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Executive Summary

High densities of submarine cables (including both power and telecommunication cables) and pipelines (for oil or gas transport) run across large stretches of the North Sea. These cables and pipelines serve many different industries and this density is growing significantly in line with general energy industry development. This report specifically focuses on offshore grid development and electricity interconnectors which are closely linked to the increasing generation of offshore renewable energy to meet EU energy and interconnection targets for 2020 to 2030 and decarbonisation by 2050. It is the ambition of the EU to have a fully-integrated internal energy market, however cross-border interconnections are limited and some countries are in danger of not achieving the 10% EU interconnection target by 2020 nor the 15% target by 2030.

Offshore linear energy infrastructure may cover a greater area than the offshore wind farm itself, cross country borders, pass through environmentally sensitive areas and interact with other marine activities and users. The role of MSP for grid development is to ensure effective routing, configuration and location of grid infrastructure. MSP can help by identifying areas of least constraint to locate cable corridors which match up offshore energy resource to suitable grid connection points on land, whilst carefully routing around environmentally sensitive areas.

There is an increasing need to understand the current and future spatial demands for submarine cables in the NSR. Countries are faced with the need to accommodate those cable systems already in service as well as the growth of new connections and networks that are being installed to serve energy generation and distribution policies. The European co-funded NorthSEE project addresses these challenges directly.

This report is specifically focused on WP5 Energy where the task was to investigate the *status quo* of offshore linear energy infrastructure, the future trends, grid connection points, interconnectors and interconnection demand in the NSR.

Chapter 1 (Introduction) gives an overview of EU energy policies including EU interconnection targets. It also includes regional cooperation initiatives and drivers and barriers to offshore linear energy infrastructure. The main transnational drivers for grid development in the NSR include interconnection demand and increased grid connection points and barriers include grid connectivity and grid integration. Chapter 2 (Status Quo) presents summaries of country profiles found in full in Annex 1, including existing offshore linear energy infrastructure in the form of an inventory, planning and licensing provisions, technical and spatial planning criteria and two interconnector case studies. It also discusses NSR interconnection specifically and focuses on the countries which have not met the 2020 interconnection target e.g. Germany and the UK. In terms of planning provisions, Germany demonstrates best practice with their German Spatial Offshore Grid Plan including designated cable corridors and gates and German TSO model which is best suited to the evolution of cross-border offshore grid projects. Chapter 3 (Future trends) gives an insight into the predicted future interconnection levels for NSR countries and the future planned interconnectors, future trends and decommissioning. In terms of future interconnection levels, predictions show that the UK will be unlikely to meet the 15% interconnection target for 2030. Other future trends include TenneT’s ambition for a North Sea Wind Power Hub in the middle of the North Sea. Chapter 4 (The role and impact of MSP) highlights to the role and importance of MSP for facilitating transnational coordination and planning for the future which is essential for optimal grid expansion. It also discusses issues for MSP in terms of spatial overlap with other marine activities and planning solutions and route proposals. Lastly, Chapter 5 (Conclusions) details the main findings which includes the fact that current grid and linear energy infrastructure is nationally focused and largely disconnected, with only limited transnational coordination. Denmark currently has the most interconnector cables in the NSR and Belgium has the least. This has important implications for energy security and stability but is also dependent upon current energy requirements and future demand. Differences exist in level of established grid planning including planning provisions between NSR countries and also in terms of planning criteria and between criteria being Government-led or Industry-led. There is also currently no over-arching regulatory regime facilitating the association of offshore grid with offshore renewable projects across national sea basins in the NSR. To date most wind parks in the North Sea have been connected to shore by an individual electricity cable, a so-called ‘radial’ connection, but a hub/interconnector or integrated approach may be the way toward achieving transnational coordination of a North Sea offshore grid. Overall, the NSR needs more landfall points in the Northern North Sea order to meet future needs and more interconnectors are required in the UK and Germany to help them achieve their 2020 and 2030 interconnection targets. However, despite higher interconnection demand in the future, there might be less of a requirement for landfall points if a meshed or more integrated grid solution is implemented.

The report makes a series of recommendations aimed at marine planners and other bodies to help facilitate greater transnational coherence and cooperation in maritime planning.

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List of acronyms and abbreviations

AC	Alternating Current
CCS	Carbon Capture and Storage
DC	Direct Current
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GW	Gigawatt
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organisation
MSP	Marine/Maritime Spatial Planning
MW	Megawatt
MWh	Megawatt hour
NSCOGI	North Sea Countries' Offshore Grid Initiative
NSR	North Sea Region
OWE	Offshore Wind Energy
OWF	Offshore Wind Farm
PCI	Project of Common Interest
RES	Renewable Energy Sources
TW	Territorial Waters
TSO	Transmission System Operator
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WP	Work Package

1. Introduction

This chapter gives a background to the report including an overview of EU energy policies and targets including those for energy security, a fully-integrated internal energy market and interconnection targets. It also highlights the current mechanisms and initiatives to facilitate regional cooperation between NSR countries in order to meet the EU energy targets. In addition to this, drivers and barriers to grid development are discussed.

1.1. Background

High densities of submarine cables (including both power and telecommunication cables) and pipelines (for oil or gas transport) run across large stretches of the North Sea. Their linear nature reflects the term 'offshore linear energy infrastructure' which is used in this report. These cables and pipelines serve many different industries and this density is growing significantly in line with general energy industry development.

The growth of the offshore energy industry was discussed in the previous '*Status quo* report on offshore energy planning provisions in the North Sea Region'. This report included predicted offshore wind growth scenarios for 2020, 2030 and 2050, future energy trends and the spatial requirements needed to meet these industry forecasts. To summarise, ambitious environmentally-friendly energy and climate change targets set by the EU and Member States are driving the growth of offshore renewable energy developments. In addition to this growth, future energy industry trends include larger, more powerful offshore wind turbines further offshore in deeper waters, floating wind, multi-rotor turbines, increased ocean energy developments, multi-use developments, and decommissioning of Oil & Gas platforms. WindEurope's growth scenarios and in particular their central scenario for offshore wind installed capacity estimates the space requirements for fulfilling 2020 and 2030 growth targets in the North Sea Region (NSR). Assuming that the spacing of wind turbines will remain at 1 km distances in the years to come, space requirements were calculated for incremental offshore wind turbines size scenarios (7 MW to 15 MW). The North Sea is roughly 750,000 km^2 in total and the total space occupied by offshore wind farms is ca. 3,500 km^2 by 2020 and over 8,000 km^2 by 2030.

Growth in the offshore energy industry results in an increased interconnection demand. This is coupled with the European Commission's desire to create an integrated internal energy market [1] where energy can flow freely across Member States. However current grid and linear energy infrastructure is nationally focused with only some transnational coordination in the form of integrated connection of a number of offshore wind parks and between nations in the development of interconnectors [2]. As stated by WindEurope in their wind energy scenarios [3], in order to meet 2030 renewable energy and climate change targets, there will need to be efficient and improved power interconnections between Member States. This will require extensive coordination between NSR countries for the dream of a North Sea offshore grid [4] to become a reality.

There is currently (as of March 2019) only 7250 MW of electricity capacity share between NSR countries via transnational interconnectors (Figure 1). Most of this electricity share occurs between Denmark and Sweden. There is currently a lack of interconnectors between the UK and Norway, however this is work in progress as there is one interconnector under construction and another with consent approval.

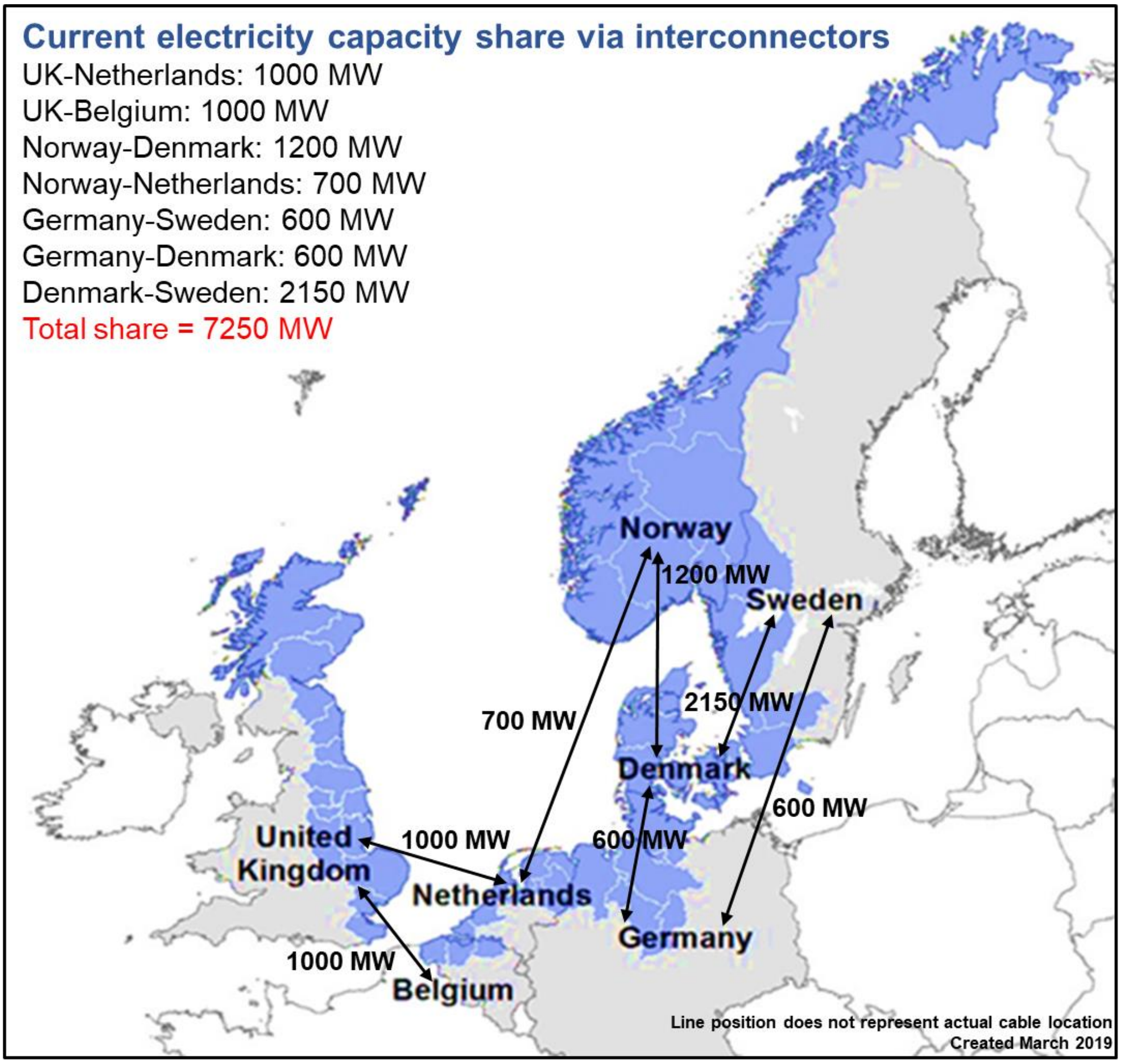


Figure 1. Current electricity capacity share via NSR interconnectors (as of March 2019)

There is also an increasing need to understand the current and future spatial demands for submarine cables in the NSR. Countries are faced with the need to accommodate those cable systems already in service as well as the growth of new connections and networks that are being installed to serve energy generation and distribution policies. The European co-funded NorthSEE project addresses these challenges directly.

Offshore Cable and Pipeline's are location-driven and influenced by the existence of a given resource (offshore renewable energy and oil/gas extraction) or by the necessity of connecting to onshore Oil/Gas or energy substations. There are two types of offshore cables: telecommunication cables and electricity cables (export cables and electricity interconnectors); as well as four types of pipelines: Oil Pipelines, Gas Pipelines, Disposal Pipelines (chemicals and wastewater) and Connection Pipelines (fresh water).

This report focuses largely on interconnectivity and the energy infrastructure which facilitates this called interconnectors. Interconnectivity is, as the name suggests, the connecting up of Member States energy networks and electricity interconnectors are the physical components to facilitate electricity trade, improved security of supply and integration of the rapidly-growing share of renewable electricity production. They also stimulate and strengthen regional cooperation between Member States. Interconnectivity involves both onshore and offshore components and the main focus of this report will be on the offshore components however landfall points on land are also an important consideration for offshore energy planning.

For the purpose of this report the main focus is electricity cables and associated energy infrastructure due to its predicted prevalence in the future of North Sea energy. Oil and Gas pipelines are also included in this report but due to its 'finite' future in the North Sea in comparison to renewable forms of energy and the prediction that the number of new pipelines is expected to stabilise after 2020, it is less focused upon. However, the decommissioning of oil and gas infrastructure could give way to opportunities for carbon capture and storage so this also features in the report. Telecommunication cables are not included as this report largely focuses on the production and transportation of energy. The report does not reference the financial/technical aspect of grid development as the report focuses mainly on planning provisions.

1.2. Report Layout

In this report, we present an overview of offshore linear energy infrastructure planning provisions for the national and transnational transportation of energy in the North Sea. The report is structured in 5 main chapters: Introduction, Status Quo, Future Trends, The role and impact of MSP on grid development and Conclusions. Chapter 1 (Introduction) gives an overview of EU energy policies including EU interconnection targets. It also includes regional cooperation initiatives and drivers and barriers to offshore linear energy infrastructure. Chapter 2 (Status Quo) presents summaries of country profiles found in full in Annex 1, including existing offshore linear energy infrastructure in the form of an inventory, planning and licensing provisions, technical and spatial planning criteria and two interconnector case studies. Chapter 3

(Future trends) gives an insight into the predicted future interconnector demand, future trends and decommissioning. Chapter 4 (The role and impact of MSP) highlights to the role and importance of MSP, issues for MSP in terms of spatial overlap with other marine activities and planning solutions and route proposals. Lastly, Chapter 5 (Conclusions) details the main findings and key lessons learned so far, including recommendations targeted at marine planning authorities and other relevant stakeholders. All background information is contained within annexes.

1.3. Aims of the report

The *status quo* of offshore linear infrastructure in the NSR is presented in this report. The report aims to:

- ✓ review and report linear infrastructure developments
- ✓ identify future trends in the linear infrastructure policy landscape and industry developments across the NSR,
- ✓ identify grid connection points on land;
- ✓ identify interconnection demand;
- ✓ consider the spatial implications of interconnectors for Maritime Spatial Planning in the NSR; and
- ✓ develop proposals for routes and gates in the NSR.

