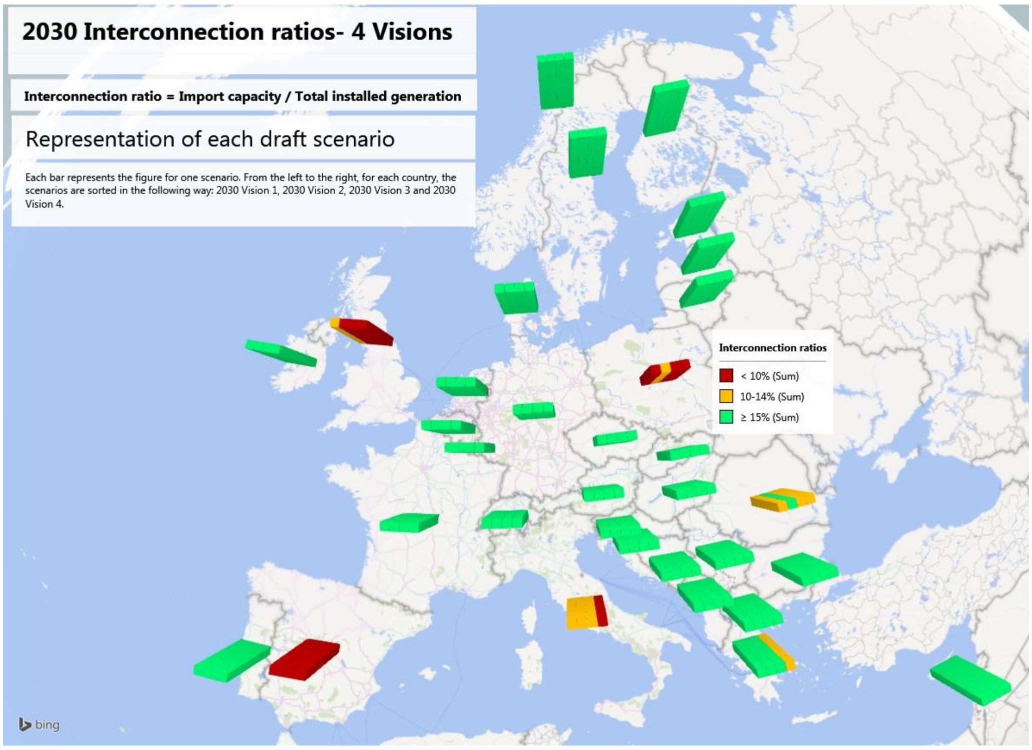

Figure 5-3 Interconnection ratio – 2030 Visions - import capacity divided by net generating capacity

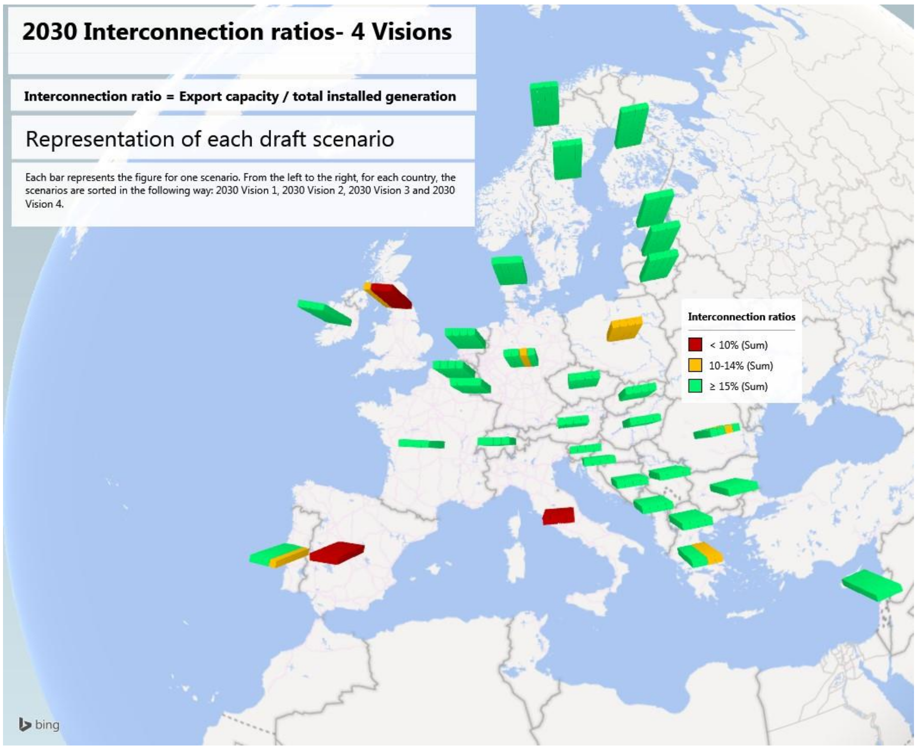

Figure 5-4 Interconnection ratio - 2030 Visions - export interconnection capacity divided by net generating capacity

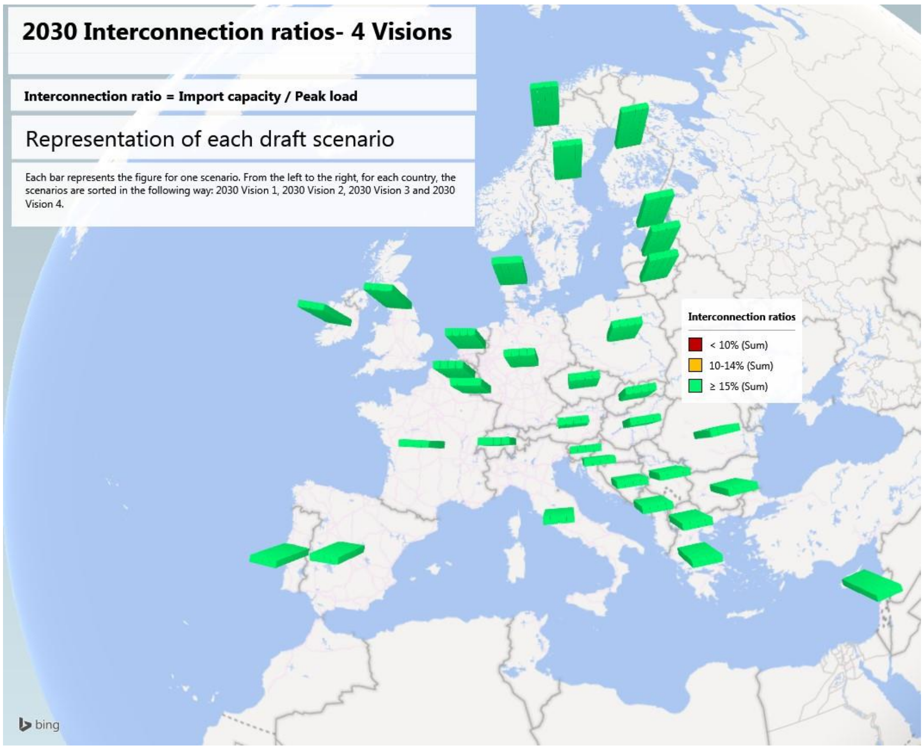

Figure 5-5 Interconnection ratio – 2030 Visions - import interconnection capacity divided by peak load

Three maps are presented for the 2030 interconnection ratios. These represent three different ways of defining the interconnection ratio for each country: the combined import capacity of its cross border interconnections divided by its total installed generation; the combined export capacity of its cross border connections divided by its total installed generation, and its import capacity divided by its peak load. The import and export capacities include planned mid and long term projects, but do not include future projects (those that would be commissioned beyond 2030).
Only one map is presented for the 2020 situation: this is as there is one accepted definition of interconnection ratio for the 2020 goal of 10% interconnection. This is import capacity divided by total installed generation.

For Great Britain; visions 3 and 4 show a significant growth of renewable out to 2030. Notably there are also large amounts embedded generation growth which has not previously been significant. This presents itself as a high level of installed generation capacity. This creates continued opportunities for wider European integration via interconnectors.

For security of supply reason, the interconnection target ratios 10% for 2020, 15% in 2030 should be put in relation to the dependency of importation and export capacity, the consumption and the net generating capacity. Despite a positive remaining capacity countries may be highly dependent on addition imports from neighbouring countries with generation surplus. Additional transit flows may also impact security of supply of smaller countries.

5.6 Long term perspective, remaining challenges and gaps

When looking beyond 2030, at a time horizon such as 2050, it is expected that the share of renewable on the electricity market will increase further, and within the context of a policy driven transition towards a low carbon future, the conventional generation portfolio will subsequently have to change.

Given these expectations along with the potential for further RES development in Europe, it is reasonable to develop high level long-term project concepts that may come into focus for future scenarios. These conceptual ideas are driven by objectives such as electricity market and RES integration.

Consequently, two long-term conceptual projects have been added at Regional Group level, and illustrated in the maps in figure 5.5. The two projects are as follows:

Long-term conceptual West-East Corridor in North Sea

- *Driver: Long-term perspective as per the analysed TYNDP14 Vision 4 scenario induces reflection upon a corridor from Great Britain to Central Europe, with possible multi-terminal take-off points in Benelux, France and Germany*
- *Description: potential synergies between interconnectors and internal grid reinforcements, enabling further market integration between Great Britain and Central Europe is to be further studied within the concept of a "west-east corridor"*

Long-term conceptual North Seas Offshore Grid Scheme

- *Driver: RES integration and increase the integration level between countries, including necessary onshore reinforcements*
- *Description: potential synergies to be further studied given the preliminary ideas on a global scheme for offshore infrastructure in the North Seas, complemented with the long term perspective for further market integration as per analysed TYNDP2014 vision 4 scenario.*

Figure 5.5 - long terms concepts as future project candidates under consideration for the North Sea region.

5.7 Long term concept: Case study – Denmark as a multi-terminal HVDC system

The concept of a multi-terminal HVDC system can be envisaged as a potential reinforcement strategy beyond 2030. For the purpose of this study, this concept has been as an example applied to a potential situation of Denmark, giving first indications on cost-efficiency in comparison to the business-as-usual approach, i.e. point-to-point HVDC connectors to the nearest suitable substations.

The methodology and procedure of combining of single HVDC connectors into the Danish multi-terminal HVDC system is presented in section 7.3 in the Appendix.

Some potential for additional interconnectors to Denmark-West has been detected during the market analysis. As per the TYNDP 2014 projects, such interconnectors would have to be established as HVDC connectors because the Danish grid is asynchronous to the major non-continental foreign systems. This potential would lead to a total transport capacity heavily exceeding the difference between the generation capacity and consumption in Denmark-West, implying that the Danish grid would become a transit area with only a small amount of energy exchanged with the Danish grid itself. Since only a small amount of energy is exchanged with the grid itself, the number of the HVDC VSC stations could then be reduced without reducing the market flows.

Figure 5.4 explains the difference between conventional point-to-point HVDC connectors (business as usual) and the multi-terminal HVDC system. The arriving HVDC connectors are combined into a HVDC hub which forms the multi-terminal HVDC system in Denmark-West, utilizing 2 instead of 3 HVDC VSC stations.

The main drivers behind a potential multi-terminal HVDC system are its cost-efficiency, technical advance and reduced stress on the internal HVAC transmission system. The cost-efficiency is emphasized through that the multi-terminal HVDC system would need fewer HVDC VSC stations in Denmark for facilitating the same number of HVDC connectors and the same energy and power transport with the foreign areas. The cost efficiency is investigated through the assessment of the capital expenditures and the reduction of energy conversion losses capitalized over the expected life-time of the potential projects.

Additional benefits of the multi-terminal HVDC system include no-needs of reinforcement investments in Denmark to facilitate the heavily increased trans-border flows and expected reduction of the transmission losses. The transmission losses are expected to be reduced because the losses in DC are lower than those in AC (presence of reactive power in the HVAC system causing higher losses, but not in the HVDC system). The cost reduction due to the multi-terminal HVDC system in Denmark-West is summarized in table 5.1.

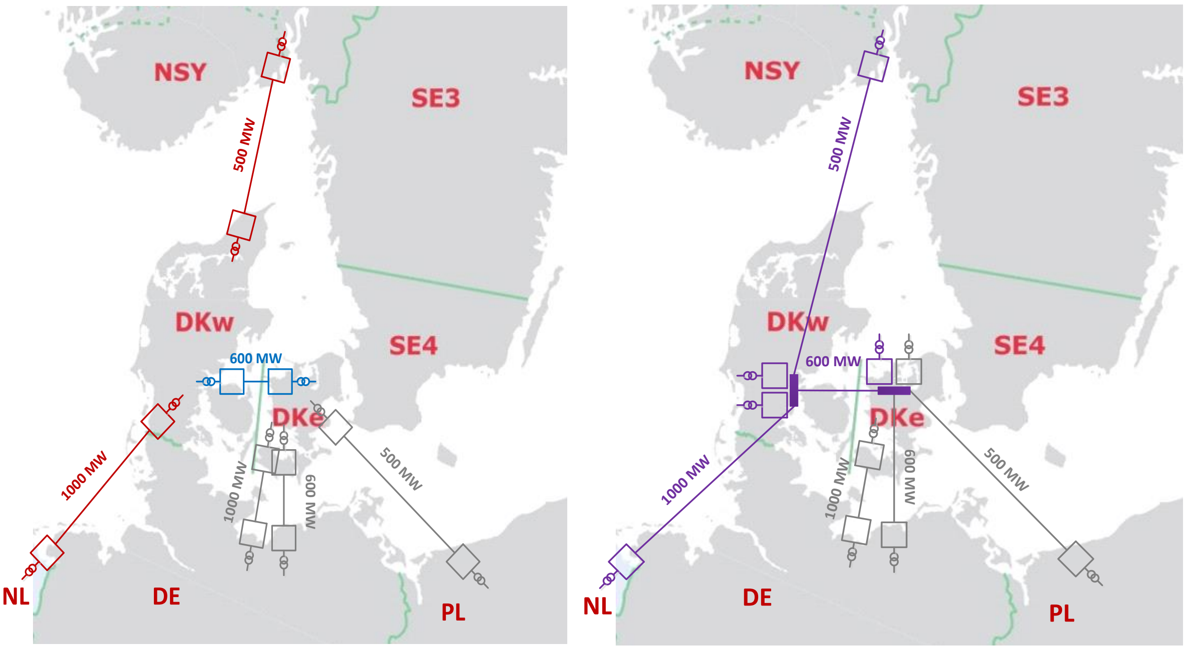

Figure 5.6: Point to point (left) and multi-terminal (right) HVDC solutions in Denmark

The map on the left in Figure 5.6 shows Denmark-West with point-to-point HVDC optional projects and TYNDP-2014 projects using seven HVDC VSC stations. Meanwhile, the map on the right shows Denmark-West as a multi-terminal HVDC system, using five HVDC VSC stations. The colours of the lines in figure 5.4 indicate the following: blue indicates TYNDP 2014 projects, red indicates potential projects, purple indicates a multi-terminal HVDC system, and grey indicates candidate projects in Denmark-East (investigated in Regional Group Baltic Sea).

Multi-terminal HVDC system	Cost reduction [M€]
Capital cost reduction **(Disregarding savings on internal grid reinforcements)**	~100 (33,5)
Smaller energy conversion losses	~60
Total cost reduction	160

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(Disregarding savings on internal grid reinforcements)	(94,5)

Table 5.1: Potential cost reductions for the Denmark-example

Table 5.1 shows the estimated cost reduction of the proposed multi-terminal HVDC system in comparison to establishment of point-to-point HVDC connectors in Denmark-West for the same energy transport with the foreign systems. Losses capitalization: 65 €/MWh in Denmark in average, 30 years expected life-time, 5% discount rate.

The comparison has shown that the multi-terminal HVDC system will be up to 160 M€ cheaper than conventional point-to-point HVDC connectors in Denmark-West at given pre-conditions of the market results. However, the results are indicative, volatile to energy and equipment prices as well as to other external factors which are beyond the scope of this study.

It is important to state that the proposed multi-terminal HVDC system is assuming the two hubs being installed on-land, and not offshore.

The main idea uses the same technology and general basic idea as discussed earlier in the context of various offshore grid research projects. Thus, some of the general findings above might also be translated into discussions and commercialization of offshore grid infrastructure, but the difference in cost assumptions for on- and offshore assets has to be considered.

6 NEXT STEPS

6.1 A two-year cycle & CBA evolvement

Assessment methodology

The present version of the Cost Benefit Analysis (CBA) methodology, developed by ENTSO-E in close collaboration with stakeholders and ACER, was officially approved by EC in February 2015. The TYNDP2016 assessments of projects will be carried out based on this version as required by Regulation (EU) 347/2013. The previous TYNDP2014 was already to a large extent based on a nearly final CBA methodology, and the lessons learned in this process will contribute to the TYDNP2016 process. The CBA methodology provides for a multi-criteria assessment of all TYNDP projects across a wide range of indicators as presented in the figure below.

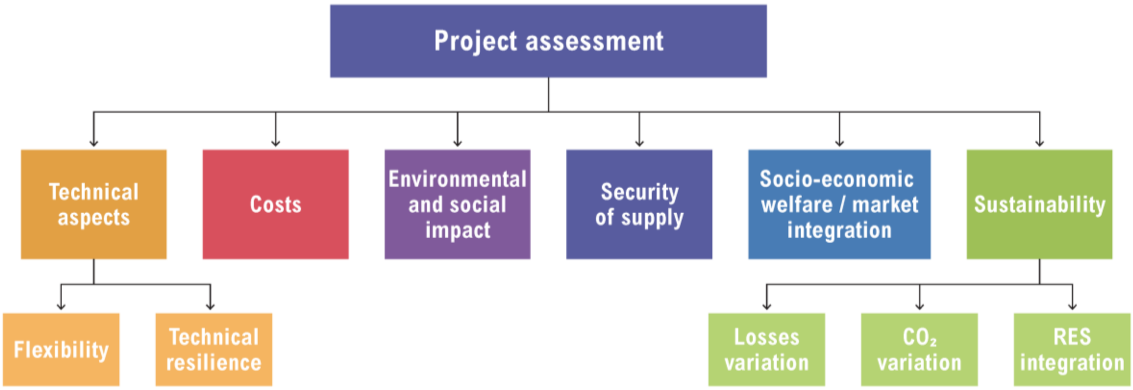


Figure 6-1 CBA Indicators

Even as an approved CBA methodology is ready for use in TYNDP2016, work is continuing to further improve the methodology for future TYNDPs. Several elements which are already being explored further is how storage, Security of Supply and Ancillary Services can be addressed in a transparent, objective, and European consistent manner.