The target audience of the report includes planning authorities around the North Sea as well as the offshore energy and grid industries, ranging from offshore wind farm developers, power cable developers, to grid operators.

The status quo report also serves as an internal project report for the NorthSEE consortium. The report documents progress towards Task 5.1 “Status quo of energy infrastructure provisions in national MSPs” , Task 5.5 “Identification of grid connection points on land”, Task 5.6 “Identification of interconnection demand” and Task 5.7 “Interconnector routes and gates” as listed in the project agreement. Outputs of this report will contribute to future WP5 Tasks for the identification of the critical elements impacting the coordinated sustainable development of offshore renewable energies; and will provide maritime planners with management recommendations to help facilitate transnational cooperation in NSR.

1.4. EU energy policies and targets for offshore linear energy infrastructure

The EU is building an energy union to ensure Europe's energy supply is safe, viable and accessible to all. This energy union will require more efficient use of energy in order to tackle climate change and transition to a low-carbon economy. Implementation of the energy transition will require an electricity system to which renewables will contribute around half of the generation in 2030 and that will be fully decarbonised by 2050. This will result in significant challenges in terms of adapting regulations and infrastructure. The EU's energy union strategy is made up of five dimensions:

1. Security, solidarity and trust
2. A fully-integrated internal energy market
3. Energy efficiency
4. Climate action – decarbonising the economy
5. Research, innovation and competitiveness

The new rules on governance of the energy union require EU countries to develop integrated national energy and climate plans that cover these five dimensions for the period of 2021 to 2030. Efficient planning of offshore linear energy infrastructure in the NSR will support the achievement of these five dimensions of the energy union strategy. However, the focus will be on energy security and a fully-integrated internal energy market.

Energy security

Security of energy supply is an integral part of the Energy Union Strategy. Improvements to grid infrastructure and international interconnectors in addition solidarity and regional cooperation will help the flow of energy across borders at any time to where it is most needed. International interconnectors will also play an important role in the EU's risk preparedness in the electricity sector. As part of the 'Clean Energy for All Europeans' package, the Commission published a proposal for new regulation on emergency and restoration regulations and plans to manage electricity transmission systems in emergency, blackout and restoration states. The newly agreed regulation will enter into force in spring 2019 ensuring security against major risks and electricity crises.

A fully-integrated internal energy market

Despite progress made in recent years, Europe's energy system is still not fully functioning and the energy landscape is still too fragmented [14]. This leads to weak competition and poor investments. The EU has therefore decided to give a new political boost to their ambition to create a fully integrated energy market [14]. The EU believes that energy should flow freely across the EU - without any technical or regulatory barriers. The three actions that the EU intends to implement include:

1. designing a new energy market;

Achieving the EU Energy Union goals will require a fundamental transformation of Europe's electricity system, including redesign of the European electricity market.

2. empowering energy consumers; and

Energy consumers should be at the core of the Energy Union and an integrated internal energy market would give consumers more information and a wider choice of energy providers enabling them to save money and energy.

3. helping energy cross borders.

Investments in infrastructure that connects countries will allow energy to flow, improve energy security, lessen dependency on imports and prepare networks for renewable energy. Figure 2 includes interconnectors as one method to help energy cross borders. There are missing interconnection links between several countries and building these interconnectors will require mobilisation of all efforts from all countries in order to achieve a fully functioning and connected internal energy market.

One of the objectives is to enhance regional cooperation within a common EU framework and the NorthSEE Project aims to address this objective for the NSR. Energy market design and energy consumerism is out with the scope of the NorthSEE Project and this report.

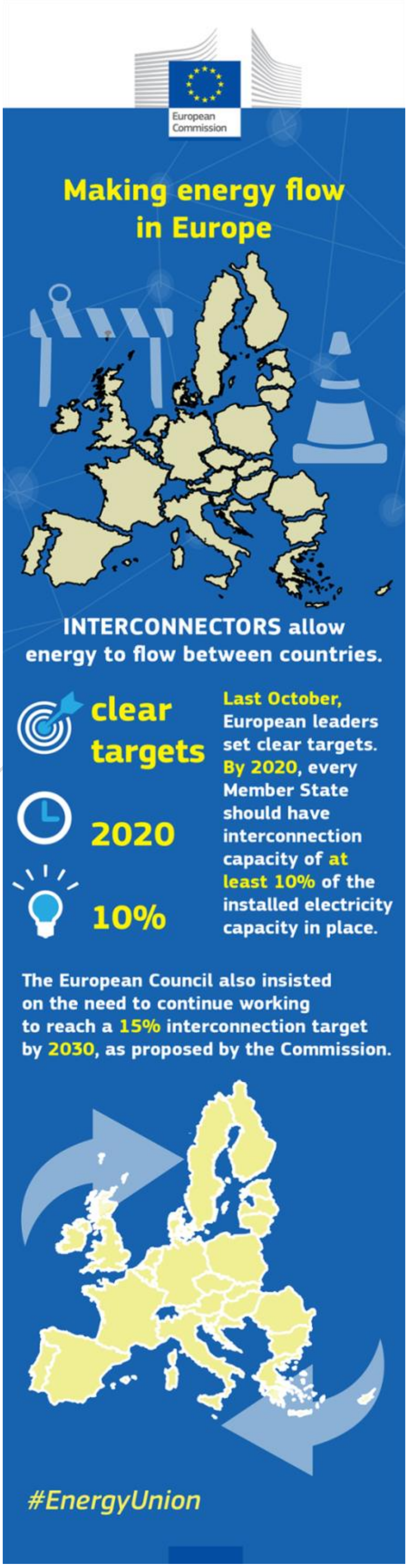


Figure 2. EUs ambition to make energy flow in Europe. Source ec.europa.eu

1.5. EU interconnection targets

Currently, European electricity transmission systems, notably cross-border interconnections, are not sufficient to allow the internal energy market to work properly and address the problem of energy islands in some regions of Europe [13]. Therefore in 2002 the European Council set a 10 % electricity interconnection target (defined as import capacity over installed generation capacity in a Member State), whose delivery date was eventually prolonged until 2020. In May 2014, the European Commission suggested as part of the European Energy Security Strategy that the 10 % target should be extended to 15 % by 2030. This target was endorsed and means that each country should have in place electricity cables that allow at least 15% of the electricity by its power plants to be transported across its borders to neighbouring countries.

To make the 15% target operational, The European Commission established the Expert Group on electricity interconnection targets in March 2016 composed of 15 leading experts on the European energy market and infrastructure from industry organisations, academia and NGOs, as well as the Agency for the Cooperation of Energy Regulators (ACER) and the European Networks of Transmission System Operators for Electricity and for Gas (ENTSO-E and ENTSOG). The Expert Group presented a report on its work in November 2017. The report highlights the fact that Member States demonstrate considerable differences in terms of their energy mix, size of the energy market and geographical location, which influence their interconnectivity potential and needs. In the Expert Group's opinion it is important to take these inherent different energy profiles into account when planning electricity infrastructure.

At the same time, the Expert Group emphasises the need for cooperation in energy infrastructure and renewables deployment, especially between areas of renewable abundance and renewable shortage but also between renewable sources with complementary generation patterns (e.g. wind/photovoltaic). Therefore, the capacity of the EU Member States to supply renewable electricity to the EU market should be taken into account when setting interconnection targets.

The report recommends assessing the need to develop further interconnection capacity, reflecting the different energy realities in EU countries and the different roles interconnectors play in supporting the completion of the internal energy market, enabling the integration of renewables and ensuring security of supply.

In the light of this report, in the Communication on strengthening Europe's energy networks published in November 2017, the Commission proposed to refine the 15% target for 2030 through a set of additional and more specific thresholds. The thresholds are:

1. Additional interconnections should be prioritised if the price differential exceeds an indicative threshold of 2 euro/MWh.

2. Countries where the nominal transmission capacity of interconnectors is below 30% of their peak load should urgently investigate options of further interconnectors.
3. Countries where the nominal transmission capacity of interconnectors is below 30% of installed renewable generation capacity should urgently investigate options of further interconnectors.

The use of these thresholds will serve as indicators of the urgency of the action needed in order to help the EU achieve its energy policy and climate objectives.

See section 3.1 for NSR countries performance against the 3 thresholds.

1.6. Regional cooperation initiatives on offshore linear energy infrastructure

In general, offshore grid infrastructure has already been under development for several decades, and will continue evolving. Already, ambitious offshore grid initiatives and projects in the region are ongoing. These initiatives include:

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

The Electricity Regional Initiatives Project

The Electricity Regional Initiatives Project was launched in 2006 as an interim step to speed up the integration of Europe's national electricity markets [10]. The initiative was launched by the European Regulators Group for Electricity and Gas (ERGEG) and aimed at bringing together national regulatory authorities (NRAs), transmission system operators (TSOs) and other stakeholders in a voluntary process to advance integration at the regional level as a step towards the creation of a well-functioning Internal Energy Market (IEM). The regional initiatives represent a bottom up approach to the completion of the IEM, in the sense that they bring all market participants together to notably test solutions for cross-border issues, carry out early implementation of the EU acquis and come up with pilot-projects which can be exported from one region to the others.

The Agency for the Cooperation of Energy Regulators (ACER) is an EU agency which was created by the Third Energy Package to further progress the completion of the internal energy market for both electricity and natural gas [11]. When it launched in March 2011, ACER changed the regional initiatives scope to fit a new vision surrounding improved involvement of all Member States and stakeholders that will help the regional initiatives to make a stronger contribution to move from national or regional markets to an integrated IEM [12].

The North Seas Countries Offshore Grid Initiative (NSCOGI) and the Political Declaration on energy cooperation between the North Sea Countries

An example of regional cooperation in the North Sea was The North Seas Countries Offshore Grid Initiative (NSCOGI) which was a framework for regional cooperation to find common solutions to questions related to current and possible future grid infrastructure developments in the North Seas. Under the initiative EU Member States are encouraged to work together, with energy regulators, the European Commission and Transmission System Operators to explore the potential for the coordinated development of offshore grids in the North and Irish Seas.

The NSCOGI was formed as the responsible body to evaluate and facilitate coordinated development of a possible offshore grid that maximised the efficient and economic use of those renewable resources and infrastructure investments. The Memorandum of Understanding (MoU) was signed on 3 December 2010 by the 10 countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and Sweden, and later also the UK) (Figure 3) around the North Seas represented by their energy ministries, supported by their TSOs, organised in the European Network of Transmission System Operators for Electricity ENTSO-E), their regulators (organised in the Agency for the Cooperation of Energy Regulators ACER) and the European Commission, together forming the "North Seas Countries' Offshore Grid Initiative (NSCOGI)". This was the first time that these different stakeholders joined forces, which at the time, indicated the topic's importance on the European energy agenda.

Figure 3. NSCOGI study area

The aim of the NSCOGI was to establish a strategic and coordinated approach to improve current and future energy infrastructure development in the North Seas, with particular focus on the connection of offshore wind, onshore grid reinforcements and cross-border capacity.

The initiative aimed at coordinating all efforts towards necessary investigations on a) technical and grid planning questions, as well as b) identifying market and regulatory barriers and c) proposing measures to streamline the permitting process, in order to assess the economic interest of offshore grid development.

The overarching objective was broken down into a set of deliverables to be taken forward, initially for a two year period, by three Working Groups (WGs): WG1 – grid implementation, WG2- market and regulation and WG3 - permissions and planning.

WG3 which is focused on planning is of most relevance to the NorthSEE project and this report. The final report from WG3 identified differences between planning procedures but no incompatibilities between countries to integrated cross-border grid infrastructure development. It also identified solutions to improve coordination between countries and harmonise the permit process by considering country pairings for interconnection. The country pairings were compared and analysed in terms of their planning procedures and consent activities and this allowed common solutions and best practices to be shared.

The NSCOGI has shown the importance of cooperation between Governments, the European Commission, Regulatory institutions and TSOs for the development of a common understanding of future requirements and possible routes and barriers. Continuation of the Initiative was therefore recommended in order to further investigate the requirements of a 2030 grid. Since the North Seas are recognised in the infrastructure package as being one of the priority corridors and expected to supply a significant volume of RES up until 2030 and onwards, the Political Declaration on energy cooperation between the North Sea Countries was initiated as a continuation of the NSCOGI. The same NSR countries have agreed to further strengthen their energy cooperation, to improve conditions for the development of offshore wind energy in order to ensure a sustainable, secure and affordable energy supply in the area. The declaration will support the development of this priority corridor. The initiative focuses on building of missing electricity links, allow more trading of energy and further integration of energy markets and reinforcing regional cooperation which will help reduce greenhouse gas emissions and enhance security of supply in the region.

In terms of MSP and development and regulation of offshore grids and other offshore infrastructure, participating countries have agreed to work on from 2016 to 2019 [6]:

MSP

- Coordinating the planning and development of offshore wind and grid projects beyond national borders including area mapping;
- Developing a common environmental assessment framework;
- Increasing the availability and interoperability of marine data for planning, impact assessment, licensing and operations; and
- Exchanging best practices on permitting procedures and work on the modalities of a coordinated permitting process for concrete regional or sub-regional joint offshore projects.

Offshore grid development

- Improving the coordination of regional and point-to-point grid planning and development, promoting projects with regional benefits and exploring models of cost allocation (i.e. compensation), to help generate win-win options for concrete (sub)regional cooperation;
- Exploring options for developing hybrid projects linking offshore windfarms with interconnectors; and
- Exploring potential synergies with the conventional offshore sector, including operational cooperation and the electrification of platforms.

European Network of Transmission System Operators (ENTSO-E)

ENTSO-E represents 42 electricity transmission system operators (TSOs) from 35 countries across Europe. It was established and given legal mandates by the EU's Third Package for the Internal Energy Market in 2009, which aims at further liberalising the gas and electricity markets in the EU.

TSOs are responsible for the bulk transmission of electric power on the main high voltage electric networks. They provide grid access to the electricity market players (i.e., generating companies, traders, suppliers, distributors, and directly connected customers). In many countries, TSOs are in charge of the development of the grid infrastructure e.g. Belgium, Denmark, the Netherlands and Germany. TSOs in the European Union internal electricity market are entities operating independently from the other electricity market players.

There are four Trans-European Networks for Energy (TEN-E) electricity priority corridors which are focused on regions. The North Sea region is covered by the North Seas Offshore Grid 10 Year Network Development Plan (TYNDP) Regional Insight Report.

In the TYNDP 2018 report, there are three separate scenarios for the year 2030 which reflect different possible pathways to meet future EU decarbonisation targets, but all have common themes with regards to renewable generation. The three scenarios include:

1. Sustainable Transition (ST) – this scenario is achieved by replacing coal by gas in the power sector, leading to quick and economically sustainable CO_2 reduction. There is also steady growth of RES.
2. Distributed Generation (DG) – this scenario represents a more decentralised development with focus on end user technologies e.g. smart technology, electric vehicles, battery storage systems etc. There is also an efficient usage of renewable energy resources at the EU level.
3. Scenario "EUCO 2030" – this scenario is designed to reach the 2030 targets for RES, CO_2 and energy savings, taking into account current national policies, like German nuclear phase out. The EUCO 30 models the achievement of the 2030 climate and energy targets and includes an energy efficiency target of 30%.

With relevance to this report, the main scenario result is that there will be large increases in wind and solar generation from 2016 to 2025 and on to 2030, with the DG scenario seeing the highest installed capacity.

BEAGINS - Baseline **E**nvironmental **A**ssessment for the **G**rid in the **I**rish and **N**orth **S**eas

The European Commission ordered a Baseline Environmental Assessment Study called BEAGINS to ensure that environmental concerns and impacts are appropriately considered in the development of an offshore energy grid system in the

North and Irish Seas. Focusing on Belgium, Denmark, Germany, Ireland, the Netherlands and the United Kingdom, the study aimed to compile an environmental baseline including maps, constraints, risks, impacts, ways of mitigation and alternatives. The Baseline Environmental Report has determined the effects (positive and negative) of several future energy and grid scenarios for 2030. The scenarios included:

1. High Renewables: This scenario refers to a high level of offshore renewables deployment, combining multiple sources. The offshore wind capacity development (2015) is based on the European Wind Energy Association (EWEA) 'High' wind energy scenario for 2030. The wave and tidal capacity is based on the European Commission (EC) Energy Roadmap 2050 'High Renewable Energy Source' scenario combined with the country-specific offshore energy roadmaps of Ocean Energy Services (OES) and an IEA Technology Initiative.
2. PRIMES Reference: This scenario is similar to NSCOGI scenario, but presents a stronger deployment of offshore wind energy development.
3. NSCOGI: This reference scenario was developed in 2011 by The North Seas Countries' Offshore Grid Initiative (NSCOGI) in collaboration with the TSOs, governments and regulators. In this scenario, the year 2020 is based on ENTSO-E EU2020 scenario, following the national RES targets defined. The 2030 scenario is based on the PRIMES model, and was adjusted to take into account the views of national authorities.

The recommendations of the study included suggestions relating to development of an appropriate planning framework; coordinated infrastructure roll-out; development of an appropriate management framework; data management and storage; development of best practice guidance; and monitoring and data requirements. Overall, the study recommends a meshed grid solution as the reduced footprint of nearshore cabling utilising the meshed solution has greater potential, in combination with sensitive siting, to reduce habitat displacement and avoid sensitive coastal sites [23]. The results can be used to inform any future plans for renewable energy generation, energy storage, electricity cables and associated equipment in the North and Irish Seas. Available as a resource to the relevant Member States and stakeholders, it has allowed for commonly agreed environmental baselines to be incorporated into the assessment of plans, programs and projects early in the policy, design or planning processes.

PROMOTioN – Progress on meshed HVDC offshore transmission networks

The project 'PROgress on Meshed HVDC Offshore Transmission Networks' (PROMOTioN) [9] applied in 2015 for funding under the EU Horizon 2020 (H2020) programme call 'Competitive Low-Carbon Energy' 5 (LCE 5). Within the framework of modernisation of the European electricity grid, this call focused on advancing innovation and technologies relevant to the deployment of meshed off-shore HVDC grids. Its specific objective is to pursue an agreement between network operators and major equipment suppliers regarding a technical architecture and a set of multi-vendor interoperable technologies in order to accelerate HVDC grid development. A regulatory and financial framework will be developed for the coordinated planning, construction and operation of integrated offshore infrastructures, including an offshore grid deployment plan (roadmap) for the future offshore grid system in Europe.

PROMOTioN is the biggest energy project in the EU's Horizon 2020 Research Program and includes 33 partners from 11 countries. All NSR countries are involved in this project and have contributed major HVDC manufacturers or TSOs, along with several wind turbine suppliers, offshore wind developers, as well as leading academics and consulting companies.

PROMOTioN addresses the following objectives:

- Identify requirements for energy infrastructure priority corridors
- Facilitate agreement among operators and manufacturers
- Demonstrate cost-effective HVDC grid technologies
- Prepare the first phase for deployment of innovative compounds
- Propose market rules and revenue streams
- Propose regulations for permitting and environmental compatibility

1.7. Drivers and barriers

To achieve the ambitious climate and energy goals set by the EU and national governments in their respective jurisdictions is the over-arching driving force behind the need to improve offshore grid and cross-border electricity interconnections. This is coupled with the growth of the offshore wind industry, the need for increased energy generation and distribution and the desire for EU internal energy market integration which has driven the European Commission to invest and adapt European energy infrastructure for future needs. The desire for more secure, sustainable and affordable energy for all European consumers is also a major driver for improvements to energy infrastructure.

The main transnational drivers that are relevant for NSR countries are interconnection demand and increased grid connection points. These will facilitate not only the flow of offshore renewable energy back to National onshore grids but also flow of energy across borders. There are also numerous benefits of an offshore grid such as allowing countries such as the Netherlands, Germany and the UK, to develop portions of their EEZ's that are further from shore, increasing their potential installed capacity [5]. These are driving the need for improved transnational maritime spatial planning and coordination between NSR countries on transnational aspects.

In terms of barriers to grid development, grid connectivity and grid integration cause issues. Increasing energy production offshore, in particular offshore wind, will require more cables to transfer energy back to the grid. In turn, leading to an increasing demand for grid connection and some landfall points around the NSR are already at full capacity. There is also a mismatch between onshore and offshore energy sectors and their subsequent technical guidelines and standards for grid integration and connection. These are key barriers to the large scale deployment of offshore energy. Technology limitations can also act as a barrier to grid development, for example, the previous WP5 '*Status quo* report on offshore energy planning provisions in the North Sea Region' discussed the trend of offshore wind farms moving further offshore or becoming floating wind and these longer distances will require longer and more expensive HVDC cables.

The current grid infrastructure is also a barrier to the development of wave and tidal energy projects. The issue being that Europe's high wave and tidal energy resource areas are in locations where the grid infrastructure is severely lacking, making development a costly and difficult challenge for developers. The issue is two-fold as regulators are hesitant to facilitate grid connections without the guarantee of projects to connect and fully exploit them but on the other hand, wave and tidal projects cannot get financial investment due to uncertainty with grid connection. Grid integration issues are therefore likely to hinder the development of wave and tidal pilots and early arrays, bringing the future progression of the ocean energy industry to a severe halt. However, the Commission's Directorate-General for Energy is exploring combining Horizon 2020 funding for demonstration projects with structural funding for grid connection upgrades [8]. An example of one of these projects is the PROMOTioN project which is included in more detail in section 2.3. This may present a novel solution for removing grid barriers from pilot arrays. Another barrier effecting ocean energy is the recent trend of decentralisation of energy which means that energy is produced close to where it will be used, rather than at a large plant elsewhere and sent through the grid. This may increase security of supply but it discourages the need to improve the grid. This is a particular issue for small-scale ocean energy, for example, which is dependent upon grid connections to energy centres.

Barriers to present and future increase of cross border energy exchange and trade of power between the NSR countries is the shortage of interconnection development and capacity. This barrier will need to be addressed in order to meet EU interconnection targets for 2020 and 2030.

Chapter 1 Summary

- Growth of offshore wind and increased demand for energy distribution is a main driving force for the development of a North Sea offshore grid.
- There is an increasing need to understand the current and future spatial needs of more submarine cables.
- EU desire for more secure, sustainable and affordable energy.
- It is the EU’s ambition to create a fully-integrated internal energy market where energy flows freely across borders
- Grid connectivity and grid integration are barriers to offshore grid development
- Decentralisation of energy will cause a barrier to the development of ocean energy projects

2. Status Quo of Offshore Linear Energy Infrastructure and MSP in the NSR

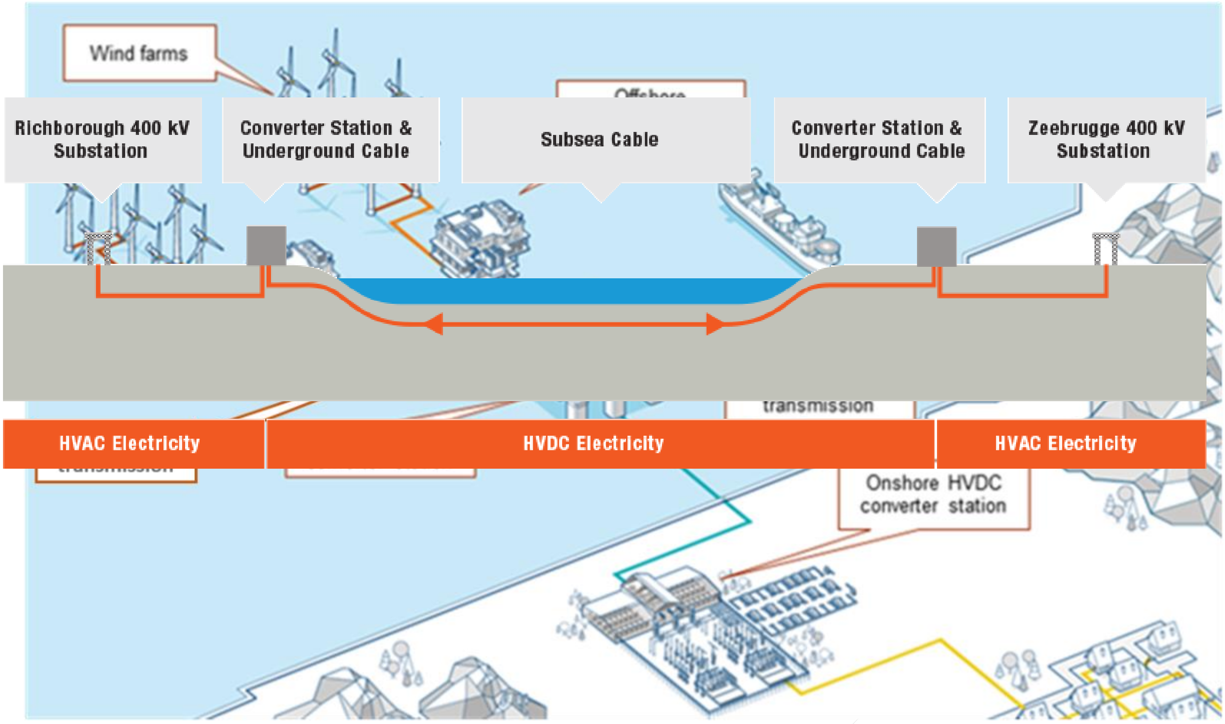
This chapter provides an overview of existing offshore linear energy infrastructure in the NSR including transmission assets for offshore wind, interconnectors, landfall points and national connection points. The current levels of North Sea interconnection are highlighted along with the current ‘Projects of Common Interest’. Also as part of this chapter, planning provisions and spatial and technical planning criteria related to grid and cables have been collected from project partners and summarised. Full country profiles on grid planning provisions can be found in Annex 1.

2.1. Existing offshore linear energy infrastructure and grid connections

For maritime spatial planning it is important to consider the routing of existing and planned subsea interconnectors and offshore wind connections in the NSR. These types of offshore linear energy infrastructure can cover more area that the offshore wind farm itself, involves crossing country borders, passing through environmentally sensitive areas and interacting with other marine activities and users.

Transmission assets for offshore wind

Offshore wind farms are connected via transmission assets to the shore which usually consist of array cables to an offshore substation (see Figure 4). The offshore substation acts as a transformer to convert the voltage level of electricity to allow it to be brought to shore via an export cable. The onshore station then transforms that electricity to the required voltage to be connected to the grid. In the German section on the North Sea, converter stations have been built to convert AC from several parks to DC and export to shore over longer distances. For smaller offshore wind farms built inshore, cables can be bundled and run directly to the shore without the need for an offshore substation.



Source: http://new.abb.com/systems/offshore-wind-connections/dc-solutions

Figure 4. Diagram showing the transmission system from wind farms to landfall point via various cables, substations and converter stations. (Source: ABB)

Interconnectors

Electricity interconnectors are the physical links which allow the transfer of electricity across national borders (see Figure 5 for an example of an interconnector transmission system). This exchange of power helps to ensure safe, secure and affordable energy supplies. They also facilitate cross-border energy exchange from areas with surplus production to areas with supply shortfalls. Examples are times of planned or unplanned outages, or during times with low production of renewables, especially wind and solar energy. In terms of the North Sea, interconnections provide a crucial increase in interconnectivity between the smaller and relatively isolated British and Irish power systems (with already high shares of wind generation), the hydro-dominated Scandinavian systems, and the Continental European countries going through a rapid conventional-to-renewables shift.

Table 1 shows an inventory of existing transnational electricity interconnectors in the North Sea which are fully commissioned. Currently (as of March 2019) there are 11 fully commissioned interconnectors. Also as shown, Denmark is the most popular country to connect to due to its large share of renewable energy.

Figure 5. Diagram showing a typical interconnector transmission system. This is an example of the Nemo Link between the UK and Belgium which is under construction.

Table 1. List of existing North Sea transnational electricity interconnectors

Name	Capacity	Country 1	Country 2	Status
Skagerrak 4	700MW	Norway	Denmark	Fully Commissioned
BritNed	1000MW	UK	Netherlands	Fully Commissioned
Norned	700MW	Norway	Netherlands	Fully Commissioned
Baltic Cable	600MW	Germany	Sweden	Fully Commissioned
Kontek	600MW	Germany	Denmark	Fully Commissioned
Skagerrak 1 and 2	500MW	Norway	Denmark	Fully Commissioned
Konti-Skan 1	380MW	Denmark	Sweden	Fully Commissioned
Konti-Skan 2	360MW	Denmark	Sweden	Fully Commissioned
Bornholm	60MW	Denmark	Sweden	Fully Commissioned
Oresund 132kV	1,350MW	Denmark	Sweden	Fully Commissioned
Nemo Link	1,000MW	UK	Belgium	Fully Commissioned

NSR interconnectors are visualised in Figure 6 where they overlap offshore wind farms. The map shows both interconnectors and offshore wind farms at different development stages to give a current and future overview of offshore linear energy infrastructure in the NSR, excluding export cables and oil and gas.