In the final TYNDP2016 report, the reader can expect to see an assessment sheet for each individual TYNDP project in the following format:

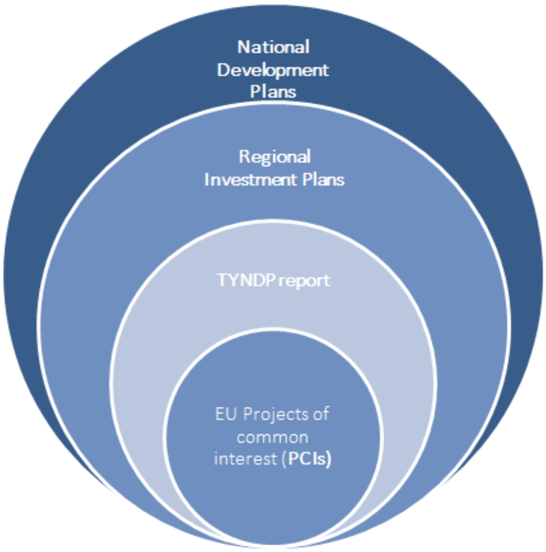
	CBA results non specific scenario		CBA results for each scenario								CBA results non specific scenario				
	GTC increase - direction 1 [MW]	GTC increase - direction 2 [MW]	TYNDP scenarios	Contribution to Intercon-nection rate [%]	B1 - SoS [MWh/y]	B2 - SEW [M€/y]	B3 - RES integration [MWh/y or MW/y]	B4 - Losses [MWh]	B5 - CO2 Emiss [kT/y]	B6 – Technical Resilience	B7 – Flexibility	S1 - protected areas [km]	S2 - urban areas [km]	C1 - Estimated cost [M€]
Assessment results CLUSTER															

Scenarios

While this set of Regional Investment Plans is being published in summer 2015, ENTSO-E recently concluded a public consultation on a proposed Scenario Development Report in May-June 2015[5]. This report proposes a set of possible futures, describing storylines, methodologies, assumptions, and resulting load/generation mixes. One best estimate scenario for 2020 and four possible contrasting visions for 2030 have been proposed. These provide the mid- and long-term horizons as referred to in the CBA methodology against which all TYNDP2016 projects will be assessed.

Other infrastructure plans

It is worth highlighting how the TYNDP and the Regional Investment Plans are related to national plans and EU support measures.



- National Development Plans: provided by TSOs at specific time intervals and based on (national) scenarios which not always one-to-one relate to those of the Community-wide TYNDP. These are developed according to Article 22 of Directive 2009/72/EC.

- Regional Investment Plans: developed by TSOs in ENTSO-E's cooperation structure, following Article 12 of Regulation (EC) 714/2009.

- Community-wide Ten Year Network Development Plan: a key ENTSO-E deliverable as mandated by Regulation (EC) 714/2009. It inter alia needs to build on national investment plans, taking into account regional investment plans and, if appropriate, Community aspects of network planning.

- Projects of Common Interest: Procedure set forth in Regulation (EU) 347/2013, aiming to stimulate particular infrastructure projects with direct funding, financial leverage and/or permitting streamlining. PCIs are adopted by the EC in every year in between two TYNDP publication years. To be eligible for PCI labelling, inclusion in the last available TYNDP is an explicit condition.

[5] https://www.entsoe.eu/news-events/announcements/announcements-archive/Pages/News/TYNDP-2016--ENTSO-E-calls-for-views-on-the-scenarios-report.aspx

7 APPENDICES

7.1 Detailed description of the methodology used

In chapter 2.3 General methodology, the overall process overview was described, for the readers for faster orientation and better understanding of the whole Common Planning Studies process. This chapter will describe both market and network methodologies used in more details, also with practical examples given.
The Common Planning Studies are an important part of the TYNDP2016 process. They were carried out jointly and coordinated by all regional groups of ENTSO-E for the TYNDP2014 Vision 4 model. Beside this, regional groups could carry out additional regional scenarios and sensitivities, to analyze specific impacts, issues or particularities of the regions, which they wanted to be shown in this report.

Market modelling description of the approach

The aim of the Common Planning Studies was to identify beneficial borders that will be increased in 500 or 1000 MW steps. Preliminary to the market studies members of the regional network-groups provided a list of costs for each possible increase and border. These costs included necessary internal reinforcements to make the additional cross-border capacity possible.
It was not necessary to specify costs for borders where new projects are not feasible. However – a good reason for why an increase of the cross-border capacity at this border is not feasible had be provided and agreed with the regional groups involved.
The following approach has been used.

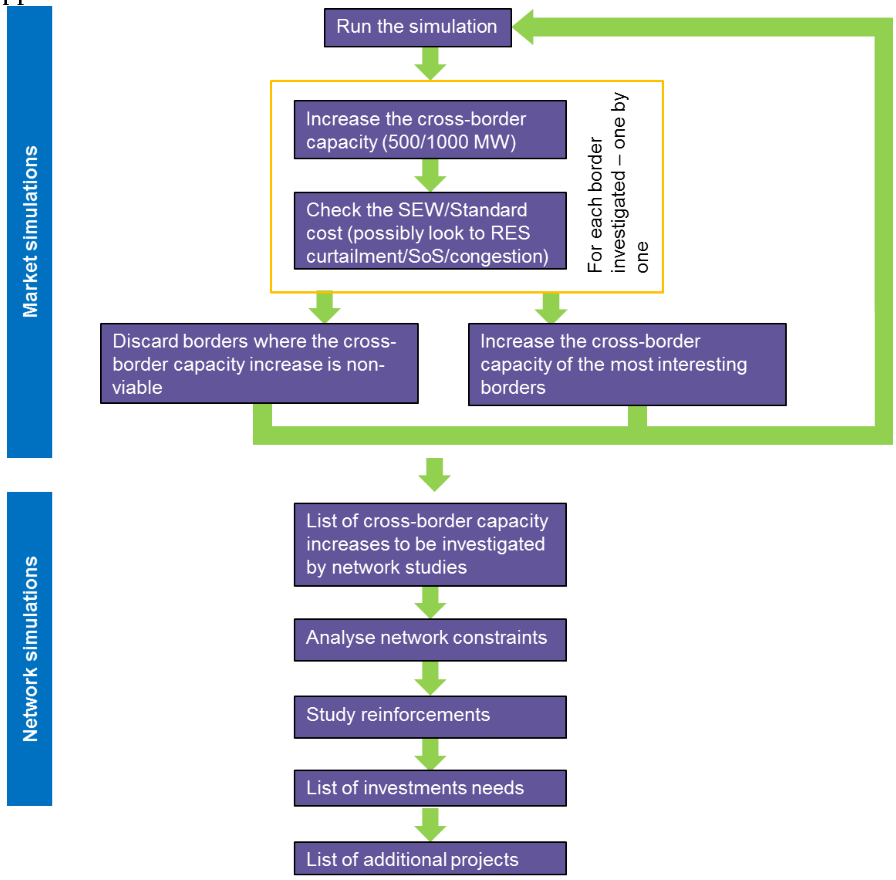


Figure 7-1 Overall overview of the Common Planning Studies process

1. The market simulation were run for the base case which was defined:
   - on the base of data used TYNDP2014 V4 2030 Regional assessment (high RES conditions),

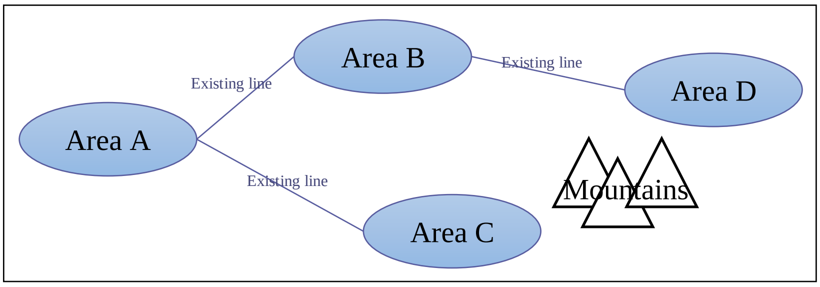
- on the base of an alignment performed by Project Group Market Modelling (PG MM) members respect the installed generation capacity and the generation profile (provided by PECD – Pan European Climate Database) for photovoltaics and wind,
- on the base of an update of the reference capacities (in order to guarantee consistency with the TYNDP 2014 projects list).

Additional details were permitted in the Regional area.

2. One market simulation was run for each border with an increased capacity of 500 or 1000 MW.
3. The socioeconomic welfare of all increases were calculated (by subtracting the SEW from the base case simulation of step 1 from each simulation of step 2)
4. The increase(s), which gave the highest SEW/cost ratio in the region ("the most interesting borders"), were put into the (new) base case
5. Some borders shown results that make further simulations and checks of these borders unnecessary. These borders could be removed from the list and were not analyzed any more in this process. However, it was needed to be careful which borders might be removed. A bottleneck can indeed move from one border to another when the border capacity is increased. It was important not to remove borders from the list too early.
6. Then the loop started again with the updated base case. Unless no more beneficial increases could be identified, process went back to step 2[6].
7. After every beneficial increases on all borders of the region were identified, the market groups could present a list of borders, which capacity should be increased and the amount of these increases (the same border can be chosen in more than one loop, increasing the capacity by 500MW each time).
8. Regional network subgroups investigated the new "target capacities" and converted these into possible project candidates.

Practical example

Purpose of this practical example is to visualize the above mentioned market modelling approach and process. This example assumes four market areas A, B, C and D. Areas A-B, A-C and B-D are already connected. Due to geographical constraints it is not possible to connect area C and D. To connect area A with area D is not possible either because of too large distances.



1. The network group has specified the following list of costs for increasing cross border capacity (only as example):

Border	+500 MW (first increase of 500 MW)	+1000 MW (second increase of 500 MW)	+1500 MW (third increase of 500 MW)
A-B	100 M€	110 M€	100 M€

[6] New base case do not need to be re-calculated. This simulation has just been done!

A-C	100 M€	120 M€	100 M€
B-C	70 M€	140 M€	200 M€
B-D	300 M€	300 M€	500 M€

2. The picture above shows the base case.
3. The market simulation is run for the base case.
4. Market simulations for all feasible borders (A<->B, A<->C, B<->C and B<->D) are run
5. Socioeconomic welfare are calculated for all border increases
6. Project B-C has for instance a SEW of 20 M€, giving a SEW/cost ratio of 2/7 which is the highest value of the four projects. Project B-C is put into the base case.
7. Project B-D has for instance only a SEW of 5M€ and with a cost of 300 M€ this gives a ratio of 1/60. This border is considered not necessary to be investigated further.
8. In this stage the market groups run again market simulations for all remaining feasible borders (A<->B, A<->C and B<->C) – by continuing the loop with step 4.

Network modelling description of the approach

This chapter describes the primary network studies performed by the regional groups during the Common Planning Studies for TYNDP2016. The aim was to simulate the impact of the increased border capacities, as simulated in the market simulations of the Common Planning Studies, on the European grid and detect the corresponding new concerns for grid development (“investment needs”). The outcome of this study was a map of internal bottlenecks in each country and a list of additional network reinforcement investments, with a brief technical description and the associated transfer capacity contribution (order of magnitude).

In the framework of the Common Planning Studies, the scope of Network Studies was to analyse, according to the market studies[7] findings, the most promising borders in terms of transfer capacity increase and identify the candidate projects which would achieve such potential transfer capacity increases in a feasible and cost efficient manner.

The work of the network studies during this phase is described below:

- The Common Planning Network Studies were based on market outputs results in each Region (8760 hours simulations).
- Duration curves were displayed directly using market study results. For example, by sorting out the hours according to exchange between 2 countries or Wind in North Sea and PV in Southern Europe. These curves were used as one of the indicators for selection of points in time.
- RG Network Studies selected a number of representative snap-shots so called points in time (PiT) within the market study outputs and PTDF (Power Transfer Distribution Factor) Matrix. For instance wind production, high market exchanges on long distances, low load, high load etc. The selection of PiT was a regional specific process, according to the regional most important parameters.
- Based on PTDF Matrix, the market data of each hour were transposed into the simplified grid represented by the PTDF Matrix. Then a PTDF flows were calculated for each of the 8736 hours and on each synchronous borders. Each synchronous are was represented through grid parameter duration curves showing loading of profiles. As mentioned above these PTDF flows were used to define detail points in time calculated by full AC load flow calculation to obtain particular line loadings together with voltage profile.

[7] The input reference capacities data of Market Studies are aligned to Vision4 TYNDP14 and projects assessed in the TYNDP14, including several updates

- The results of calculation were displayed on a regional map (based on a Pan European common tool), allowing possible further reinforcement identification. This map of was based on a visualisation of the combined frequency and severity of line loading (e.g. overloads).
- Project candidates with its investment items were identified based on the described process above without any preference whether internal or cross-border project.
- Expected grid transfer capacity per project candidate was appointed proceeding to load flows on already selected PiT. At this stage no detail calculation according to CBA were performed yet (carried out in assessment phase from mid 2015).

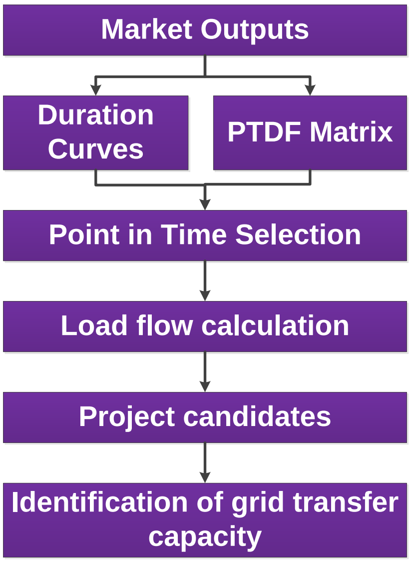


Figure 7-2 workflow of the Network Studies during Common Planning Studies

Network modelling

Network analyses were performed under the following framework:

- Network datasets used to perform network simulations: the starting point for each region was the 2030 Vision4 regional grid data set developed in TYNDP 2014 covering entire continental synchronous area.
- Models were updated according to the new projects listed in TYNDP 2014 and if relevant by other cross-border or national investment items.
- At the end of the Common Planning Studies, the network models will be updated accordingly.

Inputs from market results

The following detailed Market outputs from final market simulation run were required to create points in time (per country and per hour):

- Thermal generation per fuel type and efficiency
- Renewable generation sources (wind, solar, …)
- Hydro generation (pumping, turbine)
- Dump energy per country
- Demand
- Energy not supplied
- Balances

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- Market exchanges on the border of the modelled perimeter (mostly HVDC connection to Northern countries or UK)

Load flow simulations

First of all, the main critical activities of the network simulation were an AC convergence after a PiT is implemented under the condition of scenario assumptions.

Bottleneck identification

In order to evaluate the importance of bottleneck, following "FS²" criteria can be used, where:

- F: frequency of occurrence (% of the year);
- S: severity (% of overload)

Example of calculation of FS² in N conditions for a line (based on 5 PiT, with winter and summer limits):

PiT (N condition)	Weight (%)	F	P (MW)	Limit (MW) N condition	Overload (%)	S
WINTER 1	0,10	10	750	1000	-	0
WINTER 2	0,40	40	1100	1000	0,10	10
SUMMER 1	0,30	30	850	800	0,06	6
SUMMER 2	0,15	15	550	800	-	0
SUMMER 3	0,05	5	900	800	0,13	13
	FS²	5 925				

Figure 7-3 Workflow of the Network Studies during Common Planning Studies

The reinforcement projects:

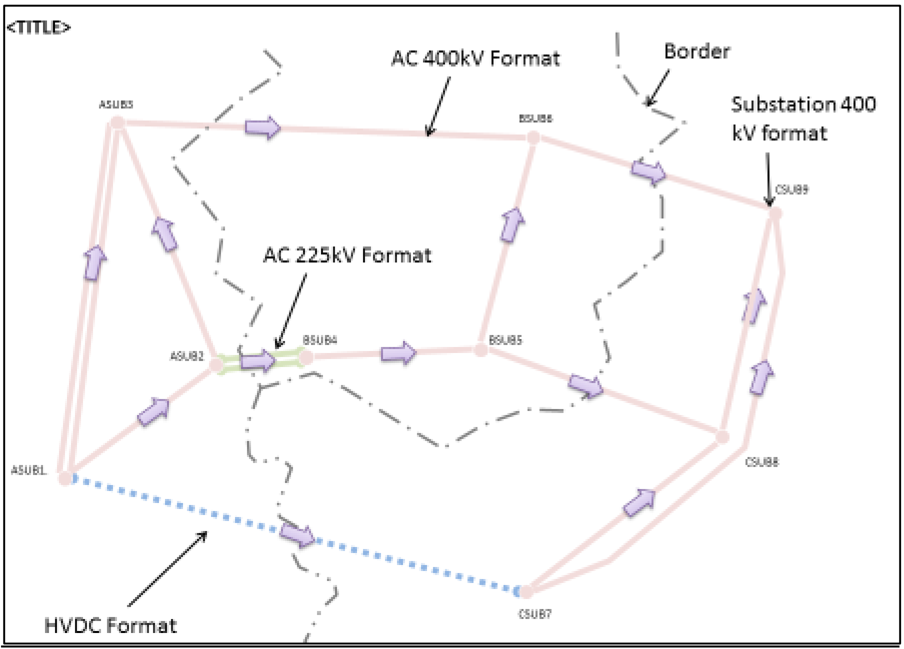
- were selected considering the gravity and frequency of the bottlenecks
- considered first the border concerned by market increased target capacities

Map representation

Maps to illustrate physical flows:

Following types of map can were used:

- bulk power flow maps (e.g. percentile 95% or 80% and 5% or 20% of the cross-border yearly distribution from PTDF flows)
- map of link loadings using AC load flow calculation



Maps to illustrate bottlenecks:

- Map illustrating bottlenecks in N and N-1 condition, using a qualitative approach with colors, based on the results of the FS² criteria:
  - Color green = no bottleneck
  - Color yellow = occasional bottleneck in N-1
  - Color red = structural bottleneck in N-1
  - Color highlighted red = bottleneck in N

7.2 Detailed regional walkthrough of process

7.2.1 Market Analysis

The North Sea Regional Group uses three market simulation tools in parallel –Plexos, ANTARES, and PowerSym, with each of the tools having its own particular strengths. This approach provides an opportunity to converge the individual model results, which are based on the same input data, towards each other and thus provide greater confidence in the results.

The outputs of the three simulation tools were compared in depth, enabling verification of the results and to increase the quality of the market analysis. It should be noted that these tools assume a perfect competitive energy-only market; some of the internal constraints and congestions are simplified. Thus the models deliver cross border energy flows triggered by the market price differences. The results are generally similar, and are averaged where market results are presented in this chapter.