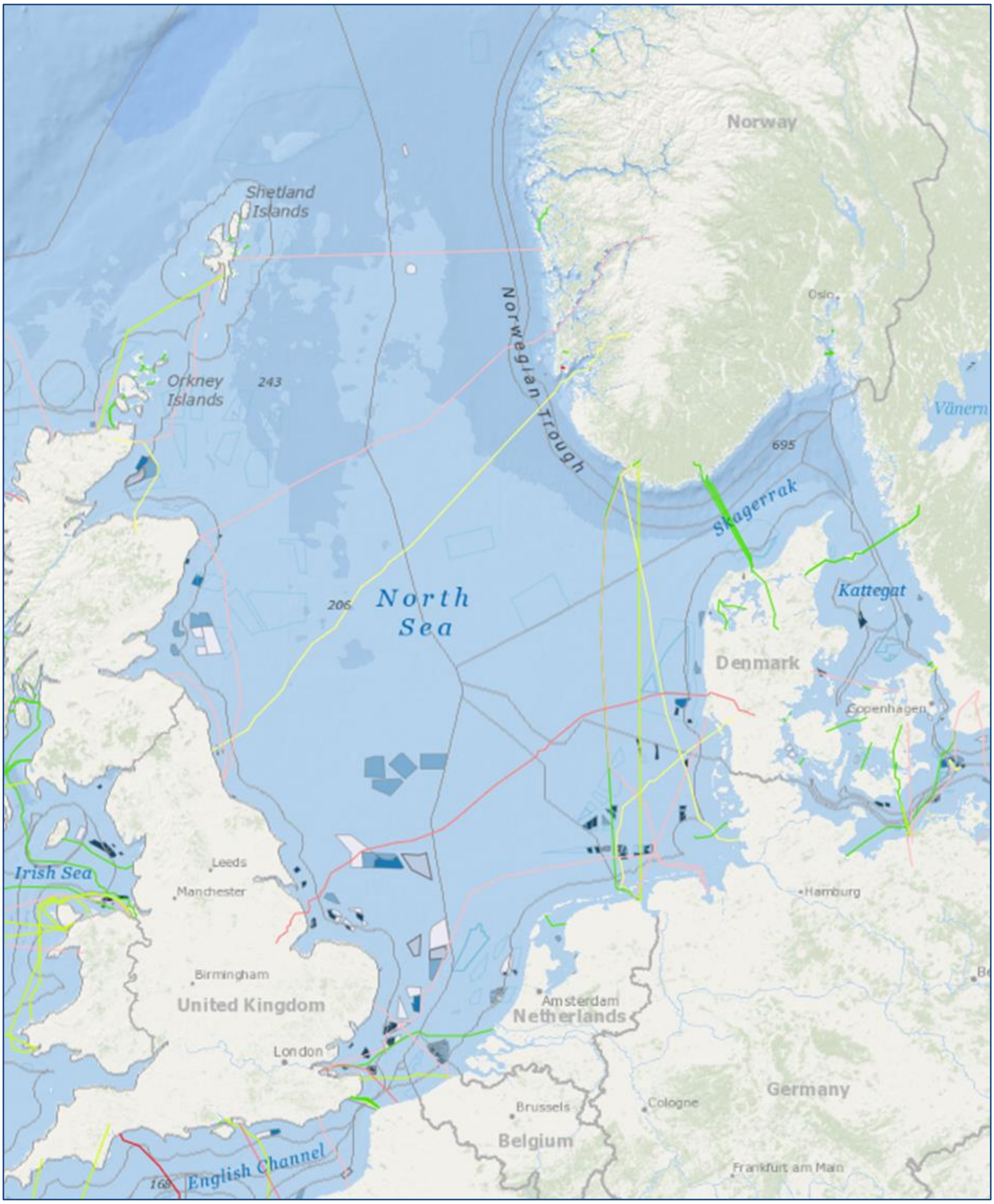


Figure 6. Map of NSR interconnectors overlaying the offshore wind farm dataset. Source: 4COffshore

Land fall points

Landfall points are locations where cables come onshore to connect to the grid and in the North Sea, these are in high demand and are already limited in capacity. There is also a variety of factors which make it challenging to identify appropriate locations for large converter stations and sites to connect to the grid such as offshore environmental and geophysical constraints and onshore planning permission. In Scotland for example, there are only two landing points to facilitate North Sea connections, Peterhead and Cockenzie. However, Peterhead is already very full and Cockenzie is situated in a challenging location and therefore an unlikely connection point. The next available connection point is Hull in England. In Germany some landfall points are currently used in Lower-Saxony and Schleswig-Holstein. They have still some capacities, however they are limited. Landfall points across the NSR can be seen in Figure 7.

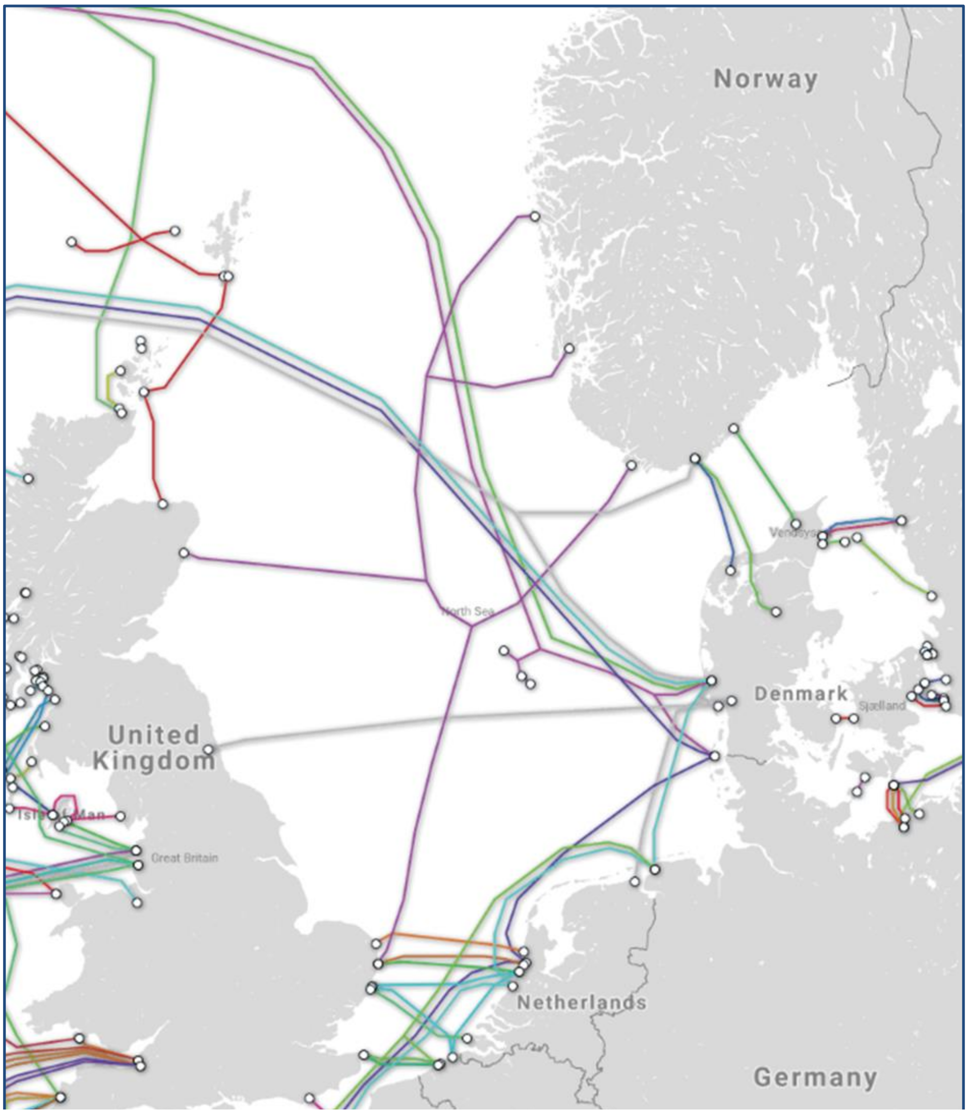


Figure 7. Map of NSR landfall points including interconnectors. Source: submarinecablemap.com

National connection points from EEZ to territorial waters

As part of their Spatial Offshore Grid Plan, Germany has designated a series gates which act as connecting points for cables to travel through from their EEZ to TW. Every cable or pipeline has to use gates for crossing the border. This has a bundling effect to reduce the use of space and also minimise the demand for landing points.

2.2. North Sea Region interconnection

The North Sea as a region is a net exporter of electricity where energy is exported to meet demands outside the region. In terms of country size, the Netherlands is the greatest exporter of electricity with also Germany being a big exporter. In terms of importing electricity, the UK and Belgium are the greatest importers. However it should be noted that this does not necessarily mean that they rely on energy from other countries. Prices of neighbouring markets are lower making it more economic to import than to produce electricity with their more expensive national generators.

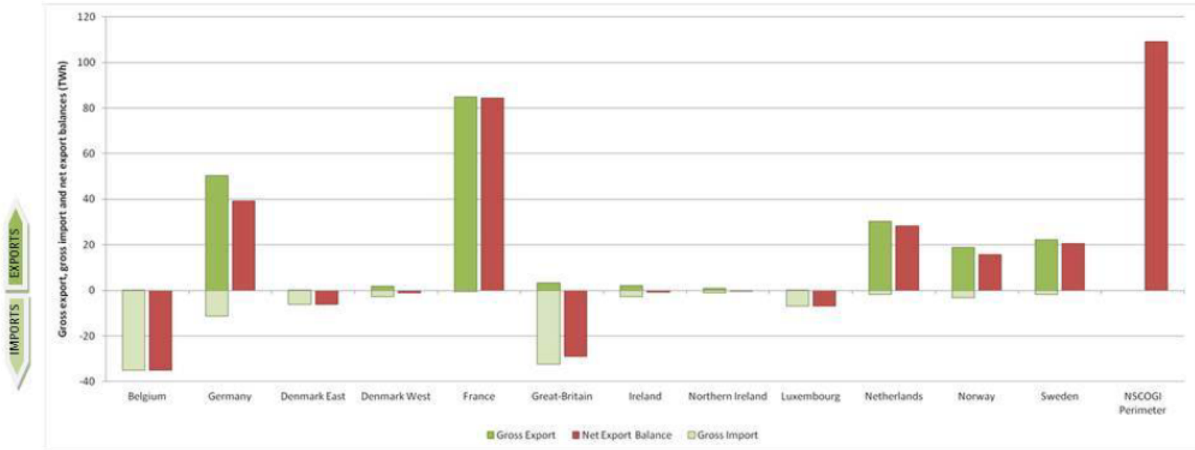


Figure 8. Import/Export balance in TWh by NSR countries and other countries in the NSCOGI Reference Scenario for the year 2030 with grid 2020 capacities (North Seas Grid Study, NSCOGI 2012).

In terms of interconnection and energy sharing, the latest report on the state of the Energy Union (23 November 2017) found that 11 Member States have not yet reached the 10 % electricity interconnection target, including Germany and the United Kingdom as NSR countries, so now need to step up their efforts (see Table 2) . In any case, the Commission predicts that only four will be unable to reach the 10 % interconnection target by 2020 and this includes the United Kingdom [13].

A well interconnected grid is crucial for sustainable development and decarbonising the energy mix as it enables the grid to accommodate increasing levels of variable renewables in a more secure and cost-efficient way. Relying on renewable sources for a greater part of the generation mix contributes to meeting the EU climate goals, by reducing CO_2 emissions, and moreover increasing security of supply. Higher interconnections are also essential to meet the EU ambition to be world leader in renewable energy, which is not only a matter of a responsible climate change policy but also an industrial policy imperative.

Table 2. Interconnectivity levels for electricity in NSR countries (except Norway) in 2017 (European Commission 2017).

NSR Country	Interconnection levels in 2017
BE	19%
DK	51%
DE	9%
NL	18%
SE	26%
UK	6%

Interconnection in NSR countries was also compared based on their interconnection capacity in terms of number of cables existing now that are fully commissioned, cables that are under construction, and future planned cables. Figure 9 shows that Denmark has a large amount of interconnection capacity, which is deemed crucial in facilitating the large share of wind power in the Danish generation mix. It currently has the most interconnector cables compared with other North Sea countries and can therefore be deemed to have a higher level of energy security. The least interconnected country is Belgium with the fewest existing and planned interconnectors between countries. Sweden and Norway are beginning to catch up in the medium term and the UK and Germany have more planned interconnectors in the future. The UK has relatively poor levels of interconnection. This is partly explained by its geographic position as island states. Interconnectors to Norway are particularly popular. This can be explained by the country's high share of flexible, low-cost hydro power generation capacity and pumped storage facilities to accommodate increasing shares of intermittent renewable electricity production.

Benefits of interconnector expansion are the increase in cross-border trade capacity, resilience of grid and able to cope with variable renewable electricity production.

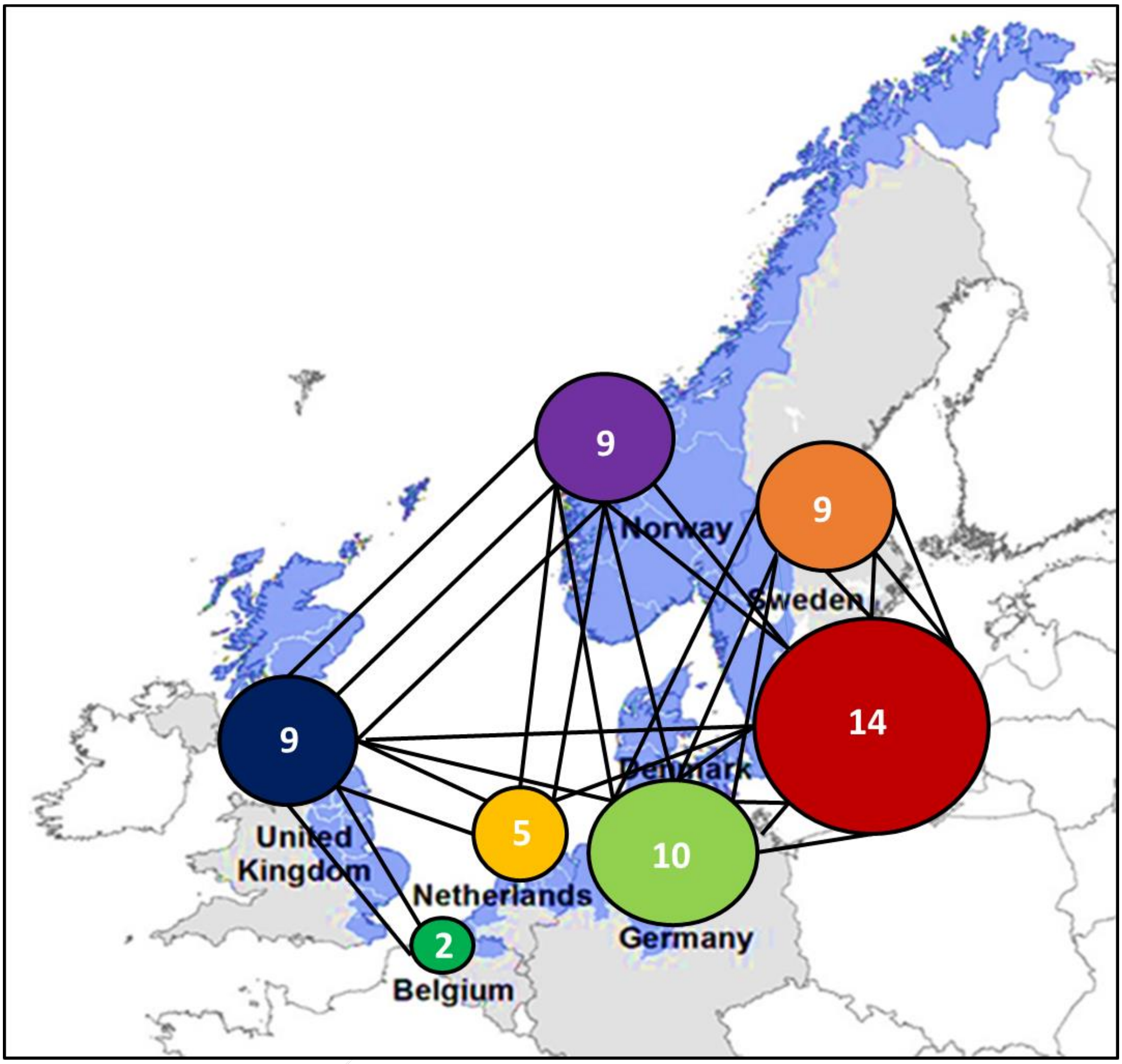


Figure 9. Existing, under construction and future planned electricity interconnectors in the North Sea. Circle and number representative of number of interconnectors.

Projects of Common Interest and Trans-European Networks for Energy

In order to obtain the 15% interconnection target, Projects of Common Interest (PCIs) in energy infrastructure were proposed as the method of implementation. PCIs are key cross border infrastructure projects – selected every two years - that link the energy systems of EU countries. They are an important EU tool for accelerating the deployment of energy infrastructure and ensuring the delivery of secure, clean and affordable energy across European borders [18].

The project must have a significant impact on energy markets and market integration in at least two EU countries, boost competition on energy markets and help the EU's energy security by diversifying sources as well as contribute to the EU's climate and energy goals by integrating renewables. The selection process gives preference to projects in priority corridors, as identified in the Trans-European Networks for Energy (TEN-E) strategy. PCIs located in the NSR can be seen in Figure 10 and are as follows:

- NorthConnect (Scotland to Norway)
- North Sea Link (UK to Norway)
- COBRAcable (Denmark to Netherlands)
- NordLink (Germany to Norway)
- Viking Link (Denmark to UK)

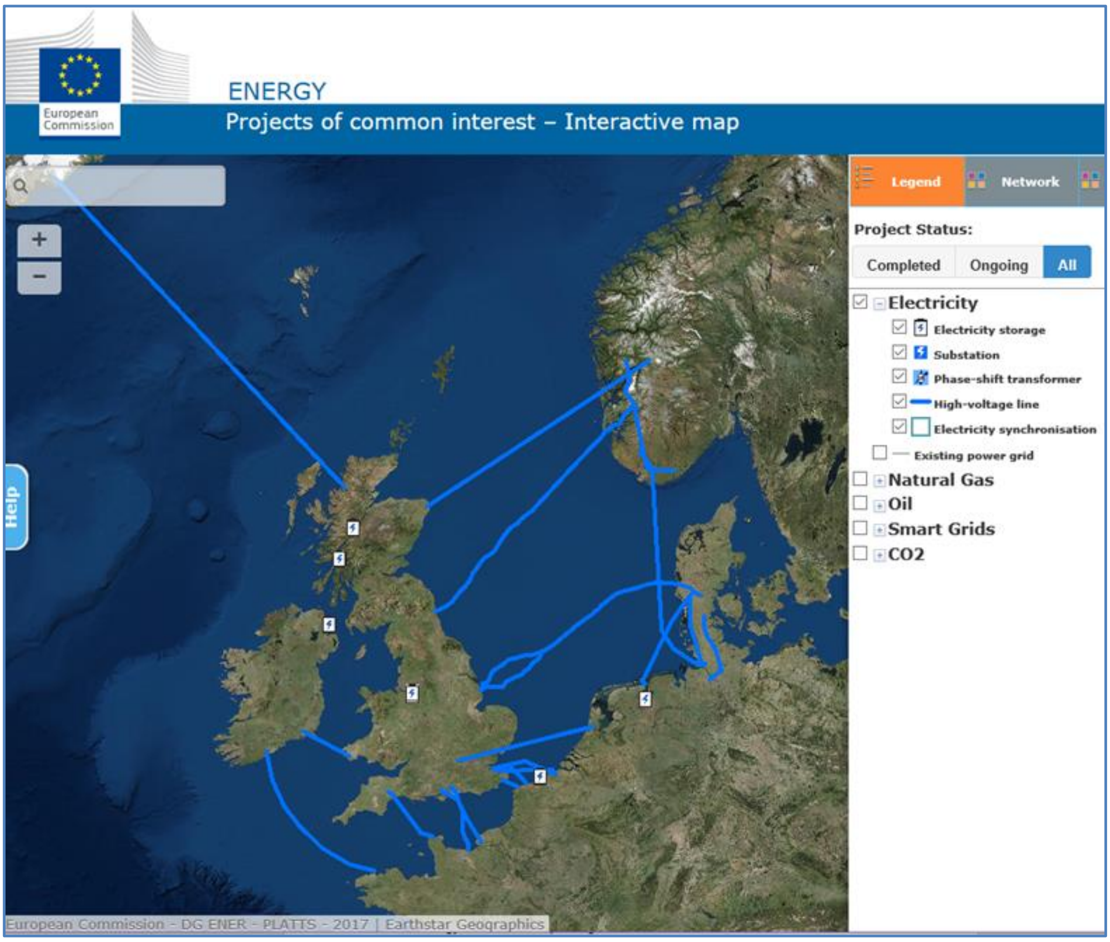


Figure 10. Projects of Common Interest in the NSR. Source: European Commission

The swift implementation of the PCIs will be necessary for the connection of the European energy markets and is one of the political priorities in 2018, as many of these infrastructure projects are orientated towards improving electricity interconnection between the Member States.

2.3. Planning and licensing

Planning for grid infrastructure in the North Sea is currently largely nationally focused with limited transnational coordination. This is reflected in energy infrastructure which is largely disconnected [19]. Differences also exist in planning provisions and processes which becomes more apparent when planning for interconnectors which are transnational in nature. Cables connected to offshore renewable developments are naturally linked to the offshore energy planning processes, however other cables such as interconnectors appear to be either planned for separately or not planned for at all. In countries such as Germany, Belgium and the Netherlands, there are designated cable corridors or priority areas for cables which are Government-led, however in Scotland, for example, cable routes are located by industry and then approved by planning and licensing authorities.

North Sea countries are also at different stages of grid planning and this may be explained by different spatial needs for planning. For example, Germany has a more established and focused approach to grid planning where they have created an offshore grid development plan which explores scenarios for offshore grid expansion. This plan covers installations until 2025 and will then be replaced by the offshore spatial development plan. The new plan will be a more comprehensive planning tool which brings spatial and chronological planning of offshore wind farms and grid connections together. The goal of the plan will be to spatially coordinate the existing and future grid infrastructure, particularly in view of the offshore wind farm grid connections in the EEZ, within the parameters given, and to define them in the interests of forward-looking and coordinated overall planning**.** The plan contains cable routes for interconnectors which are routed through specific gates which link German's EEZ and to their national as well as international waters. As well as corridor and gates, the German plan also includes descriptions of possible cross connections. Planning for cables also features in The Netherlands 2016-2021 Policy Document on the North Sea and Scotland's National Marine Plan. However, the Netherlands and Scotland's approach to grid planning is less established than the German approach and only features as a chapter rather than a dedicated grid plan. Considering MSPs under preparation, for example Sweden and Denmark, not all plans include regulations for offshore energy cables. Swedish MSP has a more guiding character and therefore does not include any spatial rules for electricity cables. Denmark is at a very early stage of their MSP and have not yet decided how to treat electricity cables in their national MSP.

In terms of transnational cooperation of planning, which is limited, Germany takes into account plans of cross-border subsea cables in its grid plan.

Grid development is one of those maritime industries that infrastructure crosses the land-sea boundary where land planning is just as important as planning in the sea. In order to support the increased energy generated from windfarms, Germany are also carrying out grid improvements on land. They are re-designing their electricity cables and creating new connection points to account for the higher energy demand in the south of the country.

In terms of licensing for cables, this is often split between national waters and EEZ where differences apply due to different legislation. This is the case for Germany and Scotland. However the procedure for planning and licensing cables within EEZ and national waters and cross border is the same in the Netherlands. There are also various licences granted such as a construction licence and a transmission licence and transmission is usually dealt with by a designated Transmission System Operator (TSO). The TSO is responsible for providing safe and reliable energy supply. Germany and The Netherlands share the same TSO, called TenneT, who are the first European cross-border grid operator.

TSO's are important in grid planning in the NSR as some countries such as Belgium, Denmark, the Netherlands, Germany and Norway, TSOs are in charge of the development of the grid infrastructure. Differences exist NSR countries between TSO models where for example, the UK has a 'third-party model' and Germany has a 'German TSO model' [21].

The UK decided to organise tenders to allow third-parties, Offshore Transmission Owners (OFTOs), to compete for the ownership and operation of offshore transmission assets. The main reasons for doing so are to deliver cost efficient investments, attract the necessary fresh capital and bring in technical expertise. The OFTO regime has been in place since 2009, before offshore wind farm grid connections were built, owned and operated by the wind farm owners themselves. Because of unbundling requirements, the offshore generation developers could no longer hold both generation and transmission assets. However, in the current regime, developers of offshore generation projects may still choose to either build the transmission assets themselves or to let the OFTO be in charge of the construction. In terms of planning and coordination, the approach followed where OFTOs bid for individual assets focusses mainly on achieving value-for-money on a case-by-case basis and does not directly support coordination [21] and this is why coordination has so far been limited. Ofgem, the Government regulator for electricity markets in the UK, is developing measures that will help to enable coordination of offshore transmission networks while retaining the benefits of the competitive offshore transmission regime.

In comparison, in Germany, the offshore connections are constructed, owned and operated by the TSOs. German TSOs first tried the "reactive TSO model". This meant that grid connection was legally guaranteed and was, therefore, not a part of the wind park developers' responsibility. The government obliged the relevant TSOs to provide a guaranteed grid connection, but the TSO in charge of the connections of offshore wind farms in the North Sea faced severe challenges in providing the grid connection, resulting in significant delays. To avoid these delays, Germany worked on a new approach to offshore grid connection, the "proactive TSO model". The developer's right to request connection has been replaced by an objective, transparent and non-discriminatory allocation procedure that allows for transmission assets to be shared across individual wind farms. In terms of planning and coordination, although there were significant coordination issues between the construction of offshore generation and offshore connection in Germany, it can be argued that by making the TSO responsible for the connection offshore grid planning, more specifically the coordination among generation projects, is encouraged [21].

The Danish model, in place since the first significant investments in offshore wind, is very similar to the German ‘proactive TSO model’. Belgium and the Netherlands, both with concrete plans to develop a ‘power socket at sea’, are converging to the German model, only in the UK it is not the TSO who owns the offshore cables but a third party.

In terms of regulatory models for NSR countries, the UK ‘third-party model’, the German ‘TSO model’ and the Swedish ‘generator model’ have been compared in a study by Meeus 2014 [22]. The study aims to test which model is most suitable to support the two ongoing future energy trends e.g. the more towards larger offshore wind farms further out to sea, and the move towards cross-border offshore grid projects. Sweden’s ‘generator model’ has been used in some projects where the offshore wind farm developers are responsible for their own connection to shore. The results indicate that the third party and generator models are better suited to support the evolutions towards larger scale offshore wind farms that are increasingly developed farther out to sea, while the TSO model is better suited to support the evolution towards cross-border offshore grid projects [21] [22]. This means that there needs to be a trade-off between the two as there are currently no existing regulatory models that can fulfil all the requirements. It was suggested by the author that this trade-off has to be made at the regional or EU level because different national regulatory frameworks are incompatible when applied to a cross-border offshore grid project.

Table 3. Comparison table of NSR countries grid planning provisions

Country	Plan	TSO	Spatial areas designated for cables	Spatial & technical planning criteria
BE	Belgium's MSP	Elia	Yes, designated cable corridors	• 250 m min of free space on either side of cable
DK	None, no MSP existing	Energinet	No	• Not decided yet
DE	Offshore Network Development Plan 2017-2030 (till 2025) Offshore Site Development Plan (as of 2026) Spatial Offshore Grid Plan (till 2025)	TenneT TransnetBW Amprion 50Hertz	Yes, cable corridors and gates	• Bundling of cables by parallel routing • Routing via gates • Crossing of priority & reservation areas for shipping by shortest route & right-angled • Routing as far outside Natura2000 areas as possible • Consideration of marine heritage & cultural assets
NL	Integrated Maritime Spatial Policy map and North Sea Policy Document 2016-2021	TenneT	Yes, priority areas for cables	• Ensure efficient use of space and obstruct other users as little as possible • Cables not to impede shipping or fishing • New cables forbidden in anchoring locations • Maintenance zone of 500 m • Bundle cables & routes run in parallel • Cable crossings in shortest & straightest way • Avoid sand extraction zones
NO	None	Statnett	No	• Consider environmental, visual impact, biodiversity, land use and socioeconomic benefits
SE	None, no MSP existing	Svenska Kraftnät	No	• None

SCOT	Scotland's National Marine Plan	National Grid Scottish Power Transmission Limited for southern Scotland and Scottish Hydro Electric Transmission plc for northern Scotland and the Scottish Islands	Yes for offshore renewables, indicative export cable route, but not for interconnectors	• New cables to minimise impacts on environment, seabed and other users • Cable routes checked spatially • Consider flooding & coastal protection policies • Separation distance of 750 m between wind turbines and existing submarine cables • 1 NM cable maintenance vessel safety zone

2.4. Technical and spatial planning criteria

In order to carry out grid planning, it is necessary to develop technical and spatial planning criteria. Technical criteria are rules which apply to the construction or placement of cables which are usually industry standards or determined by marine licence conditions. Spatial planning criteria on the other hand are principles applied to spatial position of cables.