7.2.2 Target Capacities in a high-RES scenario

The high-RES scenario utilises data from TYNDP 2014 Vision 4. Figure 10 highlights the price differentials between each market area using outputs from the reference case for iteration 1. The map shows a wide variation in the marginal cost of electricity in continental Europe compared to Great Britain, Ireland, and Norway. The low prices in these areas are due to the high availability of renewable resources such as onshore wind, offshore wind and hydro.

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Figure 3 below illustrates the borders with the greatest potential for further interconnection at the start of the study process. The additional transfer capacities identified after each iteration should cause the prices for each market node to converge.

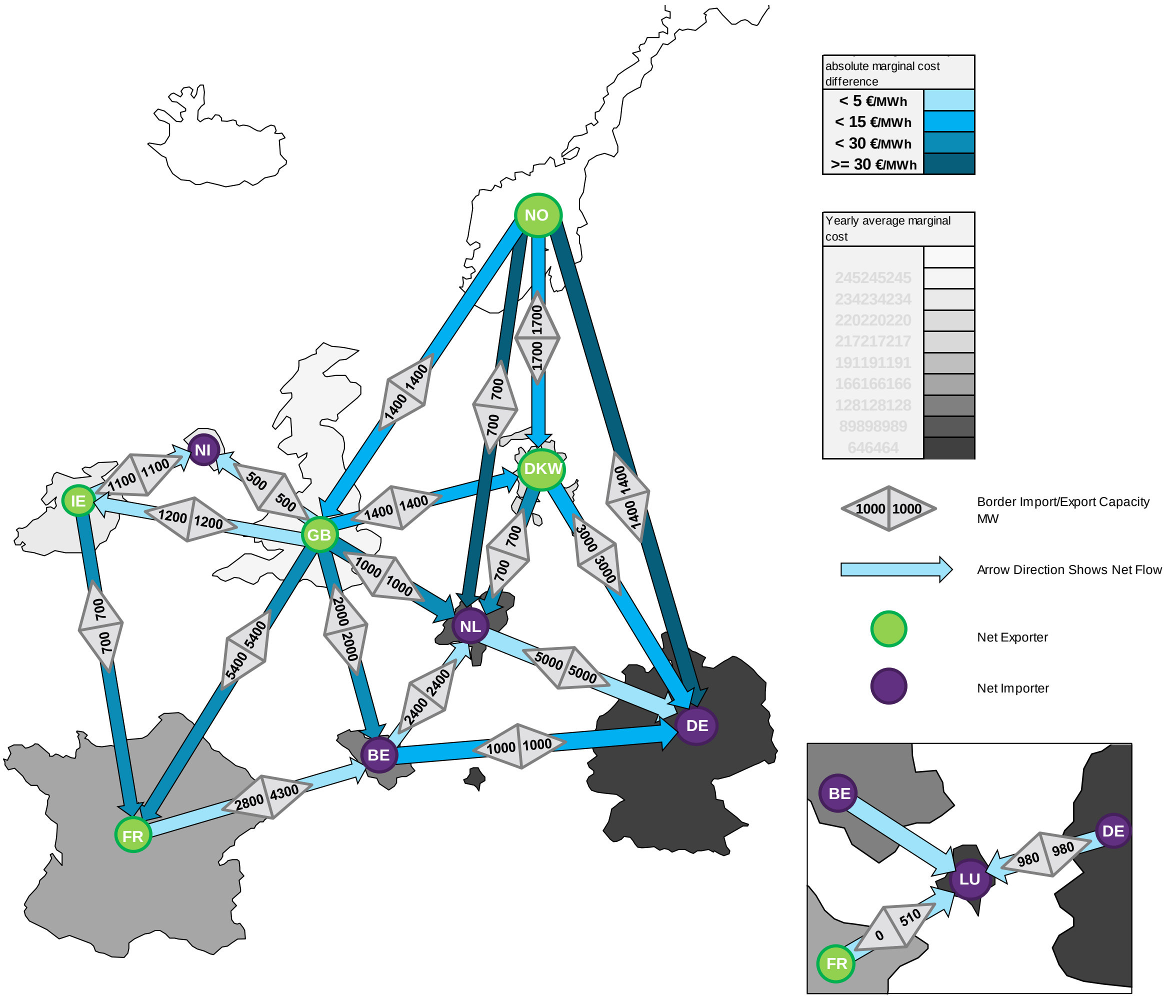

Figure 7-4 TYNDP 2014 Vision 4 data, Base Case iteration 1: Border capacities, Marginal Cost, Price difference & predominant interconnection flow direction.

The assumed carbon price is a contributing factor to the higher prices in continental Europe, since countries such as Germany still utilise coal and lignite generation in this scenario.

The SEW results are shown in Figure 7-5, where it can be seen that borders from Great Britain to continental Europe consistently gave high benefits. Interconnection projects with Great Britain are particularly advantageous in the base scenario due to the high levels of offshore wind and the nuclear capacity installed. While high SEW are also identified from both Ireland and Norway to the continent, the higher cost associated with building such interconnector projects compared to connections between Great Britain and the continent means that they will tend to show a lower benefit/cost ratio.

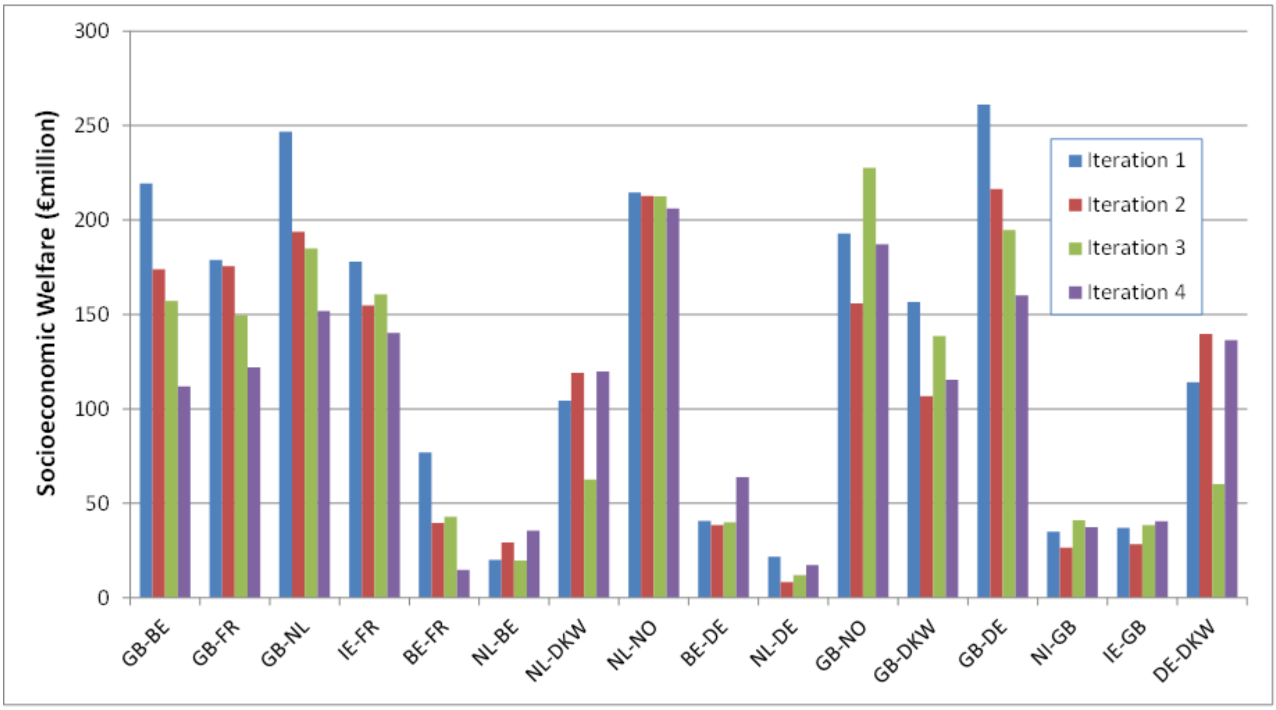

Figure 7-5 Socioeconomic welfare increase (for the 2030 calendar year) caused by increasing each border by 1 GW, for each of the study iterations.

The benefit/cost ratio was the main criteria used to determining which market exchange capacity (MEC) to increase after each iteration. It is defined as the ratio between the annual SEW as identified through the market modelling studies and the annualised investment costs for an additional gigawatt of interconnection at each border. The benefit/cost ratio for each project at each iteration is shown in Figure 7-6, and the borders selected for increase are also indicated.

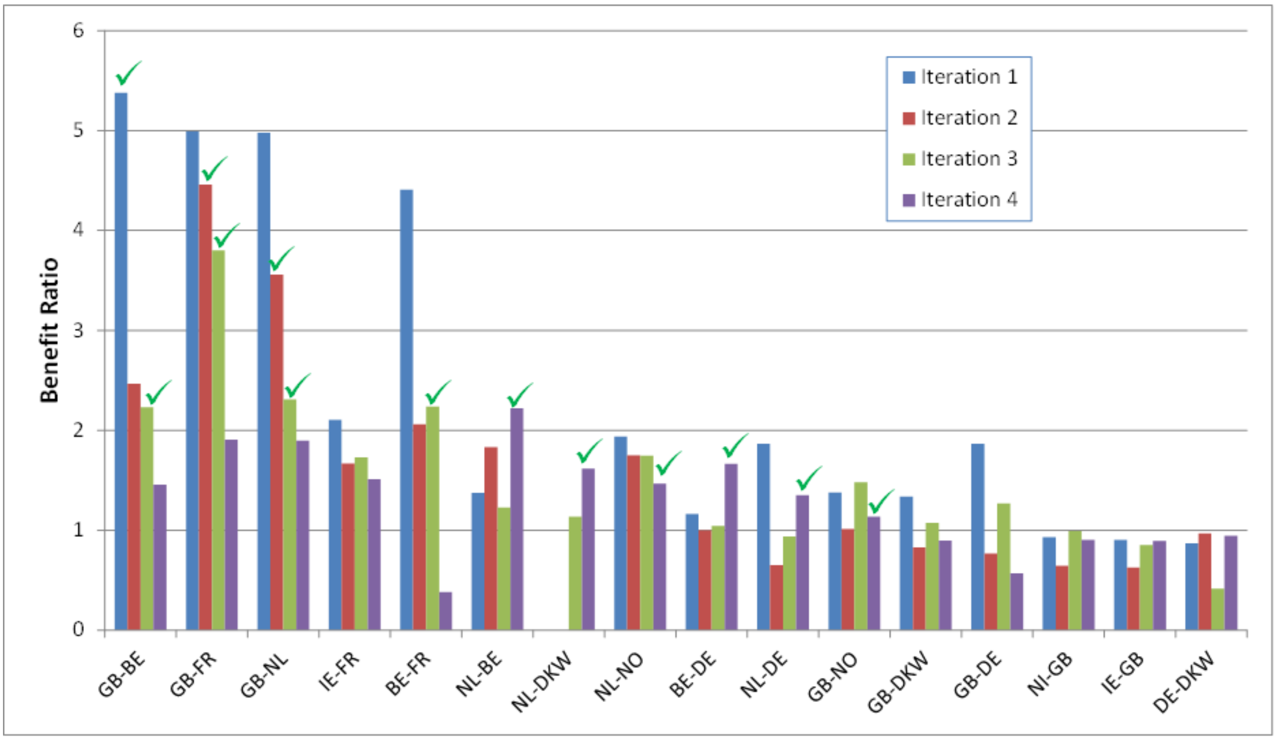

Figure 7-6 Benefit/cost ratio for increasing market exchange capacity by 1 GW for each of the study iterations. A benefit/cost ratio >1 indicates that the increase in SEW would outweigh the capital costs. The tick marks indicate the borders increased after each iteration.

7.2.3 Target Capacities using TYNDP 2016 assumptions

While the base case (TYNDP 2014 vision 4) studies were being carried out, the latest set of data for TYNDP 2016 was also released. On analysing the new data, it was observed that there was a significant change to the expected generation portfolio for Great Britain in particular. Figure 6 shows the change in installed capacity for the study area when using the newer TYNDP 2016 vision 3 data. This shows a big drop in wind, coal, and nuclear capacities for Great Britain, with France also seeing a large drop in assumptions on installed wind and solar.

These changes indicate that the main drivers for the increased MECs identified with the High RES scenario may no longer be as relevant as initially assumed. As such, sensitivity studies were carried out which partially utilised the latest available data for TYNDP 2016.

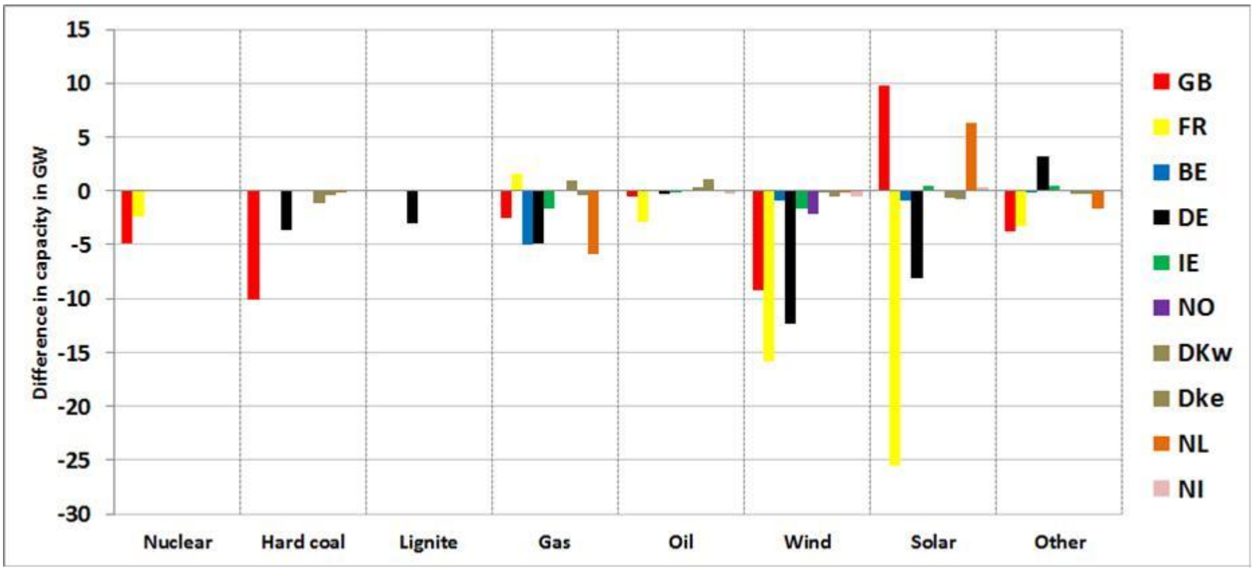

Figure 7-7 Change in the installed generation capacity in Vision 3 for TYNDP 2016 when compared to Vision 4 for TYNDP 2014.

The data behind TYNDP 2016 Vision 3 (also called the "National Green Transition" Vision) reflects a path towards the 2050 European energy goals, with 55% of load supplied by RES in 2030. In energy terms, the penetration of renewable generation is higher than the corresponding Vision in TYNDP 2014, although installed capacity of RES is similar in the two scenarios. This is due to the fact that, in the TYNDP 2016 Vision, demand is decreasing compared to TYNDP 2014 levels. Vision 3 TYNDP 2016 assumes an economic environment comparable to those of Vision 3 TYNDP 2014 as well as an important development of new uses of electricity. However an acceleration of demand-side management with efforts targeting consumption behaviours, for example total building performances is also assumed. Efforts in efficiency developments through additional subsidies thus fully compensate any increases in demand due to economic growth and new uses of electricity.

Vision 4 "European Green Revolution" alike Vision 4 TYNDP 2014 reflects an ambitious path towards the 2050 European energy goals, with 60% of load supplied by RES in 2030. The major difference between TYNDP 2014 and TYNDP 2016 Vision 4 is that a re-allocation of RES installed capacities at European level is done in order to achieve the least European system operation cost, also using the advantage of an extended interconnected European network.

The sensitivity studies showed significant reductions in the marginal cost variation across the North Sea region. This is due to a reduction in assumed renewable generation and nuclear capacities, particularly in the Great Britain market.

Another contributing factor is the drop in CO_2 cost from €93/ton (TYNDP 2014 Vision 4) to €71/ton (TYNDP 2016 Vision 3), which tends to reduce the electricity generation cost in markets with a high penetration of coal and lignite.

Market nodes that yield the highest price differentials are once again between Great Britain, Ireland, and Norway to continental Europe. However, the price differences have significantly reduced. The TYNDP 2016 V3 marginal cost difference upper range is less than €15/MWh, compared to the TYNDP 2014 V4 study with an upper range of greater than €30/MWh. This leads to a reduction in the number of potential projects that would be beneficial under this scenario.

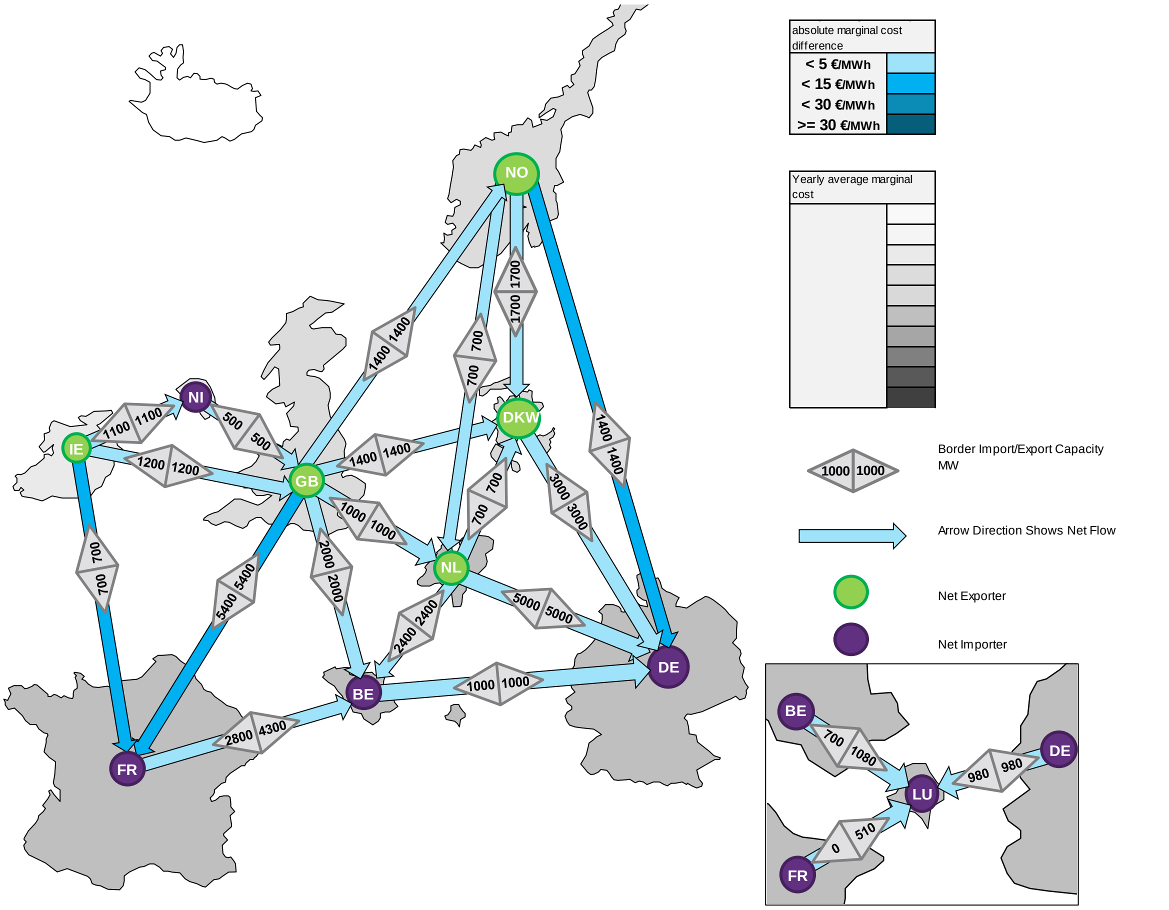

Figure 7-8 TYNDP 2016 Vision 3 data, Base Case iteration 1: Border capacities, marginal cost, price difference & predominant interconnection flow direction.

The results are significantly different from the results of the High RES scenario, and are shown in Figure 8 below. There is a considerable drop in the SEW achieved by increasing the MECs, particularly with connections between Great Britain and continental Europe. The results show only small differences between the two TYNDP16 sensitivities themselves.

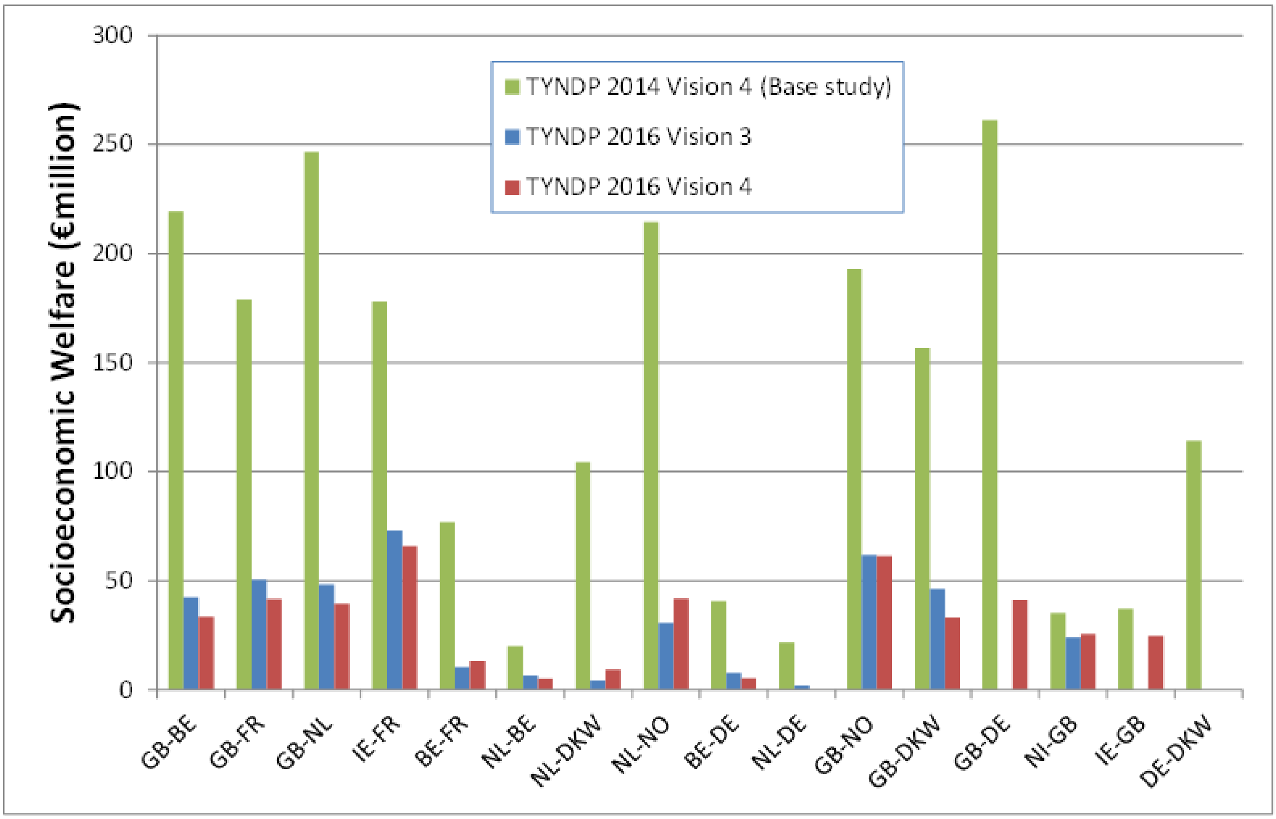

Figure 7-9 Socioeconomic welfare increase (for the 2030 calendar year) caused by increasing each border by 1 GW, for iteration 1 of each of the sensitivities. The results from iteration 1 of the base study are shown for reference.

7.2.4 Lower CO_2 price

For the TYNDP 2016 Vision 3 sensitivity, further analysis was done varying the CO_2 price used to see the impact of merit order switching between coal and gas on the MECs. These sensitivities use prices of €45/tonne and €17/tonne. The SEW calculated from these studies is shown in Figure 9, alongside those using the original TYNDP 2016 Vision 3 CO_2 price of €71/tonne[8]. While there is a change in SEW due to varying CO_2 price, it is generally not hugely significant.

The benefit/cost ratio results (Figure 10) show some differences between using a CO_2 price of €71/tonne and of €45/tonne. The border between Great Britain and France still shows a net benefit, however the ratio for all other borders drops to below 0.8. When using a CO_2 price of €17/tonne, none of the borders show a positive benefit for increasing their capacity by 1 GW.

[8] CO2 price for TYNDP 2016, Vision 3 is based on IEA World Energy Outlook 2013 in $/tons. A conversion rate was used from dollar to euro from September 2014 (when the prices for the scenarios were defined).

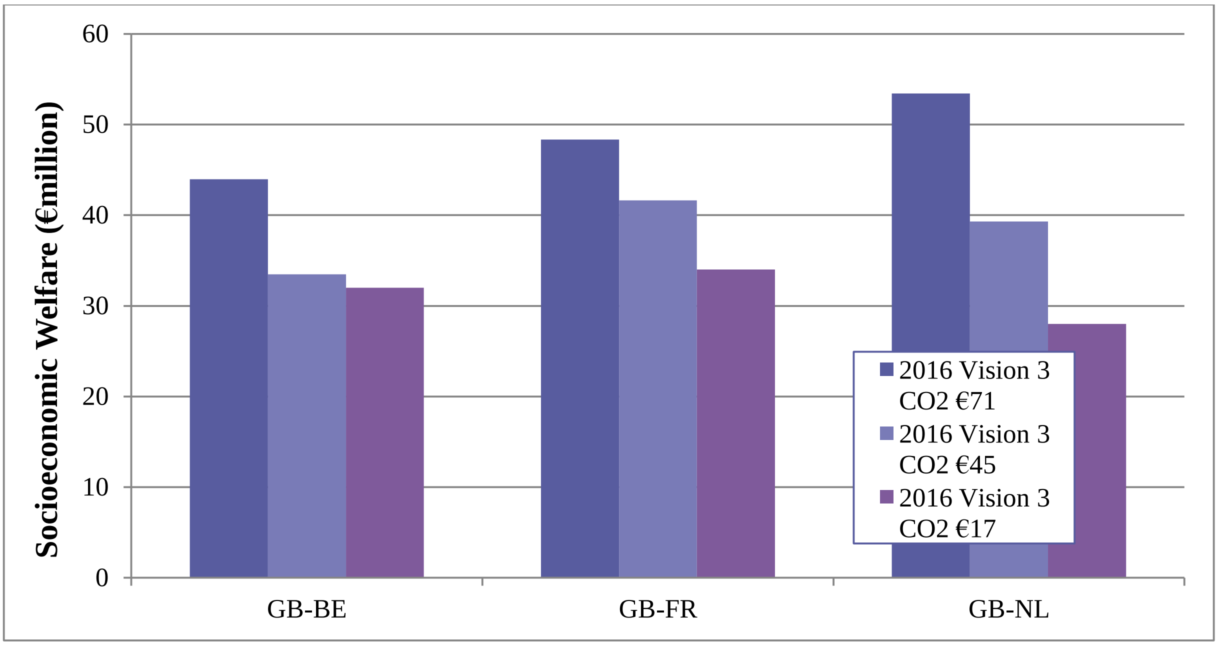

Figure 7-10 Socioeconomic welfare increase (for the 2030 calendar year) caused by increasing each border by 1 GW, for iteration 1 of each of the sensitivities.

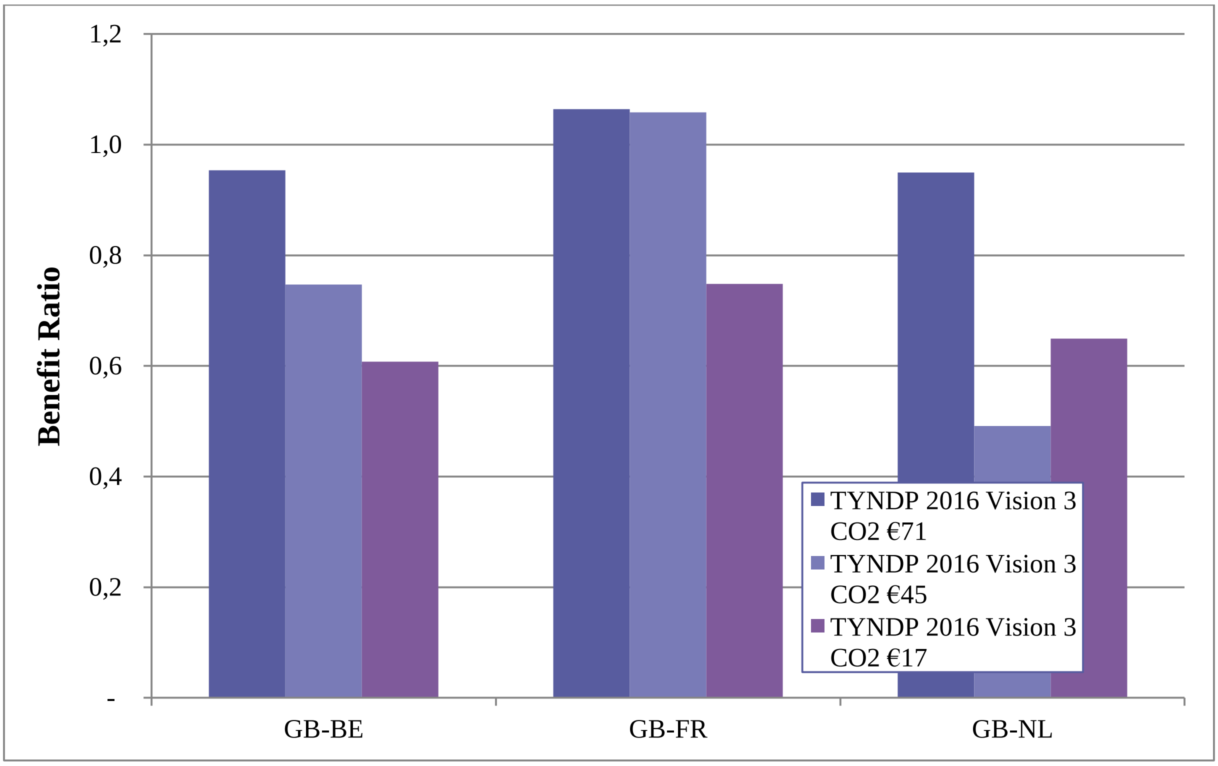

Figure 7-11 Benefit/cost Ratio for increasing market exchange capacity by 1 GW, for varying CO2 prices.

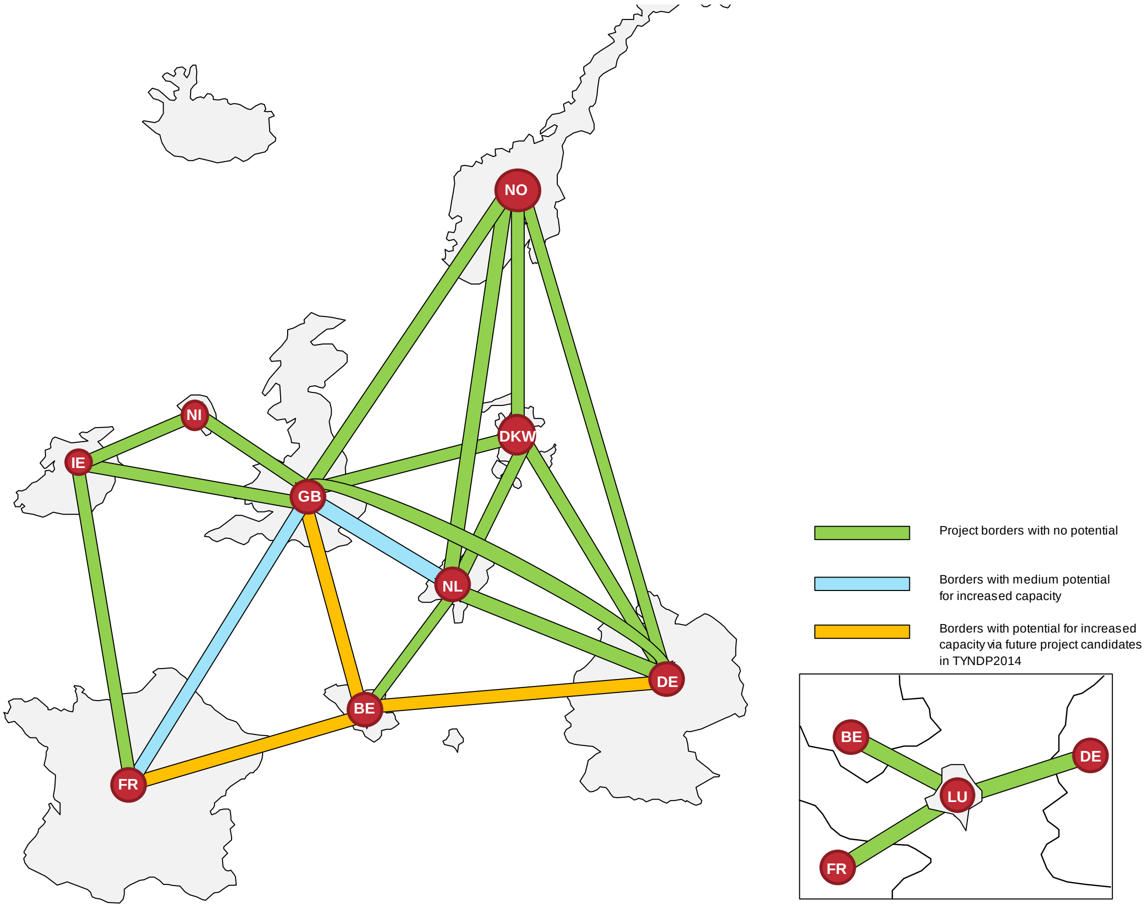

Figure 7-12 Map of study region. The MEC increases recommended by RGNS are highlighted in blue.

The results from the base case Common Planning Studies identify a bottleneck between Great Britain and continental Europe. Projects that eased this particular bottleneck consistently give the greatest savings after study iteration, even when the transfer capacity between Great Britain and the continent has been increased after previous iterations. In total, many MEC increases across ten borders were identified by the base studies.

However, sensitivity analysis using input data from TYNDP 2016 shows less market need for further interconnection. The results suggest that many MEC increases identified in the base case, only two would be required if the more up-to-date input data is assumed.

7.2.5 Network Study: Prepare & Execute Load Flow Analysis

Starting from the TYNDP 2014 High RES scenario the market analysis identified increases in transfer capacities. Given these increased transfer capacities, the market simulation delivers the demand by country, the generation by power plant type and country, and the market exchange cross-border flows for all 8736 hours of the year.

This output of the market simulation is used as input for the network study, allowing the identification of the bottlenecks related to the increased transfer capacities by executing a load flow analysis. This load flow analysis has been carried out using the TYNDP 2014 Vision 4 network model as a starting point and integrating the aforementioned output of the market simulation as explained below for each synchronous area.

Ireland & Northern Ireland

For Ireland and Northern Ireland, a full AC load flow analysis for all 8736 hours of the market dispatch was performed using in-house analysis software. As no new interconnection was proposed to IE or NI as part of the market analysis, the existing TYNDP 2014 Vision 4 network model did not have to be modified. Both N and N-1 conditions were monitored during the analysis.

Great Britain

The market analysis showed that the cheaper renewable and nuclear generations in GB are driving the interconnectors. Therefore, additional interconnections between GB and Continental Europe & Norway were suggested by the market analysis. These newly identified interconnectors are to further increase the cross border transfer capacities with a total of 8 GW. The following table lists the interconnectors that have been identified.

Border	Starting Value (MW)	Ending Value (MW)
GB-BE	1000	4000
GB-FR	5400	7400
GB-NL	1000	3000
GB-NO	700	1700

Table 7-1: List of Interconnectors between GB and Continental Europe & Norway identified from market analysis

For the purpose of this analysis, all the above mentioned interconnectors along with the following list of operational and proposed interconnectors between GB, Continental Europe and Norway were also considered.

Interconnector	Capacity (MW)	Status
IFA	2000	Operational
Britned	1000	Operational
ElecLink	1000	Proposed with connection agreement
NEMO	1000	Proposed with connection agreement
IFA2	1000	Proposed with connection agreement
FABLink	1400	Proposed with connection agreement
HVDC Norway – UK (NSN)	1400	Proposed with connection agreement

Table 7-2: List of Operational and Proposed Interconnectors between GB and Continental Europe & Norway defining the starting point in table 7-1

The base GB model for this analysis was based on winter peak demand condition. A DC load flow study was conducted monitoring N and N-1 conditions in order to identify the bottlenecks of the network. The new interconnectors were assumed to be connected at the existing connection point i.e. new GB-BE, GB-FR, GB-NL and GB-NO interconnectors are connected at Canterbury South, Sellindge, Grain and Blyth respectively.