Grid planning differs between North Sea countries, with Germany having well-established planning criteria compared to limited criteria in other NSR countries. There is also a difference between criteria being Government-led or Industry-led. For example, in Germany, the Government have defined planning principles and criteria for both offshore wind farms and for interconnectors in their designated Spatial Offshore Grid Plan, however they both follow similar principles. On the other hand, in Scotland planning principles are classed more as 'rules of thumb' by Industry and adherence to the principles is dependent on risk.

With regard to technical planning criteria for cables, suitability of seabed conditions is one of the most important issues to consider. However, there are solutions to overcome difficult ground conditions when laying cables, it is more a question of the technique of cable laying/cable securing. Techniques such as cable protection measures such as concrete mattresses or rock armour and specific depths for cable burial (for example 1 meter or 1.5 meters depending on risks) are important from the perspective of the shipping and fishing sector. Technical planning criteria for cables also includes the use of HVDC and HVAC technology for different connections as it is relevant for the capacity of the cable and therefore determines the number of cables required to transmit a certain capacity. The technical specification of the grid connection systems of offshore wind farms depends on the distance to shore. For example, longer connections such as wind farms further away from shore or interconnectors are usually HVDC cable systems as they enable transport of electricity over larger distances while featuring lower energy losses. Requirements for bundling of cables as a technical specification is also important in helping to minimise negative effects from magnetic fields on sensitive species.

Besides these technical planning criteria, countries can also determine spatial planning criteria. These can contain restrictions, guidelines or specifications for interconnectors and cables in general. A specific planning principle which is used by most NSR countries is planning cable corridors. However this involves several spatial considerations, for example, space is needed for the cable itself and its laying, for a safety or buffer zone around it to ensure sufficient space for potential repairs and ship manoeuvring, space at cable crossing areas and specific distances in case of parallel routing with other marine uses. Necessary distances between cables and other marine uses depend on the water depth, sites specific ground conditions and technical required distances for cable laying and cable repairs. Regarding the question of appropriate distances guidelines of the International Cable Protection Committee (ICPC) and the European Subsea Cables Association (ESCA) can give helpful advice. As for offshore energy cables, the International Cable Protection Committee (ICPC) recommends that existing cables in shallower waters (up to a depth of 75m) are given a default 500m exclusion zone on either side. The actual distance varies between single countries. In general, offshore renewable energy infrastructure and cable corridors should be integrated whenever possible to maximize concentration of sea uses.

One of the main advantages of spatial planning criteria is to avoid conflict with other marine users, protected or commercially important areas. For example, designated cable corridors are essential in the Netherlands as they need to route their cables around economically important near-shore sand extraction zones. Cable corridors are also useful for encouraging bundling of cables which, in terms of space, is an advantageous planning criteria. Germany and the Netherlands encourage bundling of cables where possible and in Belgium, pipelines are also clustered into corridors. Planning principles also help to select preferred routes for passing through areas such as shipping lanes or fishing areas and can advise cables to be routed to accommodate certain safety distances from shipping lanes or to run in parallel and only cross waterways in the shortest and straightest possible way.

For a full list of countries technical and spatial planning criteria see Annex 1.

2.5. Transnational Interconnector case studies

NorthConnect

Background

The NorthConnect interconnector will have a capacity of 1400 MW, will be 655 km in length and is intended to facilitate the trading of energy with Norway and continental Europe. The interconnector will be routed from Simadalen in Norway, across the North Sea to Long Haven Bay, Peterhead in Scotland (Figure 11).

Norwegian electricity is primarily produced from hydro-electric sources, while Scotland has an increasing proportion of wind power in their energy mix. This interconnector will connect two complementary and previously disconnected power systems, helping both to balance the grid between two countries, encourage international cooperation and allow wider trading across Europe. NorthConnect are aiming for the cable to be operational in 2022.

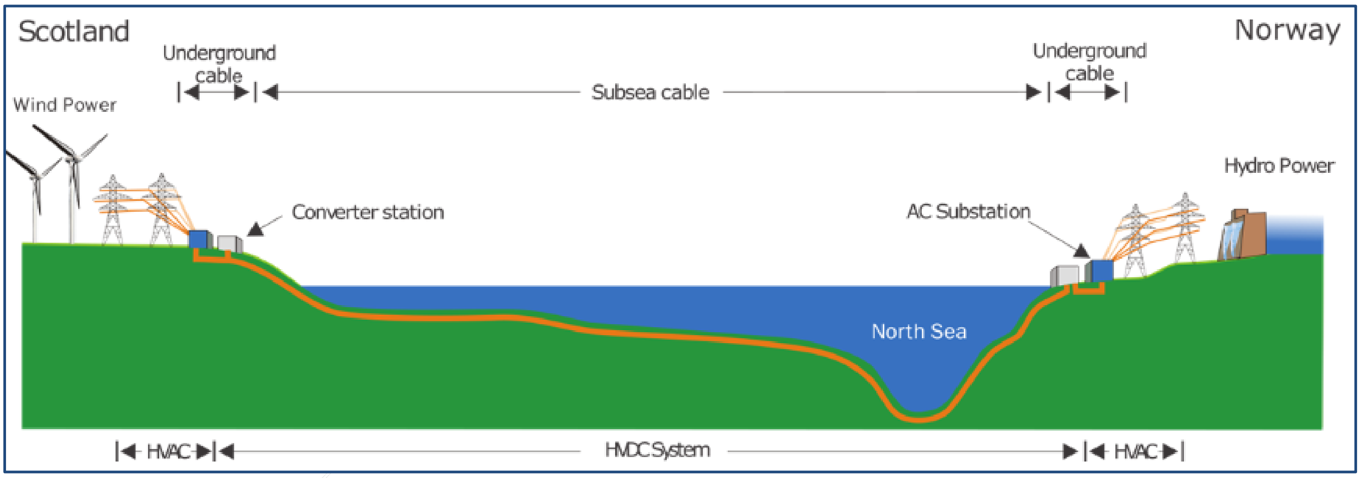


Figure 11. NorthConnect cable route from Scotland to Norway

In 2013 the NorthConnect scheme was designated as a "Project of Common Interest" or PCI, within the legal framework of the European Union and European Economic Area, of which Norway is also a signatory state. This means that NorthConnect is seen as an important project for achieving Europe's energy market and climate change targets. As a result it has been included in the 2014 Ten Year Network Development Plan (TYNDP) for European electricity projects, and is also included on the 2015 list of PCI projects.

Planning and licensing

Differences exist between Scotland's and Norway's planning and licensing procedure and there is no coherence. For example, Norway has 1 consent which covers both onshore and offshore planning whereas Scotland has 2 consents (1 for onshore and 1 for offshore). There are also differences in the timings of the planning and licensing process and in particular for the EIA process where Norway completes their EIA process at the beginning of the planning process compared to further on in the process in Scotland. It was suggested that Norway finds Scotland's planning process very onerous and long, however in comparison, Norway's process may be shorter but suggested to be less clear.

Four potential offshore cable corridors were considered initially and the routes were visualised and mapped in GIS. Data from Scotland's NMPi database and Norway's equivalent database was used. Environmental constraint mapping, technical constraints, safety constraints and economic viability was considered. The following aspects were taken into consideration in the analysis:

- Physical characteristics of the cable;
- Existing infrastructure including pipelines, cables, and offshore installations – excluded from the survey corridor by at least 500 m. Preference for NorthConnect cables to cross existing cables and pipelines at approximately 90 degrees, as opposed to obliquely
- Bathymetry;
- Seabed geology and sediment characteristics – areas of hard sediment types were excluded from the survey corridor where possible
- Commercial fisheries, shipping and navigation;
- Cultural heritage and marine archaeology - wrecks
- Benthic ecology and habitat types; and
- Designated sites and protected habitats.

The final cable route design has yet to be determined but the outputs of the survey will also aid in the identification of offshore cable protection requirements and appropriate installation technique selection. NorthConnect will also carry out an EIA and produce an Environmental Statement to support the planning and marine licensing applications for the cable.

To help mitigate some of the spatial implications, the cables will be buried to a depth of 1.5 meters to avoid snagging with fishing vessel gear, EMF impacts to elasmobranchs and diadromous fish and other magnetic field and compass deviations. The cables will also be bundled into the same trench to reduce development time and environmental impacts. In Scotland, there are no Government-led determined spatial or technical planning criteria – the 250 meter buffer zone at either side of the cable is a rule of thumb set by industry but it is not a technical restriction. Routing decisions are made by the developer and are based on risks to the cable and then approved through the marine licensing process.

The proposed NorthConnect cable route will cross other cables and pipelines in the North Sea and therefore they will follow the International Cable Protection Committee (ICPC) recommendation (No. 3, Issue: 10A) for cable and pipeline crossings (International Cable Protection Committee, 2017). The crossings shall be treated individually during detailed design considering aspects such as regional constraints, requirements from the crossed infrastructure owner, practicalities regarding trenching near the crossing, volume of rock ramps, stability and top cover. The angle between the NorthConnect HVDC cables and the crossed utility shall be as close to 90 degrees as practicable and not be less than 45 degrees for a distance of minimum 200 m from the crossed asset.

Spatial implications

Due to the scale of the development and its proximity to designated areas there is potential for the NorthConnect interconnector to have an effect on the environment. The spatial considerations for each country are quite different due to different geophysical environments. For example, on the Norwegian side, there are unique Norwegian fjords which are very deep (around 800 meters depth) which gives significant technical challenges for cable routing. Underwater rock falls are also common in the fords which can damage the cables. The fjords are also very congested with cables, particularly telecommunication cables which tend to be free-hanging because it is too expensive and difficult to trench them. The location of these free-hanging cables is also poorly recorded and largely unknown, giving routing and navigation issues. Also on the Norwegian side, there are lots of aquaculture farms surrounding the nearshore areas which need to be avoided.

On the Scottish side, the inshore area of the cable route is important commercial fishing grounds including creelers, scallop dredgers and trawling. However a good relationship has been built with the fishing industry and spatial implications are being resolved.

There are also onshore spatial implications which are important to link up the offshore infrastructure. The main issue is locating an appropriate location for the converter station which requires a large space and also locating grid connection points. On Scotland’s east coast, there are only two main sites to physically connect to the grid, Peterhead and Cockenzie. However Peterhead is already over capacity and Cockenzie is a challenging location. This means there is a substantial limit on grid strong points.

Decommissioning

The lifespan of the project is 40 years and the decommissioning plan will be fully developed prior to decommissioning. The likely approach, at a strategic level, will be to remove cables where economically viable, environmentally acceptable and practicable to do so. Due to the value of the metals in the cables it is highly likely that it will be economically viable to remove the cables to allow them to be recycled. Ecological surveys may be required to ensure it is environmentally acceptable, as there is a potential that over 40 years the habitats will have changed and protected habitats or species may have colonised the area.

How MSP can contribute to better cable planning

As suggestions from NorthConnect, MSP can contribute to better cable planning by providing open-access information and data relevant to cable development to allow developers to make good routing decisions. It can also help by identifying more locations for converter stations and onshore connections to the grid.

COBRA cable

Background

The COBRA cable is a 700 MW capacity interconnector between the Netherlands and Denmark. This PCI will have a length of around 325 kilometers between Eemshaven (the Netherlands) and Endrup (Denmark). Figure 12 shows the schematic route of the COBRA cable. It starts in the Netherlands with an existing electricity grid and is connected with a high-voltage substation and converter station. At this stage the cable is a HVAC but then the converter station transforms the electricity from HVAC to HVDC. The electricity comes from the Netherlands to Denmark or vice versa and passes through German territorial waters and the German EEZ. In Denmark there is another converter station, which transforms the electricity from HVDC to HVAC.

This interconnector will benefit both countries as for example Denmark's wind energy can be imported to the Netherlands and there will be an increased energy security. There are also future plans to connect an offshore windfarm with this interconnector. However this may pose some regulatory challenges. Overall, this interconnector will help to meet a key target of the EU, the realization of a sustainable international energy market. It is expected to be commissioned in early 2019.

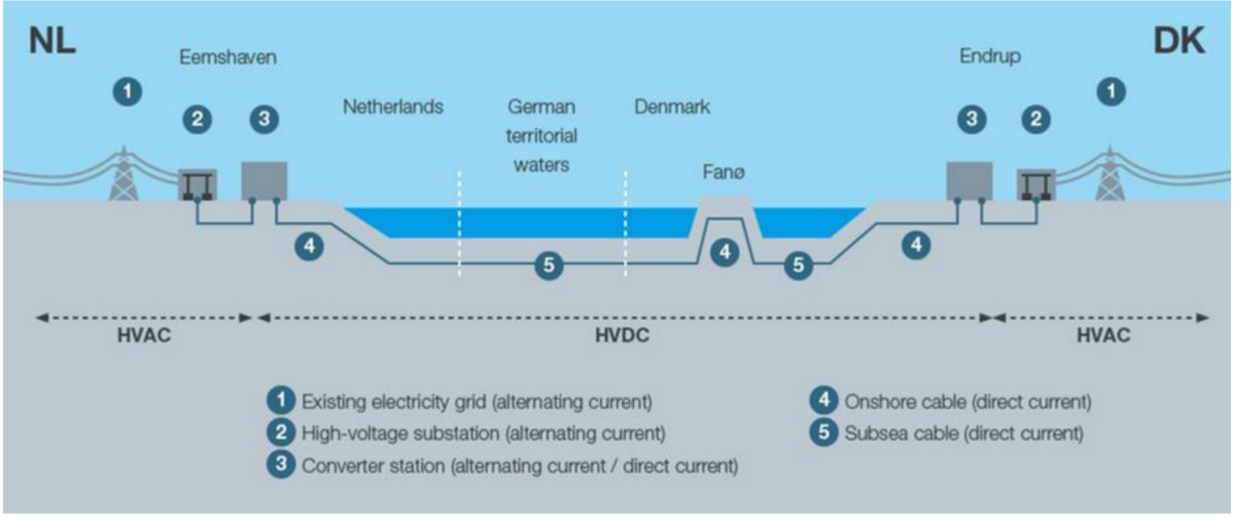


Figure 12. Overview of COBRA cable. Source: TenneT.eu

<u>Planning and licensing</u>

In the German EEZ of the North Sea the project started the approval procedure for the area of responsibility of the Federal Maritime and Hydrographic Agency in 2010 with siting and routing studies. Following this was the first consultation with stakeholders and the public. In 2012 the project sponsor paused the licensing procedure till 2014. When the project started back up, screening and scoping took place as well as some surveys and an EIA. The permit application was then prepared and consulted upon by the public and stakeholders. After a determination period, the permits were granted and a comprehensive decision was received, with this the final investment was decided. Construction then began in 2016.