Norway

Further grid analysis need to be done for the Norwegian grid, to assess the capacity of the internal grid in case of adding new interconnectors.

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Denmark West & Continental Europe

The area consisting of Denmark West and Continental Europe (Belgium, Netherlands, Luxemburg, Germany and France) has been analysed taking into account the particularities of both, whilst ensuring coherence of the physical flows across the network models.

Denmark West

For Denmark West, a full AC analysis for all 8736 hours of the market dispatch was conducted. The market dispatch was applied to the generation units by fuel type, consumption, HVDC connectors to other areas and balanced through the AC connectors to other areas. The existing TYNDP 2014 Vision 4 network model was applied as the initial grid-development stage. As bottlenecks were observed and removed, all necessary grid reinforcements were included into the grid model; the grid study was again conducted using this grid-development stage model. Both N and N-1 conditions were monitored during the study.

On top of this assessment, the planning cases used within the Continental Europe are were assessed and the resulting exchange flows at the Danish-German AC border lines and at the Danish-Dutch HVDC connectors were used as input when performing the load flow analysis in the Continental Europe part.

Continental Europe

Within Continental Europe four different load flow tools were used to facilitate the analysis. Each of these tools used the same network model. The network model has been constructed by integrating the new HVDC interconnectors into the TYNDP14 Vision 4 network model, in line with the identified increased transfer capacities across the DC borders by the market analysis. The following table lists the DC interconnectors that have been identified.

Border	Starting Value (MW)	Ending Value (MW)
GB-BE	1000	4000
GB-FR	5400	7400
GB-NL	1000	3000
NO-NL	700	1700
BE-DE	1000	2000

Table 7-3: List of DC interconnectors identified from market analysis within the perimeter of Continental Europe

No AC reinforcements were added to the network since the objective was exactly to identify the need for those in order to sustain the bulk power flows resulting from the increased market exchange capacities.

The market results were then mapped onto the network model, allowing for the physical flows to be calculated across all borders for all 8736 hours of the year. The optimizer developed during the TYNDP 2014 was used to select 10 planning cases amongst the 8736 hours. The aim was to represent the range of cross-border flows as well as the load levels and generation by type and country, except for the highest and lowest 1%. Like for TYNDP 2014, results were checked by all TSOs. Two planning cases were added to represent import into France and flows Germany to Denmark West.

Figure 7-13 shows an example of the match between the year-round data, expressed by its load duration curve, and the representation by 12 planning cases. It is understood that, no perfect matching is possible for all ~100 inputs using only 12 planning cases.

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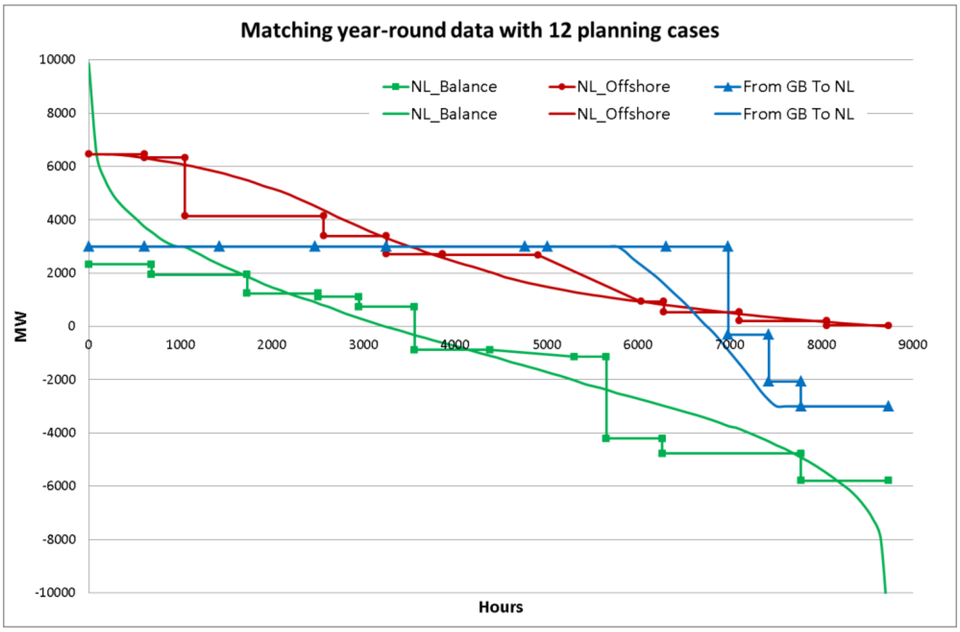
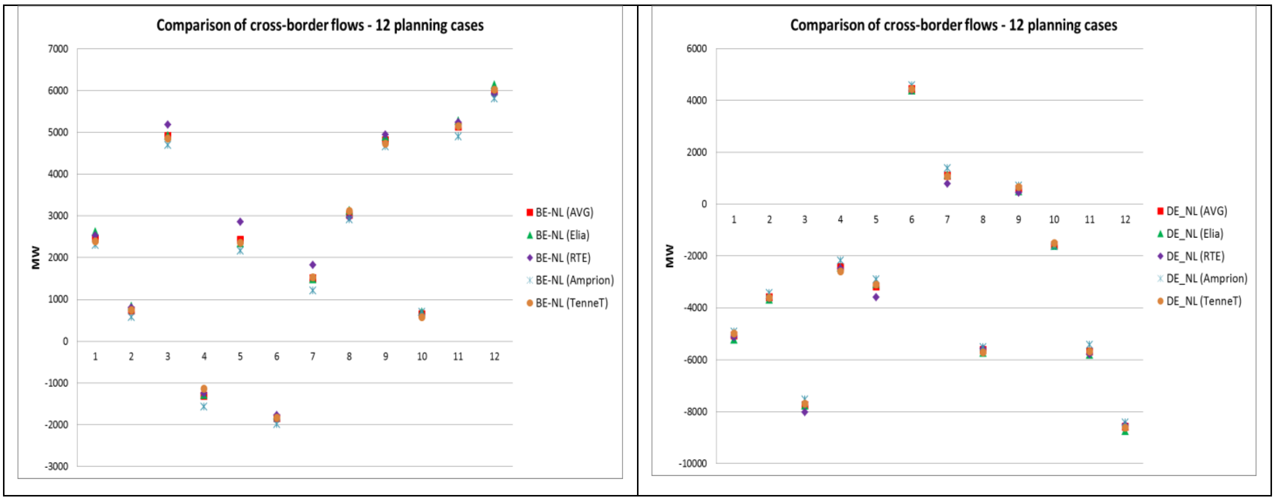


Figure 7-13 – Example of original year-round data and representation with 12 planning cases

Results of the different load flow tools were compared in detail, by checking the flows on the 380 kV network. Figure 7-14 shows the main AC cross-border flows for the 12 planning cases, as calculated by RTE, Elia, TenneT and Amprion and illustrates that a very good matching was obtained.



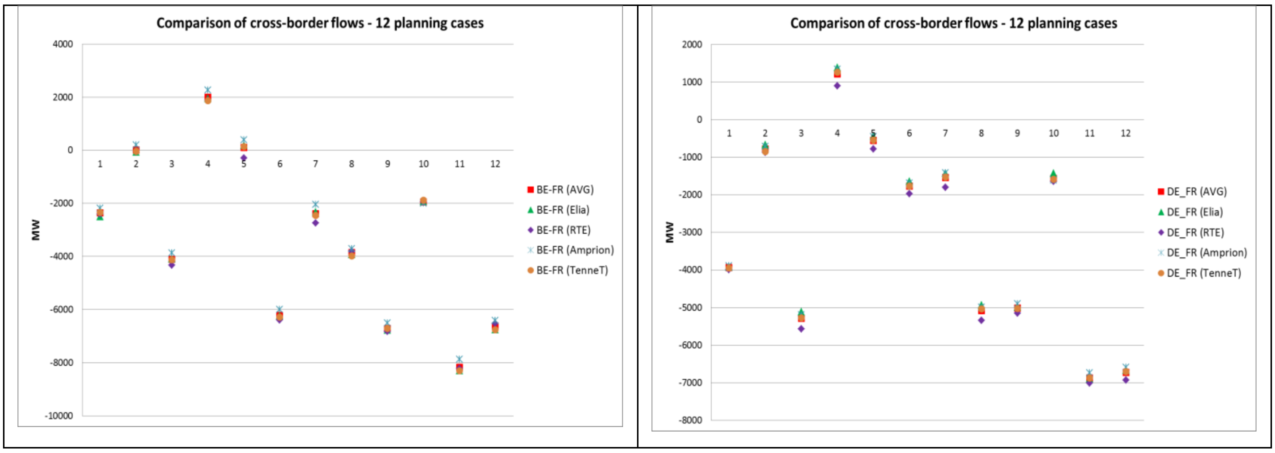


Figure 7-14 – Comparison of the physical flows over the AC borders between the 4 load-flow tools.

All 12 planning cases were analysed for N and N-1 by the different TSOs. In the first run, controllable devices like PSTs were not used; however in the second run they were used. These detailed calculations yield the bottlenecks in N and N-1 situations.

7.2.6 Network Study: Bulk Power Flows

Figures 7-15, 7-16 and 7-17 illustrate a typical flow pattern representative for the West-East and North-South bulk power flows arising throughout the North Sea region [Winter off peak for GB and Ireland, hour n°7591 for mainland system (November off peak)].

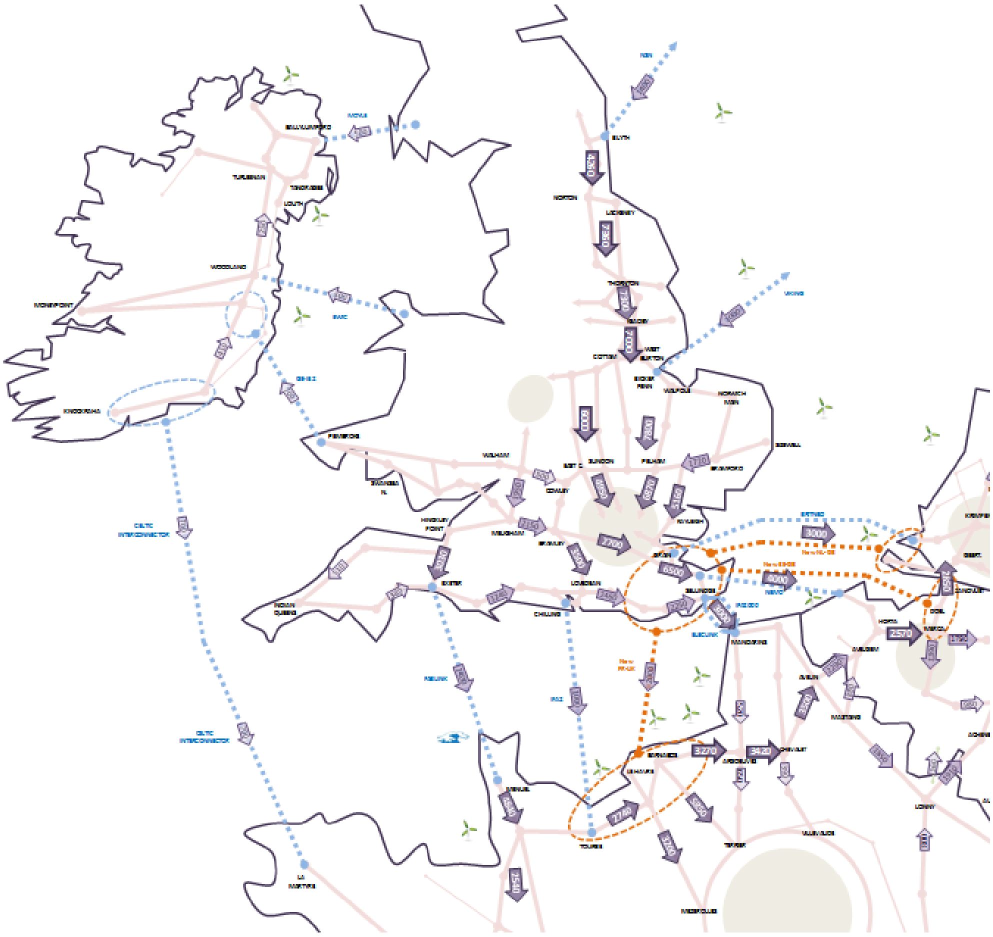


Figure 7-15 – typical flow pattern throughout the North Sea Region – Ireland, Northern Ireland and Great Britain

Within Ireland and Northern Ireland the dominant feature is the high utilisation of the HVDC interconnectors to GB and France. For example, the interconnectors to GB from both IE and NI operate at maximum capacity (either importing or exporting) for c.65% of the year; meanwhile, the proposed Celtic Interconnector between IE and France is operating at maximum capacity for c.83% of the year. Within the Irish Single Electricity Market, power tends to flow from IE to NI, mainly resulting from the significant quantities of assumed offshore wind located in IE; however, the general trend is for North-South power flows, with imports from GB, coupled with Irish renewable generation tending to be exported south to France.

For Great Britain the generation background in Scotland, East Coast, East Anglia and North West contain an excess of generation, therefore north to south power flows are most likely operating condition to meet the demand in London and also to export power to Europe through the interconnectors across the South Coast of the country.

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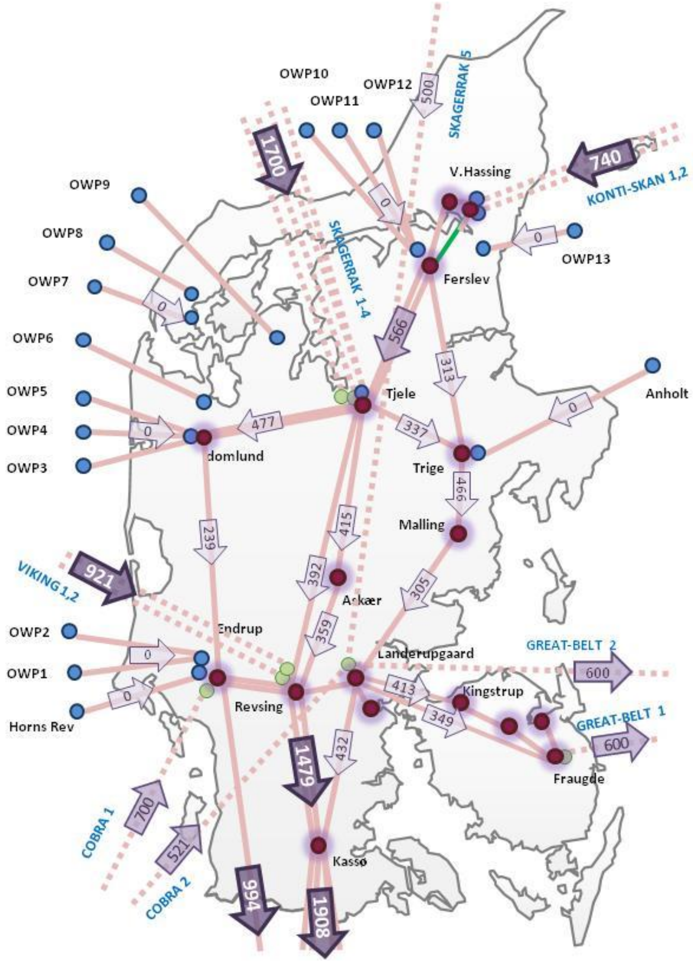

Figure 7-16 – typical flow pattern throughout the North Sea Region – Denmark West

For Denmark West the north-to-south power flow, which is superimposed to the west-to-east power flow, and low (or no) wind is defined among the typical power flow patterns which is in-line with the Continental PITs. The flow conditions are at full import from the Nordic countries, heavy import from the Great Britain and the Netherlands, heavy export to Germany and full export to Denmark-East. The presented flow pattern did result in heavy loaded back-bone of the 400 kV transmission system. The presented flow pattern is common with the Continent and illustrates a typical situation in Denmark-West, which serves as a power transport corridor between the Continental and Nordic systems. However, this shown common PIT should be superimposed by higher wind power production for being more typical for Denmark.

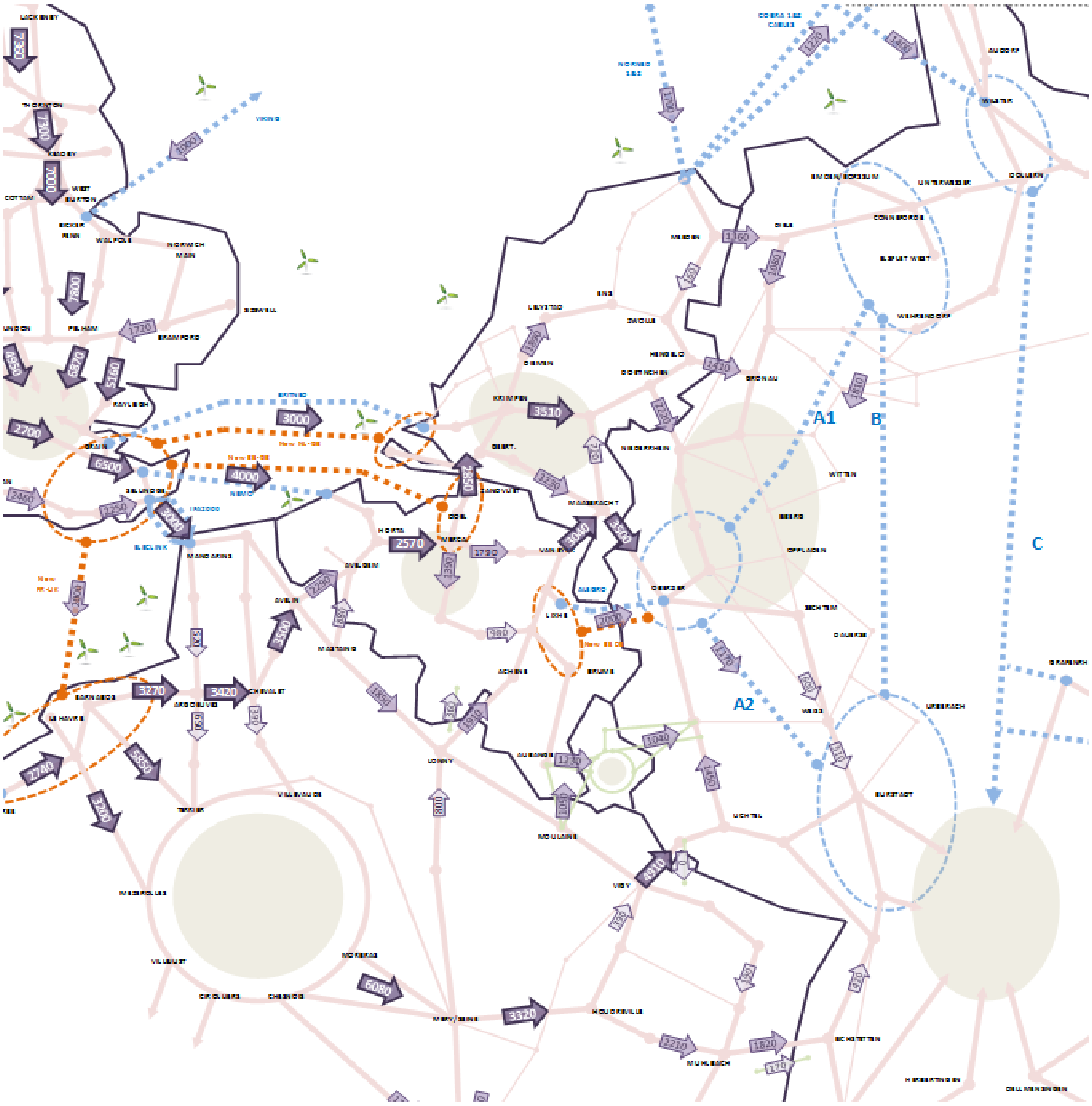

Figure 7-17 – typical flow pattern throughout the North Sea Region – Continental Europe

Within Continental Europe, the additional market exchange capacities combined with the projected amount of offshore energy implies even higher levels of power flows compared to what was depicted in the TYNDP14.

- **France** exports to Belgium and Germany during 90% of the year, with 40% of the year values reaching more than 5 GW. the flows from GB and Northern Ireland through the HVDC links add up to 8100MW for more than 40% of the year in the North-West area of France. Combined with the offshore wind and tidal generation, this represents a very significant amount of energy to bring to the Paris area and the North of France.
- **Belgium** imports during 80% of the time and is subject to severe transit flows. During 50% of the time, there is a net West-East transit of 2000 MW from GB across Belgium to Germany and during 30% of the time there is a net South-North transit France-Belgium-Netherlands of more than 4000 MW. This results into flows up to ~8000 MW on the France-Belgium border and up to ~ 6000 MW on the Belgium-Netherlands border.

- The grid in **Luxemburg** is subject to a transit flow France-Belgium-Luxemburg-Germany of typically 1000 MW. This leads to flows on the Belgium-Luxemburg border up to ~1500 MW and flows on the Luxemburg-German border up to ~1300 MW.
- **The Netherlands** is a net importer in about 65% of the time, typically importing from Belgium, Great Britain and Norway and exporting to Germany. The flow between Denmark West and the Netherlands is highly variable throughout the year. The import from Great Britain, combined with offshore wind infeed, causes high level of West-East flow.
- The grid inside **Germany** is mainly stressed by high north-south flows. Most of the time the flow on the internal German HVDC links is also in this direction. But in hours with very high solar infeed the flow can also be in the opposite direction. The north-south flows are triggered by high RES generation in North Germany. The interconnections (existing and planned) to Northern Europe will interact with these flows. In import hours high west-east flows (imports from Great Britain) can occur.

7.2.7 Network Study: Bottlenecks Identification

In order to express the relative weight of the bottlenecks, both the frequency of occurrence as well as the severity of the overloads have been taken into account using an $F.S^2$ indicator (F times S squared), where:

- *F*: frequency of occurrence (% of the year);
- *S*: severity (maximum percentage of overload)

The below sections provide more details on the bottlenecks as illustrated in figures 4-9 and 4-10 in the main body of this report.

Great Britain

As most of the interconnectors are in the South Coast of the country therefore significant amount of bottlenecks were noticed at the central London circuits and North, West and, East of London circuits. These bottlenecks were for both N and N-1 conditions.

To alleviate the bottlenecks some alternative connections points for the new interconnectors with Continental Europe and some potential internal reinforcements were proposed. Changing the interconnectors landing point from its original locations would potentially increase the load sharing across the circuits around London and South Coast. The proposed reinforcements would increase the network capacity between London and South Coast, London and East Anglia and within London area. The proposed landing point for interconnectors and the potential reinforcements are given below.

Proposed Landing Point	Proposed Reinforcement
East Anglia	New Transmission route at south coast
South Cost West	Elstree – Tilbury re-conductor
South Cost East	New Transmission routes and Quad Boosters (QBs) on East Anglia

Table 7-4: Proposed landing point for interconnectors and proposed potential reinforcements

It should be noted that the Great Britain system is planned for N-2 condition. Therefore more potential reinforcement could be required to cater for those eventualities.

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Ireland & Northern Ireland

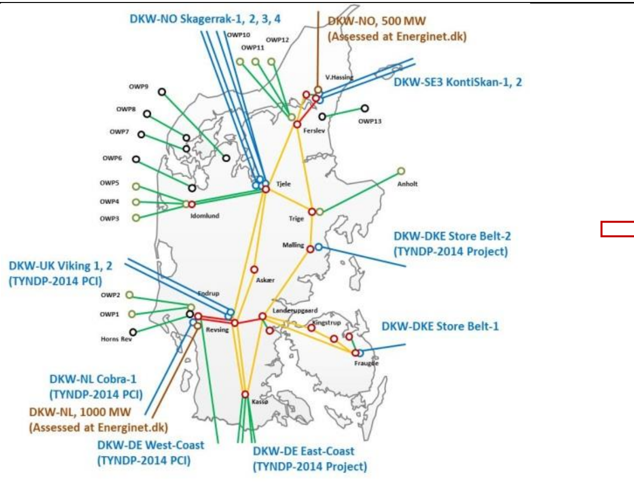
As demonstrated in figure 4-10, the IE and NI transmission network is generally sufficient at accommodating the diverse power flows in this study. The proposed 2014 TYNDP reinforcements provide strong corridors to transit the large power flows across the island associated with the interconnection to GB and France, as well as the local power flows from IE to NI within the Irish market.

One area of the network, however, is subject to significant and often severe overloads. This arises because of the connections of large quantities of offshore wind generation, and results in overloads on one 220 kV circuit south of Dublin under N-1 conditions, where the majority of this potential generation has been assumed to connect.

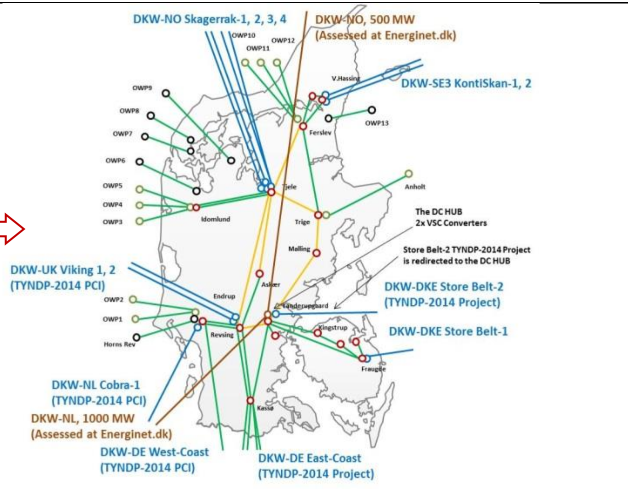
Some of the time, this issue can be resolved with re-dispatch of the conventional generation. It should be stressed that this particular bottleneck is an issue internal to the Irish network, and therefore a potential solution to this problem, were it to develop in the longer term, would be proposed by the TSO in its Transmission Development Plan.

Denmark

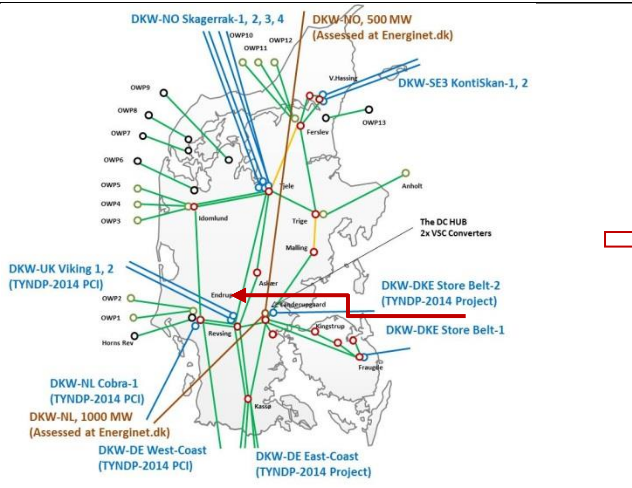
Additional interconnectors do increase the power flows throughout the Danish transmission grid. Utilization of a multi-terminal HVDC system would reduce impact and stress of the power transport on the internal AC grid, which is demonstrated in figure 7-18. The proposed multi-terminal HVDC system operates as an overlay to the internal AC grid. Most power flows are sent through the HVDC system and only a reduced amount of power is exchanged with the internal grid itself. Utilization of the multi-terminal HVDC system has shown that the Danish transmission grid is generally sufficient for the power transport in this study.



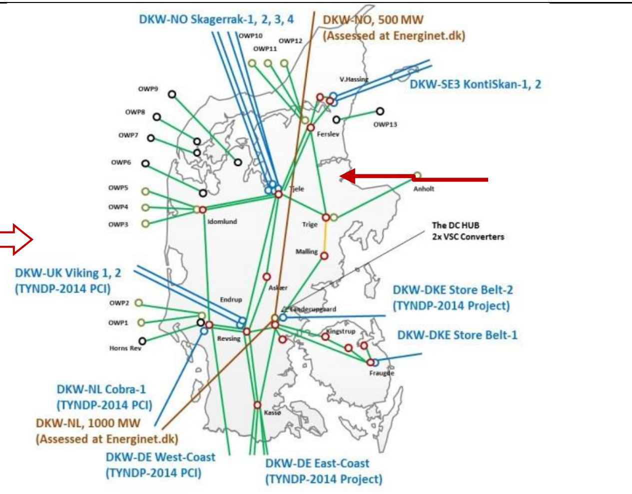
(a) – Initial transmission grid of Denmark-West and bottlenecks using point-to-point HVDC approach



(b) – Initial transmission grid of Denmark-West and bottlenecks using multi-terminal HVDC approach



(c) – Remaining bottlenecks after the 1st reinforcement



(d) – Denmark West after the 2nd and final reinforcement

Figure 7-18 – removal of bottleneck in Denmark-West

Nevertheless some additional grid reinforcements have been proposed to remove internal bottlenecks in Denmark-West. Figure 7-18 illustrates the bottlenecks and additional investments (grid reinforcements) for their removal. The reinforcements are by 400 kV overhead lines and short 400 kV cable sections where an overhead line is not applicable (e.g. environmental and social concerns).

The bottlenecks are mainly caused by the power import from many offshore and onshore wind power plants, which are mostly located in the west and north-west part of Denmark-West. The bottlenecks are only to a smaller extent caused by the additional interconnectors, in case these interconnectors would be arranged into the proposed multi-terminal HVDC system. Anyway, the distribution of related costs and benefits for facilitating a “transit” system has not been assessed yet.

The total capital cost of the internal reinforcements is in a range of 100 M€.

Continental Europe

The high bulk power flows cause bottlenecks on almost all examined borders in Continental Europe. Especially the Belgian borders are highly stressed. Although the already planned grid reinforcement on the lines from France to Avelgem (Belgium) allow to sustain higher flows across the French-Belgian border compared to today, the lines are subject to overloads given the very high flows (up to 8000 MW) arising in the studied scenario. All other interconnectors between **Belgium and France** are overloaded, even in N situations. Overloads on at least one of the interconnectors occur in around 40% of the year. Also the lines between Belgium and **The Netherlands** are overloaded in N-1 situations in ~35% of the year. On the Zandvliet-Rilland lines the problem is mainly on the Belgian side, where the PSTs are the limiting components. With the closed 220 kV link FR-BE-LU-DE flows from France through Belgium and Luxemburg to Germany cause overloads on the **Belgium-Luxemburg**-interconnectors as well as the **Luxemburg-Germany**-interconnectors. The overloads Belgium-Luxemburg occur during ~25% of the year, with ~10% of the time showing even overloads in N. On the DE-LU side the problem is mainly in N-1 condition.

High imports as well as high exports of Germany increase the flow on the German interconnectors. The lines between **France and Germany** are expected to have overloads up to 45% of the time in N-1 conditions. It is expected that the planned reinforcements in this area mitigate most of the overloads. On the border between **The Netherlands and Germany** there is a bottleneck on the southern interconnector

(Maasbracht-Oberzier) which already occurs in N conditions. In N-1 situations also the Meeden-Diele interconnection is overloaded.

The internal grid next to the borders was checked. The described transit flows through **Belgium** lead to internal bottlenecks. Problems occur on the north-south corridors as well as the west-east corridors. Most of these problems happen in N-1-situations.

In **The Netherlands** new interconnections to Denmark and Norway lead to a bottleneck in the north of The Netherlands (Eemshaven-Meeden) in N-1 situations. This bottleneck will be mitigated by project 103 investment 438: Noord-West 380 kV, an investment that was already proposed in TYNDP2014, but not included in the grid model of the common planning studies.

Due to high import from GB, Northern Ireland as well as offshore wind infeed, the **French** grid is highly stressed, from the North-West area (Normandy) to the East (Alsace), and even in the North. Especially around the load centre Paris overloads in N situations occur in more than 25% of the year.

In this very green-scenario with high interconnection capacity the **German** grid is highly stressed and the grid expansion planning as shown in the German National development plan (NEP) is needed to deal with these flows.

7.2.8 Network Study: Sensitivity Analysis

Using the results of the market analysis based upon the TYNDP16 assumptions, a sensitivity analysis from network perspective has been performed using a PTDF method.

From a network perspective, the lower level of transfer capacities compared to the TYNDP 2014 High RES scenario is expected to imply less stress on the AC grid in the Continent. The south-north (FR-BE-NL) and west-east (NL-DE and FR-DE) flows on the concerned AC borders are estimated to be less extreme. Figure 7-19 illustrates this effect.

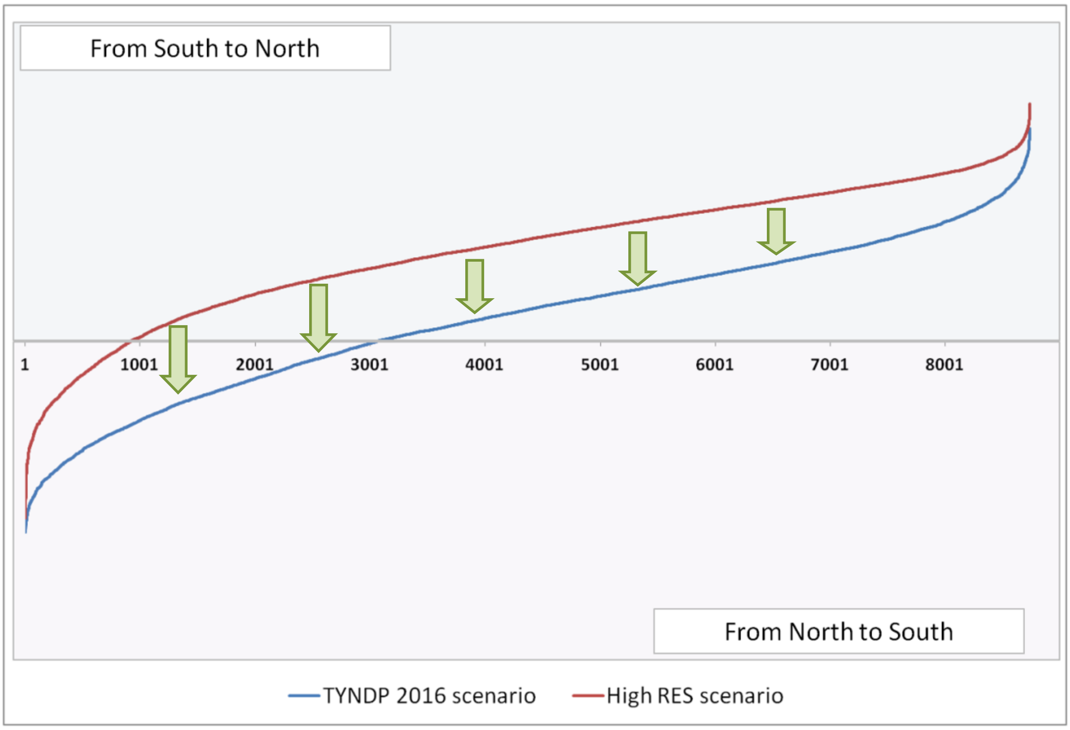


Fig. 7-19 – illustration of effect of lower level of transfer capacity on the duration curve of AC border in the Continent

Consequently, it is expected that the bottlenecks as identified in the TYNDP 14 High RES Scenario would partially disappear and/or be less severe from a year-round perspective.

7.3 Details behind the multi-terminal case study for Denmark

The application of point-to-point HVDC connectors is the usual way of energy and power transport between (two) asynchronous HVAC systems. A point-to-point HVDC connector includes a DC cable system between two AC/DC converter stations which are located within and connected to each of the two HVAC systems. The basic project cost includes:

- Capital expenditures:
  - Two AC/DC converter stations and
  - A DC cable system
- Operational expenditures:
  - Energy conversion losses due to transformation between AC and DC current and voltage within the converter stations.

The basic project cost is easy to evaluate based on the market results and without conducting any grid study. Additional project cost is derived from the grid study and includes:

- Capital expenditures for reinforcements of the HVAC systems (elimination of bottlenecks and contingencies in the grids)
- Operational expenditures of transmission losses caused by:
  - Power transport through the DC cable and
  - Power transport through the HVAC system.

When the energy and power transport volume through HVDC connections into the same geographic area becomes excessive and the HVAC system is getting constrained, a multi-terminal HVDC system might be a more cost-efficient and technically advantageous solution than extensive usage of the point-to-point HVDC connectors. This general idea has been investigated in this case study for the Danish grid.