As this interconnector is routed through three different countries, different key consents and permissions are required. For the Netherlands the key consents and permissions are: marine licence, Nature protection Licence, Exemption from the Species Protection Act (TBC), Seabed Survey Permit (TBC) and a partly EIA. The following permissions are required in the German EEZ: Seabed Survey licence, Mining law (LBEG) and Mining law (BSH), the latter follows the LBEG permit. The following permissions are granted by BSH for the German EEZ: EIA, shipping, fishing and offshore windfarms. In Denmark, consent includes 4 permits (DEA), 4a Offshore permit for installation of marine cable (DEA), 4b Seabed Survey license (DEA), Local planning permissions for onshore competent – municipalities and an EIA Permit for onshore component. This process runs parallel with the 4a (DNA).

For the German EEZ, BSH sent the application to all relevant stakeholders and asked for statements or comments, of which the developer had the chance to respond to. In the process different routing options were analysed, with consideration of the impact for different uses and sectors: shipping, airspace, fisheries, environment with flora and fauna as well animals, cables and pipelines, research, pollution of the sea, security, cultural goods, offshore windfarms and tourism.

Spatial implications

The transnational route of this cable will lead the cable through different territorial waters and EEZ's which is likely to cause spatial implications, however the cable will have to follow the respective principles and regulations of each country. Marine sectors in all countries will also have the opportunity to raise their concerns about the planned routing and how it might impact them.

Chapter 2 Summary

- Ambitious offshore grid initiatives and projects in the region are ongoing.
- Member states need to reach a level of 10% interconnection by 2020 and 15% by 2030 by developing further interconnection capacity, enabling the integration of renewables and improving transnational cooperation in order to meet this target and ensure energy security.
- Denmark has the largest amount of interconnection capacity and Belgium has the least.
- Projects of Common Interest (PCIs) are an important EU tool for accelerating.
- There are no incompatibilities between countries to integrated cross-border grid infrastructure development.
- Planning for grid infrastructure in the North Sea is currently largely nationally focused with limited transnational coordination.
- Germany has the most established and focused approach to grid planning compared to other NSR countries.
- Differences exist between grid planning principles and criteria being Government-led or Industry-led.
- Germany, Belgium and the Netherlands designate cable corridors and promote bundling of cables as efficient spatial planning criteria
- Spatial issues for cable routing include avoidance of shipping lanes, offshore energy developments, protected areas, sediment extraction, defence and cable and pipeline crossing.

3. Future trends for Offshore Linear Energy Infrastructure

This chapter aims to identify the future trends for offshore linear energy infrastructure up to 2030 and beyond. A large focus of this chapter is on future interconnection demand within the NSR which is calculated based on current interconnection levels and the EU 2030 interconnection targets. This chapter is closely linked to the future energy trends of offshore wind and the current transition to renewable energy generation which will have a direct impact on future interconnection demand. Other future trends are discussed such as NSR offshore grid plans and technical trends.

3.1. Future interconnector demand

Future interconnectors

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

To accommodate the energy transition and help the region to meet the challenges described before, a large number of projects are required in the NSR. Table 4 shows an inventory of expected and future transnational electricity interconnectors in the North Sea at various statuses from concept and early planning to under construction. As of March 2019, 5 projects are under some stage of construction, 2 in the consent process and 11 at the concept or early planning stage.

Table 4. Inventory of future transnational interconnectors in the NSR

Name	Capacity	Country 1	Country 2	Status	Commissioning
Oresund 132kV Replacement Cable		Denmark	Sweden	Under Construction	?
COBRAcable	700MW	Netherlands	Denmark	Under Construction	2019
NordLink	1,400MW	Germany	Norway	Under Construction	2020
North Sea Link (NSL)	1,400MW	Norway	UK	Under Construction	2021
Viking	1400MW	UK	Denmark	Pre-Construction	2022
Oresund 400kV		Denmark	Sweden	Consent Authorised	?
NorthConnect	1,400MW	UK	Norway	Consent Authorised	2022
NeuConnect	1,400MW	UK	Germany	Concept/Early Planning	2022
NorNed 2	700MW	Norway	Netherlands	Concept/Early Planning	?
NorGer	1,400MW	Norway	Germany	Concept/Early Planning	?
Hansa Powerbridge 1	700MW	Sweden	Germany	Concept/Early Planning	?
Maali	600MW	UK	Norway	Concept/Early Planning	2025

Hansa Powerbridge 2	700MW	Germany	Sweden	Concept/Early Planning	?
UK Belgium	1,000MW	UK	Belgium	Concept/Early Planning	2028
Kontek 2	600MW	Denmark	Germany	Concept/Early Planning	?
Kontek 3		Denmark	Germany	Concept/Early Planning	?
COBRA 2	700MW	Denmark	Germany	Concept/Early Planning	?
UK Netherlands	1,000MW	UK	Netherlands	Concept/Early Planning	2030

Figure 13 shows the projects that are promoted in the NSR for TYNDP 2018. It also shows how the UK and the Nordic region will become much more integrated with the Continental European system in the future. This will facilitate the diverse spread of renewable generation across the region to be fully exploited and shared amongst NSR countries. Figure 13 also shows the additional onshore grid required in Germany to accommodate the larger influx of energy.

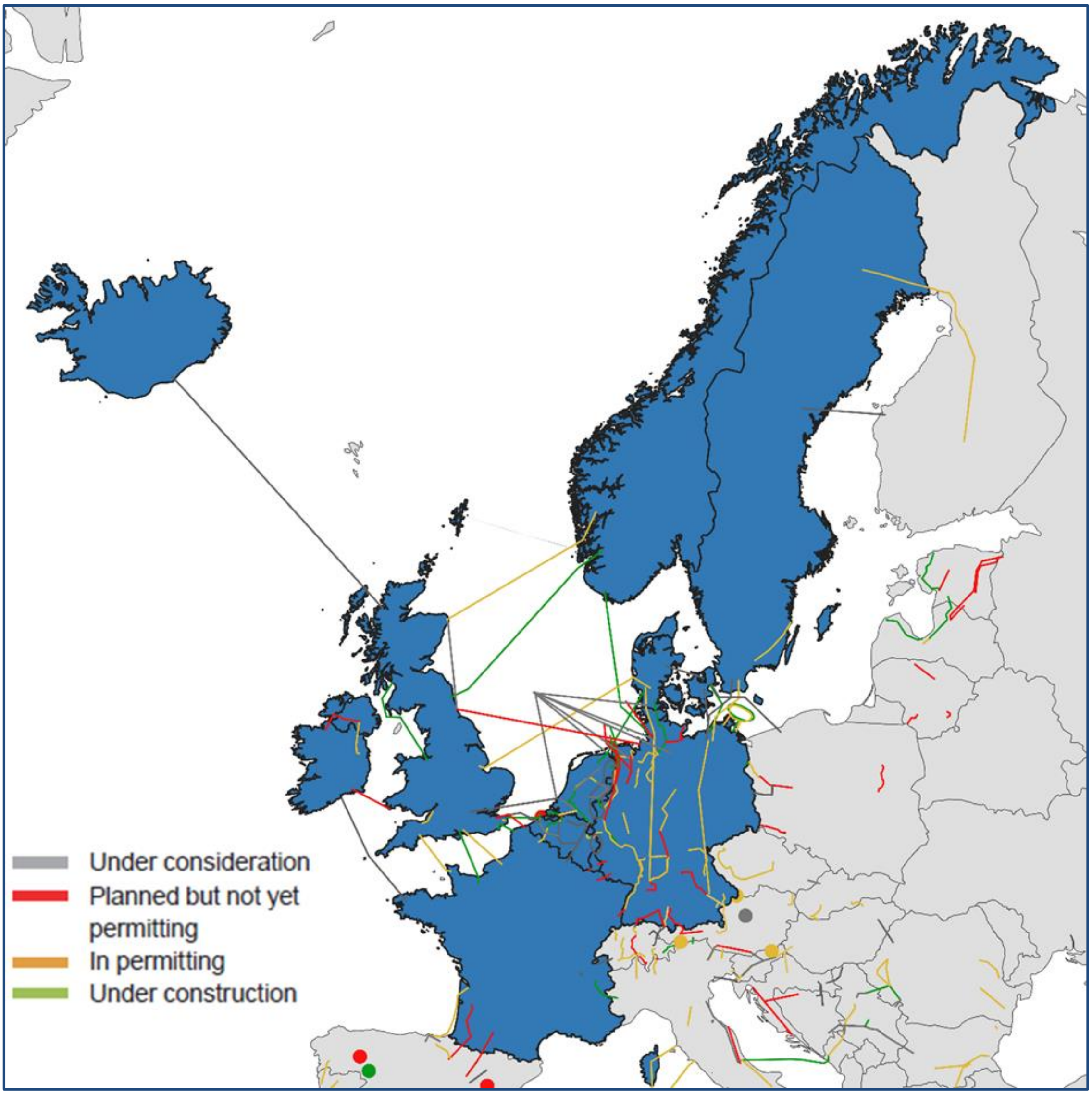


Figure 13. Future interconnectors in the NSR as promoted in the TYNDP 2018

Interconnection levels expected for 2020 and predicted for 2030

The 10% electricity interconnection target has provided political drive to increase interconnection levels through cross-border projects over the last years. All NSR countries have already achieved or are on track to achieve to 2020 target of 10%, except the UK which are not on track and unlikely to meet the target (Table 5) [20].

Table 5. Interconnectivity levels for electricity in NSR countries (except Norway) in 2017 and expected for 2020 (European Commission 2017).

NSR Country	Interconnection levels in 2017	Expected interconnection levels in 2020
BE	19%	33%
DK	51%	59%
DE	9%	13%
NL	18%	28%
SE	26%	28%
UK	6%	8%

The measurement of interconnectivity has been a recently debated topic and it has been questioned if current methods are fit for purpose for calculating future levels. Previously, interconnectivity was measured as a ratio of net transfer capacity to generation capacity and this method was used to calculate the 10% interconnection target back in 2002. However, it has been realised that the 10% target was set in a radically different energy situation where less energy was supplied from renewable sources. At present, the electricity system consists of more variable energy sources such as wind and solar and therefore it was agreed by the Expert Group that a new functional target was needed for 2030 and that the interconnection measurement method also needed adapted.

The Expert Group concluded that the national level of electricity interconnectivity should be measured by taking into account both electricity demand (import need) and supply (export potential). This means putting the nominal capacity of interconnectors in relation to the peak load as well as putting the nominal capacity of interconnectors in relation to the installed renewable generation capacity. The two formulas are therefore as follows:

1) nominal transmission capacity / peak load 2030

and

2) nominal transmission capacity / installed renewable generation capacity 2030

However the Expert Group acknowledge that no single formula can fully reflect the changing energy reality and that they need to be reviewed on a continuous basis.

Using the pre-mentioned recommended calculations, the report of the Commission Expert Group on electricity interconnection targets (November 2017) has calculated predicted interconnection levels by Member States across four visions. However the Expert Group recognise that there is no scientific consensus to measure the "interconnectivity" of Member States with diverse characteristics using a single formula. They consider the 2030 interconnection target as an important and useful policy tool to guide the development of trans-European electricity infrastructure.

Table 6 and Table 7 show the results of these two calculation methods for all NSR countries and Figure 14 is a visual representation of how the NSR countries score on the calculations and the three thresholds mentioned in section 1.5.

Figure 14. Map showing how the NSR countries score on the three thresholds in section 1.5.
Green: meet all three thresholds
Yellow: meet two of the thresholds
Red: meets one or none of the thresholds

Table 6. Interconnection levels by Member State as measured by nominal electricity interconnection capacity to peak load in 2030. The UK is highlighted in red because it is predicted to be below 30% interconnection levels by 2030.

NSR country	V1	V2	V3	V4
BE	83	88	93	88
DK	165	168	161	168
DE	62	65	67	65
NL	122	124	126	124
NO	58	54	53	54
SE	49	51	57	51
UK	8	7	7	7

Table 7. Interconnection levels by Member State as measured by nominal electricity interconnection capacity to installed renewable generation capacity in 2030. The UK is highlighted in red because it is predicted to be below 30% interconnection levels by 2030 and Germany is also highlighted in red in V3 and V4 for being below 30%.

NSR country	V1	V2	V3	V4
BE	97	97	60	68
DK	127	101	77	70

DE	35	41	28	29
NL	206	201	70	94
NO	110	110	89	114
SE	44	44	38	41
UK	11	6	5	5

Based on the two methods to calculate interconnection levels and with reference to the three thresholds mentioned in section 1.5, the Expert Group recommends that countries below the threshold of 30% on any of the two formulas should urgently investigate options of further interconnectors and report annually the results of such investigations. The countries above the 30% but below 60% thresholds on any of the two formulas are requested to investigate possible projects of further interconnectors regularly. In terms of NSR countries, the UK is below 30% on both calculation methods for all four visions (highlighted in red). Germany is below 30% for two of the visions (V3 and V4 highlighted in red) in one of the calculation methods (Table 7).

This reflects the current interconnection situation where the UK and Germany have not yet met the 10% interconnection target for 2020 and from these results, the UK may not reach the 15% interconnection target by 2030. A large step up in interconnector capacity is urgently needed in the UK. The Commission call upon Member States to prioritise the development of interconnections with those neighbours that are below any of these thresholds in a spirit of solidarity and cooperation.

However, despite these results, NSR countries demonstrate considerable differences in terms of their energy mix, size of energy market and geographical location, which influence their interconnectivity potential and needs and makes it challenging to determine future interconnector demand.

Offshore wind and grid scenarios by 2030

WindEurope has created wind energy capacity scenarios for 2030 and detailed them in their report (September 2017) [3]. The report describes three possible scenarios for wind energy capacity installations in 2030: low, central and high. It also highlights the impact of each scenario and recommends the policy and other measures that are needed to deliver the scenarios.

The report predicts that by 2030, under business-as-usual assumptions (without 2030 targets), offshore wind is expected to cover 4% of all EU electricity, rising up to 6.9% with efficient 2030 target implementation and market conditions (energy and carbon) and up to 10.1% with favourable economic conditions and industry efforts [4]. For countries surrounding the North Sea, this would mean 15% of regional demand being covered by offshore resources. This will be a key component in the move toward a fully sustainable electricity system by 2050. The realization of such an expansion in renewable power sources will depend largely on developments in grid infrastructure, amongst other factors.