In this context, the multi-terminal HVDC system is considered on-land and not offshore. This means that all large, heavy equipment such as AC/DC converter stations shall be located on-land, i.e. in the same manner as for conventional point-to-point HVDC connectors, which reduces the assumed costs significantly. The main drivers of the multi-terminal HVDC system shall be cost reduction in comparison to point-to-point connectors due to:

- Fewer AC/DC converter stations:
  - Reduced capital expenditures for the whole interconnection system
  - Reduced energy conversion losses due to fewer energy conversion cycles
  - Better environmental and social impact (fewer large station buildings in landscapes)
- Reduced stress on the adjacent HVAC system(s):
  - Alleviation of bottlenecks at increased energy and power transports throughout the system
  - Energy and power are transported through the HVDC system with reduced exchange with the HVAC grid
  - Reduction of transmission losses because DC-system losses are lower than AC-system losses (reactive power) for the same amount of transported energy.

The risks are:

- No reference to existing projects

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- Few vendors (with solid backgrounds and reputations) world-wide can offer commercially available HVDC Breakers and have capacities to develop multi-terminal HVDC projects
- Standardisation process of multi-terminal HVDC grids is well ongoing but not fully completed.
- Allocation of costs and benefits for the facilitation of pure „transit systems“ has not been assessed yet.

A multi-terminal HVDC system will have several (at least one) extended DC terminals which are called HVDC hubs. A HVDC hub accommodates:

- DC connectors (DC cables and/or DC OHL) to the AC/DC converter stations of the remote HVAC systems and
- Outlets to the near-by AC/DC stations of the local HVAC system.

The HVDC connectors facilitate the market power flows between the local HVAC system and the remote HVAC systems. The AC/DC converter stations in the hub are for the energy conversion between DC and AC current and voltage and the energy and power exchange between the local HVAC system and the HVDC connectors arriving to the hub. The main advantage of the multi-terminal topology is that the number of AC/DC converter stations in the hub is smaller than the number of the HVDC connectors arriving to the hub.

The hub topology means managing the same energy and power exchange with the local HVAC system by a smaller capacity of the local AC/DC converter stations. Thus, the main pre-condition for comparison to the point-to-point HVDC connectors shall be that the multi-terminal HVDC system allows the market power flows without congestion (restriction) within the HVDC system itself. If restrictions are present then such restrictions can only occur within short periods and shall be inferior in comparison to:

- Loss of transported energy due to disruption of unrestricted market power flows, and
- Savings due to utilizing fewer AC/DC converter stations.

It shall be mentioned that a multi-terminal HVDC system shall utilize VSC and not LCC technology for avoiding complex electro-technical solutions for flow reversing through the HVDC connectors within the same hub.

7.3.1 Methodology

At least one HVDC hub shall be considered for the price area (an HVAC system) characterized by the features below:

- Heavily connected to numerous price areas through HVDC connectors
- Serving as a transit system between different price areas with:
    - the local consumption and generation capacities being much smaller than the total capacity of the arriving HVDC connectors; the local grid is bypassed.
- Favourable geographic location, e.g. in-between other price areas.

At present, the market models of the TYNDP Project calculate the market power flows across the borders of different price areas. This method corresponds to the market flows through lumped, point-to-point connections between the different price areas. The term “lumped connections” implies that the market results present the total flows, which can go through several parallel physical connectors and without distinguishing between these physical connectors.

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For example, there are four commissioned parallel HVDC connectors totalling 1700 MW and one more assumed project of 500 MW transport capacity between Norway and Denmark-West; see **Figure 7-20** for illustration. The market results for these connectors are given by a single value in each hour and without distinguishing how the power transport is arranged between these connectors. However, the TSO's at the ends of the physical connectors will, in practice, agree upon which connectors shall be filled up more and which ones less to facilitate a requested market flow during a given hour of the year.

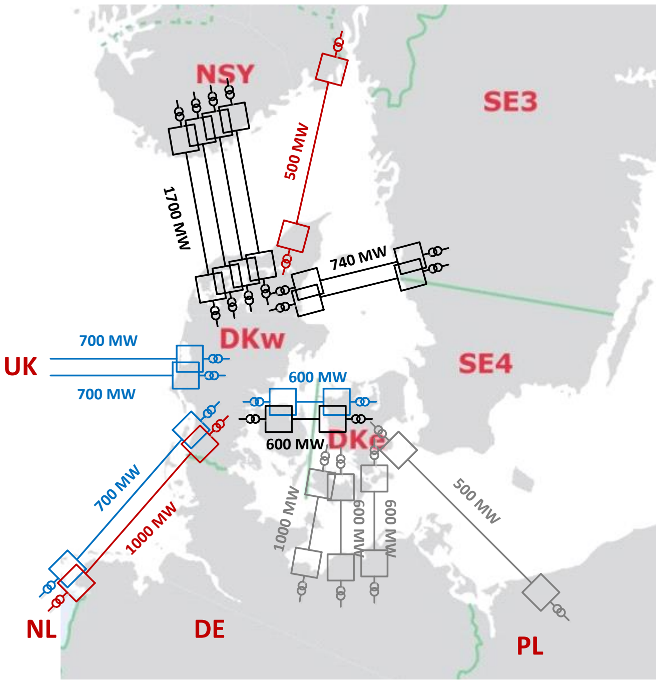

Fig. 7-20 – HVDC connections arriving to Denmark-West (DKw): black – existing, blue – scheduled or TYNDP-2014 projects, red – potential projects, grey – connectors to Denmark-East which are assessed in Reg. Group Baltic Sea.

The methodology begins after the market results have been delivered and before the network studies have begun. The methodology applies an additional process for recognizing which connectors shall be assessed as point-to-point HVDC connectors and which ones can participate in the HVDC hub; the last mentioned connectors shall be assessed as a multi-terminal HVDC system. The methodology utilizes the post-processing of the regional- and inter-regional- level market results, because HVDC hubs and multi-terminal HVDC systems shall include several connectors between more than two price areas and the relevant price areas can be present within the same or different regions. Following the Danish assessment, the HVDC candidate project to the Netherlands being assessed in the RG NS and the potential project to Norway in the RG BS, but both assumed projects arrive in Denmark-West and might be merged into the same HVDC hub.

The post-processing of the market results comprises several combinations of more than one HVDC connectors arriving from more than one price areas to the local HVAC system to identify the best suitable proposal for the multi-terminal HVDC system.

However, already existing and/or scheduled HVDC connectors should be excluded from the post-processing, unless the relevant TSOs find advantageous and feasible to re-configure the already existing/scheduled HVDC connectors. Hence, the assumed projects are potential candidates for being included in the multi-terminal HVDC system idea. In the above example with the HVDC connectors between Norway and Denmark-West, the four existing connectors are excluded from, but the fifth project candidate is included into the post-processing for definition of the West-Danish HVDC hub.

In the post-processing, the hourly values of the market power flows through relevant HVDC connectors to the local price area, $P_{N,M}$, are added $P_M=\Sigma_N(P_{N,M})$, where N is the connector id and M is the hour over the year. M varies from the first to the last hour of the year. The hourly sums of the market power flows, P_M, give the hourly net flow exchanges between the arriving HVDC connectors and the local price area.

When the hourly net exchanges with the local price area, P_M, is significantly smaller than the total transport capacity of the arriving HVDC connectors, $C=\Sigma_N(C_N)$, then these connectors can be merged into a multi-terminal HVDC system. The term "significantly smaller" means that at least one AC/DC converter station can be omitted and still facilitate the net flow exchange through the merged connectors into the local price area in each hour of the year.

Additionally, the system operation and system security rules shall be respected when considering the usage of the multi-terminal HVDC system instead of separate point-to-point HVDC connectors. This means that capacities of the AC/DC stations shall comply with the system security rules (not greater than the permitted MVA rating) and that a sufficient quantity and topology of the DC-Breakers are proposed.

7.3.2 Denmark-West as a multi-terminal HVDC system

The West-Danish price area with arriving HVDC connectors is presented in Figure 7-20. At this stage, the arriving HVDC connectors are shown as point-to-point types. The West-Danish price area is well connected with the foreign systems and subject to heavy power transports between the Nordic and the Continental systems as well as to the GB and Denmark-East. Denmark-West has also a strategic location, just between the different price and fuel-type areas, e.g. hydro-power north to and thermal, wind and solar south and west to Denmark. Therefore Denmark-West shall be considered as a power transport hub (both market flows and electric power flows) between the surrounding areas.

For this exemplarily case study, the potential new projects and some envisaged connectors, which are among the TYNDP-2014 projects, are assessed as potential connectors of the multi-terminal HVDC system with the HVDC hub located in Denmark-West. The assessment is carried out for evaluation whether the multi-terminal HVDC system is more cost efficient than the usage of point-to-point HVDC connectors. The pre-condition has been that the market flows between Denmark-West and the foreign areas are not changed and the SEW indicator has remained unchanged. Using RG NS market results, the last mentioned pre-conditions is fulfilled within more than 98% of the year-round time and only in less than 2% of the hours the market flows are constrained.

The HVDC connectors to Denmark-West which are not considered for participation in the multi-terminal HVDC system:

- The existing HVDC connectors:
  - Skagerrak 1-4 from Norway, Kontiskan 1-2 from Sweden,
  - The Great Belt-1 between Denmark-West and Denmark-East,
- The scheduled/envisaged TYNDP-2014 projects:
  - The Cobra-cable 700 MW from the Netherlands and the Viking cables 2x 700 MW from the GB.

Figure 7-21 shows the HVDC connectors, at this stage as point-to-point types, which are considered for inclusion into the multi-terminal HVDC system. This is the initial condition to the post-processing of the market results:

- The TYNDP-2014 projects:
  - The second intra-Danish connector between the western and eastern systems (The Great Belt-2 (600 MW)) and the second connector from Germany to Denmark-East, Kontek-2 (600 MW).
- The potential new projects:

- A 1000 MW connector from the Netherlands and a 500 MW connector from Norway to Denmark-West

Figure 7-21 – HVDC potential projects to Denmark-West, shown as point-to-point connectors, which can be relevant for merging into a multi-terminal HVDC system. Marking: blue –TYNDP-2014 projects, red – potential new projects, grey – connectors to Denmark-East which are analysed within Regional Group Baltic Sea.

Figure 7-22 illustrates the post-processing and the duration curves of the market power flows through the relevant connectors to Denmark-West. The post-processing has shown that the net power exchanges through the connectors arriving to Denmark-West from the Netherlands, Norway and Denmark-East does not exceed 1600 MW in more than 98% of the year-round time. The total transport capacity of these three connectors is 2100 MW. Hence, a single AC/DC converter station of 500 MW, i.e. 2100 MW capacity minus 1600 MW maximum power exchange, can be excluded from the system design without reducing benefits of the market flows. Exception is only **less than 2%** of time due to some flow constraints.

This result implies that the three mentioned HVDC connectors can be arranged into the multi-terminal HVDC system comprising the West-Danish HVDC hub. The hub will (only) have two, instead of three, HVDC VSC stations located in Denmark-West for exchanging up to 1600 MW power between Denmark-West and the three arriving HVDC connectors. The two HVDC VSC stations can either be 2x 800 MW or 1x 1000 MW and 1x 600 MW. The topology with 1x 1000 MW and 1x 600 MW VSC stations has been applied in this case study. The final design shall also address the system operation and system security rules and may change the ratings of the HVDC VSC stations.

Figure 7-23 shows the resulting HVDC connection topology within the West-Danish price area. In the network studies of this case study, the West-Danish network is assessed as the multi-terminal HVDC system with the HVDC hub of three connectors and two converter stations.

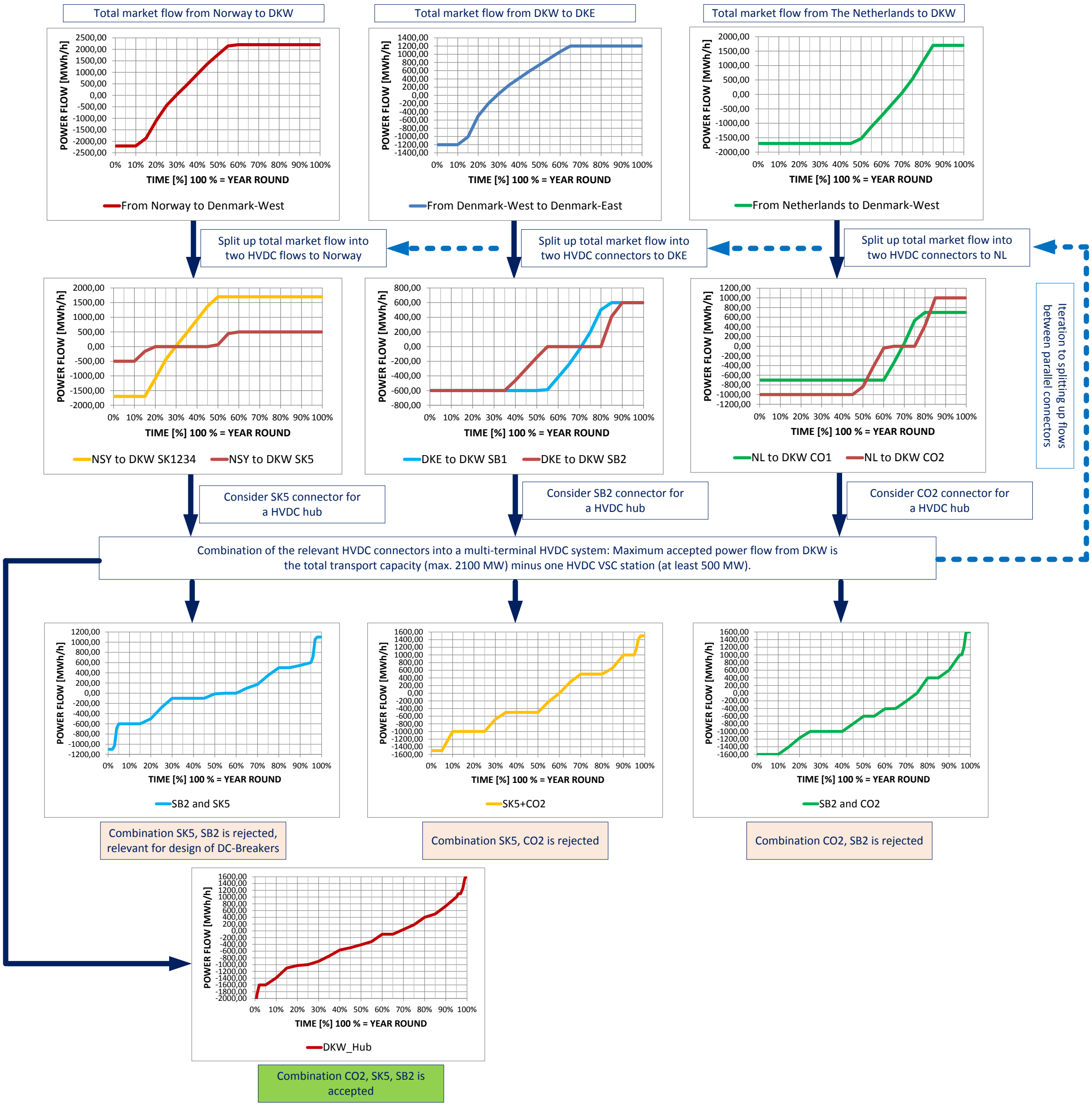

Figure 7-22 – Post-processing block-diagram of the market flows for Denmark-West for merging the HVDC connectors into a multi-terminal HVDC system. The result is merging three connectors from Norway, The Netherlands and Denmark-East into a HVDC hub with 1x 1000 MW and 1x 600 MW HVDC VSC stations. Only less than 2% of time the market flows can be constrained (because of exceeding 1600 MW transport capacity). Used abbreviations: SK 1234 = Skagerrak 1, 2, 3 and 4 existing connectors to Norway; SK5 = potential HVDC connector to Norway assessed at Energinet.dk; SB1 = Great Belt -1 HVDC intra Danish existing connector; SB2 = TYNDP-2014 project intra-Danish HVDC connector; CO1 = CobraCable planned HVDC connector to the Netherlands; CO2 = potential HVDC connector to the Netherlands assessed at Energinet.dk

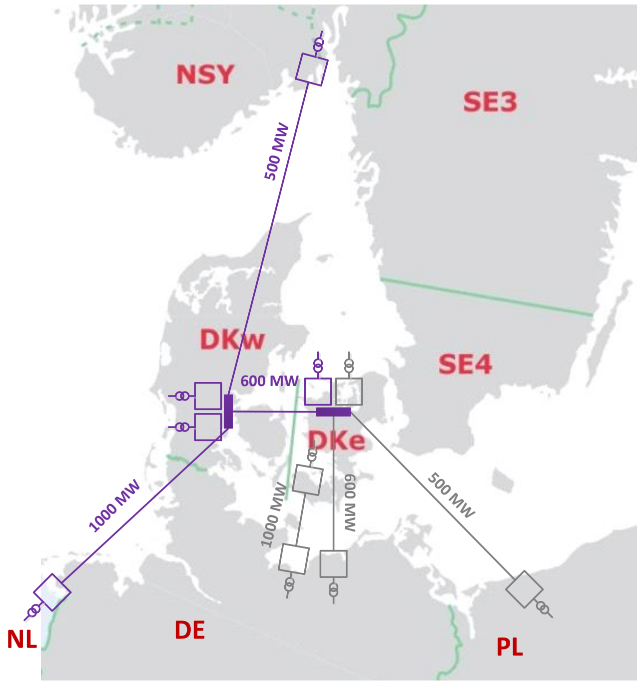

Figure 7-23 – HVDC potential projects merged into a multi-terminal HVDC system with a HVDC hub. Marking: violet – a multi-terminal HVDC system, red – a point-to-point connector, grey – candidate projects in Denmark-East (analysed in Regional Group Baltic Sea).

7.3.3 System security and DC-Breakers

The multi-terminal HVDC system shall include a sufficient number of DC-Breakers for avoiding failure of the whole system in a case of failure of a single HVDC component. Without DC-Breakers, the whole system may shut-down in a range of few seconds to few minutes, disconnect the faulted component and re-start the healthy part of the system. With DC-Breakers, only the faulted component will be immediately removed whilst the healthy part continuous uninterrupted operation.

Generally, each HVDC hub with three arriving HVDC connectors shall have three pairs of DC-Breakers. However, the quantity and location of the DC-Breakers can be optimized knowing the market power flows throughout the connectors. The post-processing of the market results has shown:

- Disconnection of the potential connector from Norway and SB2 (from Denmark-East) connectors to Denmark-West will lead to the loss of no more than 600 MW of the net power exchange (the most of time over one year) to Denmark-West.
- Disconnection of the SB2 (from Denmark-West) and PL1 (from Poland) connectors to Denmark-East will lead to the loss of no more than 600 MW of the net power exchange to Denmark-East.

The above result implies that the quantity of the DC-Breakers can be reduced by one pair in each HVDC hub. The reduction is proposed because the loss of both connectors (and their common HVDC VSC station) does not exceed the loss of a single (largest) connector. Hence, the quantity of the DC-Breakers in the West-Danish and in the East-Danish HVDC hubs is set to two pairs (in each HVDC hub).

7.3.4 Cost indicator

For the cost indicator, the proposed multi-terminal HVDC system implies reduction of the capital expenditure due to fewer HVDC VSC stations needed and reduction of the operation cost due to reduced energy conversion losses in the HVDC hubs. On the other hand, the capital cost is increased due to the usage of DC-Breakers. One pair of the DC-Breakers is estimated approx. 20% of the cost of one HVDC VSC station of the same power capacity.

Specifically for the multi-terminal HVDC system of Denmark-West, the following contributions to the capital expenditure are taken into account:

- One 500 MW HVDC VSC station is excluded from design,
- Two pairs of DC-Breakers are included into the design,
- Reduced needs of internal grid reinforcements.

And the following contribution to the operation expenditure, which is capitalized over the system's life-time, is taken into account:

- Energy conversion losses through the fewer HVDC VSC stations are reduced.

The cost evaluation does not include:

- Expected operation cost reduction due to reduction of the power transport losses. The transport losses will be lower in the HVDC system than in the HVAC system due to reactive power and reactive-current component in the HVAC system.

Table 7.5 presents conservative, indicative comparison of the capital expenditure of the multi-terminal HVDC system versus the point-to-point HVDC connectors, when disregarding the internal grid issues. This conservative comparison shows that the cost saving due the multi-terminal HVDC system can be estimated to **33,5 M€** for the grid area of Denmark-West.

Material	Units
1x 500 MW VSC station	-1
1x 600 MW DC-Breaker pair	+1
1x 1000 MW DC-Breaker pair	+1
Total cost difference	**-33,5 M€**

Table 7.5 – indicative capital cost savings due to the multi-terminal HVDC system instead of a point-to-point HVDC connectors disregarding internal grid.

Nevertheless, the internal grid shall be taken into account for getting a more accurate figure of potential benefits and drawbacks of the multi-terminal HVDC system. For the purpose of this study only the Danish internal grid has been considered, but it should be kept in mind, that the other countries' internal grids also might face similar issues. These costs are not considered here. **Figure 7-24** compares the grid topology of Denmark-West for the multi-terminal HVDC system and that for the point-to-point connectors. The point-to-point HVDC connectors will require internal grid reinforcements, though the proposed reinforcements are kept to minimum. The reinforcements serve for transporting the power flows between the Danish terminals of the point-to-point connectors, i.e. enabling the market flows with transit throughout the West-Danish grid.

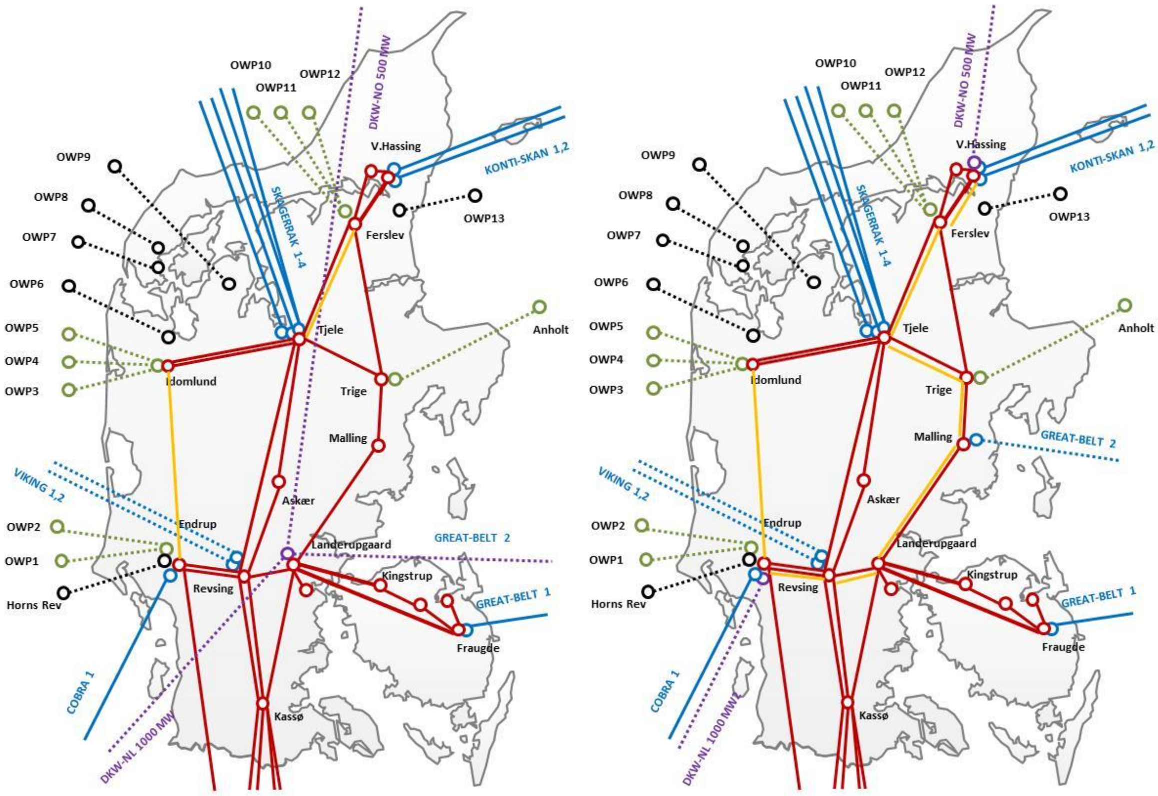

Figure 7.24 - (Left) – Multi-terminal HVDC connection and (Right) – Point-to-point HVDC connectors to Denmark-West. Colour legend: Blue – HVDC connectors prior to Common Planning Studies; Red – the Danish 400 kV transmission system prior to Common Planning Studies; Yellow = 400 kV grid reinforcements needed; Violet = potential HVDC connectors to Denmark-West.

Table 7.6 presents the capital expenditure of the internal grid reinforcements and that of the point-to-point HVDC connectors to Denmark-West. The internal reinforcements are accordingly to **Figure 7-24 (Right)**.

Point to Point HVDC	km	Technology	Cost M€
VSC (Norway)	1	DC Station 500 MW	
VSC (Netherlands)	1	DC Station 1000 MW	
VSC (Denmark-West)	1	DC Station 500 MW	1478,5
	1	DC Station 1000 MW	
DC cable	700	Submarine, Onland	

Reinforcement Technology	Distance km	Cost M€
400 kV AC OHL	30	
400 kV AC cable	111	204,9
400 kV OHL reconductoring	120	

Point to Point HVDC SB2	km	Technology	Cost M€
VSC (Denmark-East)	1	DC Station 600 MW	

VSC (Denmark-West)	1	DC Station 600 MW	
DC cable	120	Submarine	**323,4**

Point to Point Approach	Total Cost M€
	2006,8

Table 7.6 – Capital expenditures for the point-to-point HVDC connectors – potential new interconnection projects and related internal grid reinforcements in Denmark-West.

It should be noted that internal grid reinforcements in NO and NL have not been investigated in this study. However, this cost might be in the same order of size for both point-to-point and multi-terminal HVDC approaches as the same grid connection substation and the same market flows are assumed in both remote systems.

Table 7.7 presents the capital expenditure of the multi-terminal HVDC system in Denmark-West which is accordingly to the grid topology in **Figure 7.24 (Left)**. The comparison shows that the capital expenditure savings are **89,9 M€** for the multi-terminal HVDC system of Denmark-West.

Multi-terminal HVDC	km	Technology	Cost M€
VSC (Norway)	1	DC Station 500 MW	
VSC (Netherlands)	1	DC Station 1000 MW	
VSC (Denmark West)	1	DC Station 1000 MW	
DC cable	650	Submarine, Onland	**1593,5**
DC OHL	175	Onland	
DC Breaker	1	1000 MW DC	

Multi-terminal HVDC SB2	km	Technology	Cost M€
VSC (Denmark-East)	1	DC Station 600 MW	
VSC (Denmark-West)	1	DC Station 600 MW	
DC cable	100	Submarine	**313,5**
DC Breaker	1	600 MW DC	

Multi-terminal HVDC Approach	Total Cost M€
	1907,0

Table 7.7 – Capital expenditures for the multi-terminal HVDC system including potential projects to and within Denmark-West.

The total capital expenditure savings due to the usage of the multi-terminal HVDC system in Denmark-West are present in **Table 7.8** and become **99,8 M€** (almost **100 M€**) comprising the savings in Denmark-West and DKW-DKE:

Area	Capital Expenditure Saving M€
Denmark-West	*89,9*
DKW-DKE	*9,9*
SUM:	*99,8*

Table 7.8 – Capital cost savings due to the multi-terminal HVDC system instead of the point-to-point HVDC connectors accounting for internal grid savings.

The above figure of the capital cost savings is significantly higher than the raw estimate of **Table 7.5**, i.e. without inclusion of the internal grid. The result, therefore, shall be taken with precaution, because it is volatile to the material prices, line lengths and routing, whereas the raw estimate of **Table 7.5** is less volatile to such factors.

Table 7.9 compares the annual energy transports, i.e. the summarized absolute market power flows over one year, through the HVDC VSC stations to Denmark-West price area. The comparison is made for the power conversion within the two topologies:

- Three HVDC VSC stations of the three point-to-point connectors arriving to the West-Danish price area.
- Two HVDC VSC stations of the HVDC hubs exchanging the power with the West-Danish price area.

Parameter	Point-to-point HVDC topology			Multi-terminal HVDC topology
HVDC VSC station in DKW	*SB2 1x VSC*	*CO2 1x VSC*	*SK5 1x VSC*	*HVDC Hub with 2x VSC*
Energy exchange [TWh/y]	*3.20*	*6.43*	*2.71*	*6.25*
Energy Losses [GWh/y]	*32.0*	*64.3*	*27.1*	*62.5*
Cost [M€/y]	*2.08*	*4.18*	*1.76*	*4.06*
Cost Difference for DKW [M€/y]				*-3.97*

Table 7.9 – Indicative figures of energy conversion losses and their not-capitalized cost difference in the HVDC VSC stations in Denmark-West applying RGNS market study results RG NS. Resulting differences are negative for the West-Danish HVDC hub, which means a losses reduction and the cost reduction when using the multi-terminal HVDC system instead of point-to-point HVDC connectors.

The energy conversion losses, i.e. the AC/DC and DC/AC conversions, of each HVDC VSC station are set to **1%** of the net power exchange with the HVAC system. The average energy price in the Danish price areas is set to **65 €/MWh**.

The usage of the multi-terminal HVDC system instead of point-to-point HVDC connectors leads to smaller energy conversion losses and to the cost reduction by 3.97 M€/y in Denmark-West with the usage of the market flows RG NS. Assuming expected life-time of the projects is **30 years** and the discount interest is **5%**, the capitalisation factor is 15.37. The capitalized reduction of the energy conversion losses over the life-time will be = (3.97)*15.37 = **61 M€** savings in Denmark-West.

The indicative figure of the total benefit of the multi-terminal HVDC system instead of point-to-point HVDC connectors will be the sum of the capital cost savings in a range from 33,5 M€ to 100 M€ and the reduced energy conversion losses in a range of 61 M€. **Table 7.10** highlights this outcome.

Multi-terminal HVDC system	Cost reduction [M€]
Total Capital cost reduction (Figure without grid reinforcements)	***100*** ***(33,5)***
Smaller energy conversion losses	***61***
Total cost reduction (Cost reduction without grid reinforcements)	***161,0*** ***(94,5)***

Table 7.10 – Cost efficiency of the proposed multi-terminal HVDC system in comparison to point-to-point HVDC connectors in Denmark-West for the same energy transport by Common Planning Studies RG NS market results.

The total capitalized cost reduction will be in a range from 94,5 M€ to 161,0 M€, which depends on several factors, including completing grid reinforcements. The result is indicative, volatile to energy and equipment prices as well as to other external factors which are beyond the scope of this case study. The result shall be used with precaution, having in mind that respective investigations of adjacent systems has not been part of the study. Additionally, the distribution of related costs and benefits for facilitating a “transit” system has not been assessed.

It is important to keep in mind that the proposed multi-terminal HVDC system is assuming the two hubs being installed on-land, and not offshore.

The main idea uses the same technology and general basic idea as discussed earlier in the context of various offshore grid research projects. Thus, some of the general findings above might also be translated into discussions and commercialization around offshore grid infrastructure, but the difference in cost assumptions for on- and offshore assets has to be considered.

7.4 Guidelines for Project Promoters

In line with Regulation (EU) 347/2013, the EC provides a set of guidelines[9] for ENTSO-E to apply when handling all applications by project promoters for TYNDP inclusion. These guidelines ensure the same procedure, timeline and qualification criteria are used for all project promoters, and enshrine the rights and responsibilities of promoters, ACER, EC and ENTSO-E. It addresses Promoters of transmission infrastructure projects within a regulated environment, Promoters of transmission infrastructure projects within a non-regulated environment (i.e. exempted in accordance with Article 17 of Regulation (EC) No 714/2009, referred to as “merchant lines”), and Promoters of storage projects. All who aspire inclusion of their project in the PCI list in year X, need to be included in the latest available TYNDP of year X-1.

Based on the EC’s draft guidelines, and building on the experience of past TYNDPs, all promoters of electricity transmission and storage projects were invited by ENTSO-E to submit between 1 April and 30 April 2015 their application for inclusion in the Ten-Year Network Development Plan 2016.

During May 2015 ENTSO-E reviewed the data submitted in order to verify its completeness and compliance with the guidelines. Throughout May any promoter had the opportunity to complete or update its project details, and ENTSO-E was in regular contact with all promoters to ensure a smooth process. All promoters were invited to provide information via a dedicated Sharepoint platform. Ultimately it is the applicant’s responsibility to ensure the application was completed by end of May.

This procedure allowed ENTSO-E to compile a list of TYNDP project candidates which completes the picture of planning studies, regional context and investment needs sketched in the Regional Investment Plans[10]. This timely compilation of a list of TYNDP projects allows ENTSO-E to have a baseline reference architecture for CBA assessments starting in summer 2015. Any late request for TYNDP inclusion can be handled evidently in future TYNDP editions. Any request for significant change to TYNDP projects during the 2016 process will be assessed in line with ENTSO-E’s governance rules, with oversight from EC and ACER, and taking on board the role of ENTSO-E’s neutral Network Development Stakeholder Group.

The main drivers in this approach is to keep transparency over the development and updates of the TYNDP project list, and ensure clarity over the CBA assessment ‘ingredients’ (methodology, list of projects, scenarios, data).

9 https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/20150217_Guidelines_Update_ENER_TC_24.02.2015_1st%20draft.pdf

10 https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/150331_TYNDP_2016_FAQs_application_for_projects.pdf

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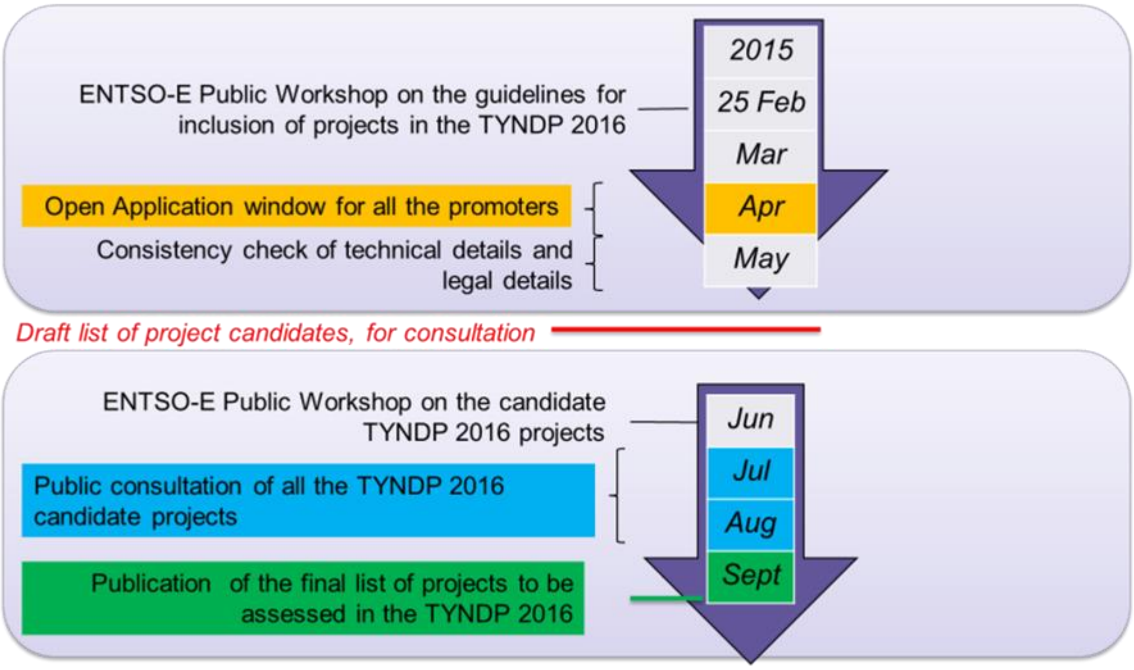

Figure 7-14 Workplan for project promotors

7.5 Abbreviations

The following list shows abbreviations used in the Regional Investment Plans 2015.

- 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
- SEW Socio-Economic Welfare
- SOAF Scenario Outlook & Adequacy Forecast
- SoS Security of Supply
- 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

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

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 have to be realised in total to achieve a desired effect.

Grid transfer capacity (GTC) – represents the aggregated capacity of the physical infrastructure connecting nodes in reality; it is not only set by the transmission capacities of cross-border lines but also by the ratings of so-called “critical” domestic components. The GTC value is thus generally not equal to the sum of the capacities of the physical lines that are represented by this branch; it is represented by a typical value across the year.

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

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, and taking into account the technical uncertainties on future network conditions.

N-1 Criterion – The rule according to which elements remaining in operation within TSO’s Responsibility Area after a Contingency from the Contingency List must be capable of accommodating the new operational situation without violating Operational Security Limits.

Project – either a single investment or a set of investments, clustered together to form a project, in order to achieve a common goal.

Project candidate– investment(s) considered for inclusion in the TYNDP.

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

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

Reference 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 which 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 and to evaluate the load flows over the lines with and without the examined network reinforcement.

Ten-Year Network Development Plan – The Union-wide report carried out by ENTSO-E every other year as (TYNDP) part of its regulatory obligation as defined under Article 8 para 10 of Regulation (EC) 714 / 2009

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

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

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