The main drivers for interconnection development between grids are the expected increase in renewable energy generation and the aim of securing a dynamic internal electricity market. This means that interconnector demand is closely coupled with offshore renewable energy production and in particular, offshore wind. Table 8 shows the three WindEurope 2030 scenarios and the predicted offshore wind capacity in Europe. Also included is the inter-linked grid situation which will be required to realise these scenarios. The Central Scenario predicts that 323 GW of cumulative wind energy capacity would be installed in the EU by 2030, 253 GW onshore and 70 GW offshore. It also assumes significant progress in system integration, allowing a higher penetration of wind energy and other renewables as well as sufficient grid infrastructure to meet the EU's 15% interconnection target. In the Central Scenario, clear policy commitments on electrification drive demand for renewable power.

Table 8. WindEurope 2030 scenarios and grid situation

WindEurope 2030 Scenarios	Predicted offshore wind capacity in Europe	Grid situation
Low	49 GW	No significant progress is made in electricity interconnections between Member States. Grid congestion issues continue to slow down new installations
Central	70 GW	Significant progress on system integration allows for higher penetration of wind energy and other renewables, and power interconnection infrastructure is strengthened to allow

		the EU to reach the 15% interconnection target
High	99 GW	The EU-wide power transmission network is further developed beyond the European Commission's 15% target. Both the new market design and a reformed ETS contribute to the phasing out of inefficient and uneconomical fossil fuels power plants and pave the way for a sustained development of renewable energy

Table 9. Offshore wind power cumulative capacity to 2030 – North Sea countries minus Norway

Country	Low	Central	High
Belgium	1,600	4,000	4,000
Denmark	3,400	4,300	6,130
Germany	14,000	15,000	20,000
The Netherlands	4,500	11,500	18,500
Sweden	300	300	800
UK	18,000	22,500	30,000
Totals	**41,800 GW**	**57,600 GW**	**79,430 GW**

The North Seas Offshore Grid 10 Year Network Development Plan (TYNDP) Regional Insight Report for 2018 aimed to analyse three separate scenarios for the year 2030 to investigate different possible pathways to meet the future EU decarbonisation targets. The 2030 and 2040 analyses clearly show that by building the proposed infrastructure, significant positive effects will be seen, including:

- benefits to the climate through the increased RES penetration and resulting decrease in CO_2 emissions
- market integration across the region through reduced price differences; and

- stable security of supply despite the energy transition

3.2. Future electricity trends and grid developments

Trends

Grid plans for the future include the push towards more 'greener' forms of energy and the grid improvements to support this. The European Expert Group on electricity interconnection targets recognizes 7 trends that are likely to have an impact on electricity infrastructure in Europe and should be considered in the view of the future review of the interconnection target [14]:

1. Electrification
2. Energy efficiency
3. Evolution of the energy mix
4. Decentralisation
5. Digitalisation
6. Storage
7. Further integration of the energy system – smart energy systems

Electrification of transport (electric cars) and decarbonisation of heating and cooling systems in line with EU carbon reduction emissions will play a major role in the transition to a clean energy system. Energy efficiency will also not only help to meet EU energy targets but it might have the potential to decrease the demand for electricity. The EU energy mix is evolving into an increasing share of decarbonised, renewable energy and the Expert Group believes that this trend will encourage investment in energy transportation infrastructure such as interconnectors. Decentralisation means that electricity will be produced close to the point of use and may reduce the need for grid infrastructure. This may be a barrier to future grid development. Digitalisation can contribute to, through data collection, the optimisation of energy generation and thus its transmission. Energy storage brings several benefits to the electricity system such as flexible generation, demand response and grid extension including interconnectors. Smart energy systems which integrate electricity, gas, heat and transport sectors can be used to ensure high flexibility both on energy supply and demand.

All of these trends will have an impact in the NSR and will shape the future development of offshore linear energy infrastructure. However those that will have an impact on spatial requirements in the NSR spatial are: evolution of the energy mix, decentralisation and energy storage. These trends will either require space in terms of marine planning for more interconnectors or energy storage facilities or alternatively potentially reducing the need for space for more offshore linear energy infrastructure in the case of decentralisation.

TenneT North Sea Wind Power Hub

Germany and the Netherlands via their TSO, TenneT, are working on extensive future grid improvement plans and the Netherlands in particular are considering creating an international grid network of sustainable wind energy in the North Sea for the long term. To safeguard grid stability, a new approach to offshore grid planning is required and it has been suggested by TenneT that this could combine wind power, interconnectors and energy storage. TenneT have proposed long term plans (after 2030) for the creation of an artificial island to act as a central hub capable of supporting offshore wind farms with a total capacity of 100 GW between 2030 and 2050 in the North Sea. The ideal location for this hub would be the Doggerbank where transnational coordination and cooperation of its development would be essential. The hub would host installation and operations and maintenance activities for OWF developers, as well as linking interconnectors and offshore wind farms to several countries. This concept, the North Sea Wind Power Hub (NSWPH), has been submitted to ENTSO-E to be included in the next TYNDP as “under consideration”. If realized, the NSWPH would be a key piece in the European energy infrastructure system and a prime enabler of the EU's goals of market integration and renewable energy source development.

Another similar energy island idea from Belgium was to create an energy atoll which was planned to be an artificial atoll which would be built off De Haan, five kilometers from the shore. The structure would gather surplus energy from offshore wind turbines and store it, then release it to the national grid when demand was high. However the project did not go ahead as it was deemed not viable and thought to lead to higher energy prices.

Figure 15. TenneT North Sea Wind Power Hub concept. Source: TenneT

Technical trends

As previously reported in WP5 ‘*Status quo* report on offshore energy planning provisions in the North Sea Region’, offshore wind development export cables are set to increase in length as the larger offshore sites are increasingly being developed in deeper water, further offshore. This will require the utilisation of HVDC technology over the longer routes (in excess of 80 km) which is more expensive than HVAC technology. This will in turn influence grid design and configuration. Currently, 65% of all TYNDP 2018 projects assessed within the NSR comprise AC technology; 35% of the projects are DC based [24]. However more DC technology will be expected in the future to enable the integration of the anticipated renewable generation, especially to strengthen connections across longer distances and cross-borders [24]. The use of DC technology for longer cable lengths in the future can be seen in Figure 16.

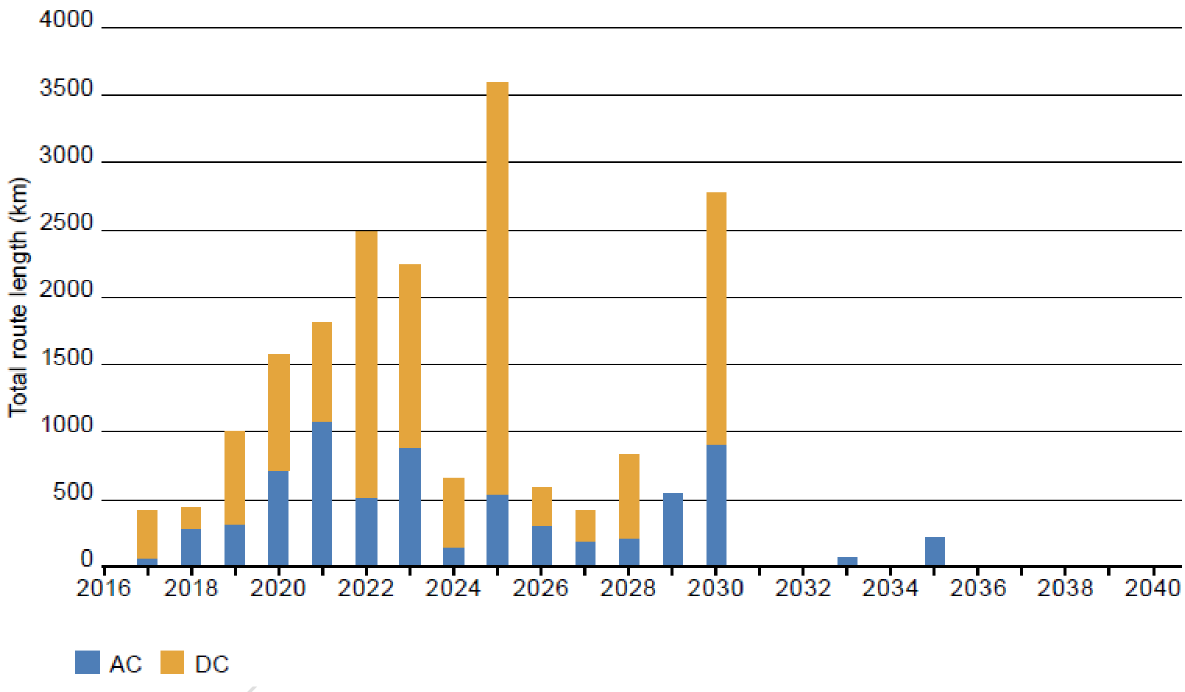


Figure 16. TYNDP 2018 promoted projects in the NSR showing the total route length against AC and DC technology over time. Source: TYNDP 2018 Regional Insight Report

The use and improvement of HVDC cables however will open up access to deeper water sites, further offshore for offshore wind, which will effectively reduce conflicts with inshore activities and also reduce visual impacts from shore.

There is also technological developments in cable manufacturing where experiments are being carried out to test different mediums such as Glass Reinforced Polymer (GRP) cables to transfer electricity which are applicable to the marine environment. The advantages of this new cable material are that it has high carrying capacity, corrosion resistance, low maintenance and a long life expectancy. This is a cost effective, long term solution which could mean that cables have a longer life span before needing decommissioned.

3.3. Decommissioning

There are already a large number of cables in the North Sea and a major issue is the decommissioning of cables that are end of life. Most countries state that there is an obligation to remove/decommission a cable after it is no longer in use. However, generally this is not enforced due to removal causing greater adverse effects than leaving them in situ. For cables left *in situ*, suitable monitoring measures are arranged but there is still with issue with some cables location not being marked properly on navigational shipping charts or cables being moved by anchors and bottom-fishing gear over time causing safety concerns. This is particular importance to fishing vessels for example who may snag their fishing nets on unmarked cables. MSP has a role to play in this challenge by ensuring that decommissioned but still *in situ* cables are appropriately marked for the safety of future marine users.

In terms of oil and gas pipelines, there will still be further development in Scotland, Norway and the Netherlands with decommissioning well underway but still the extension of new pipelines. However, the number of new pipelines is expected to stabilise after 2020.

The decommissioning of oil and gas pipelines has given rise to an opportunity which can be used to help combat climate change. The aim is to achieve a CO_2 reduction of 80-95% in 2050. Capturing CO_2 at the source and transporting it to storage locations deep underground, a technique called Carbon Capture and Storage (CCS), can achieve this. The Netherlands's CO_2 storage capacity in gas fields (current and former) is estimate to be 2,700 to 3,200 megatonnes (Mt) with 1,200 Mt being user the sea. However, there is still uncertainty as to what proportion of this capacity will be available for CO_2 storage. In order to facilitate CCS, part of the pipeline infrastructure will have to be renewed. Existing oil and gas pipelines can only be used once the fields in question have been completely exhausted. At present, the Mining Act mandates the decommissioning of depleted fields (removal of platforms not in use). In a CCS vision under development, the Central Government is assessing whether policy changes would be desirable in this respect. Scotland is also currently investing in CCS. In the long run, the ambition is to arrive at a situation in which all energy is produced sustainable. The capture, use and storage of CO_2 is a temporary solution during the transition to this situation. At the moment, this is an activity of national interest, however as it will be dependent on pipelines which cross borders, it may become of transnational interest.

Chapter 3 Summary

- Germany and the UK have not yet reached 10% interconnection which is the target for 2020 and it is thought that the UK will be unable to reach this target. Significant interconnector capacity needed in the UK in order to meet 15% interconnection target by 2030. All other NSR countries have already met or are on target to meet their 2030 targets.
- The method for calculating countries interconnectivity has been updated and now includes two calculations which take into account both electricity demand (import need) and supply (export potential). This means putting the nominal capacity of interconnectors in relation to the peak load as well as putting the nominal capacity of interconnectors in relation to the installed renewable generation capacity
- 7 electricity interconnection future trends identified and of these evolution of the energy mix, decentralisation and energy storage will be of particular spatial relevance for the NSR
- Combining wind power, interconnectors and energy storage is being considered in TenneT's North Sea Wind Power Hub which would be an artificial energy island situated on the Doggerbank.
- Decommissioned cables left in-situ and not marked probably are a major MSP issue and safety and navigation hazard.
- Further development of oil and gas pipelines in the near future in Scotland, Norway and the Netherlands but expected to stabilise after 2020.
- Decommissioning of oil and gas pipelines creates opportunity for carbon capture and storage.

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4. The role and impact of MSP on grid development

This chapter highlights the role of MSP for grid development in general and for individual NSR countries. It flags up some of the main issues for marine planning and the spatial implications and also recommends some planning solutions. Proposals for routes, gates and landfall points are suggested from a general observation point of view. In addition to this, a report is highlighted which offers proposals from an industry perspective based on grid designs and scenarios.

4.1. The role of MSP for grid development

The role of MSP for grid development is to ensure effective routing, configuration and location of offshore linear energy infrastructure such as cables, offshore converter platforms and onshore grid connections. MSP can help by identifying areas of least constraint to locate cable corridors which match up offshore energy resource to suitable grid connection points on land, whilst carefully routing around environmentally sensitive areas. The challenge is the massive expansion in renewable energy sources to meet energy and carbon reduction targets. A number of these renewable projects will involve the creation of new international electricity transmission capacity and will require extensive coordination between different national systems if they are to develop to their full potential.

Transnational cooperation is an important factor to MSP and is especially important for grid development and interconnectors. Transnational interconnectors are typically large, complex projects with high investment costs and lengthy project development timescales. They are based on governmental decisions on investments and exposed to different licensing procedures in various countries. Shared knowledge and understanding of NSR countries MSP planning provisions will ease the process of establishing new transnational energy grid infrastructure.

Cables not only cross national borders but also cross the land-sea interface from the marine to terrestrial environment. They are the transmission infrastructure which joins up offshore energy generation to onshore energy distribution. This requires not only an understanding and consideration for the different planning processes between marine and terrestrial but a stronger link for cooperation and coordination. For example, there needs to be identification of viable grid connection points and terrestrial sites for land-based converter stations early on in the planning process to enable cable efficient routing. Terrestrial planning can also aid marine planning through investments in transmission capacity on land to meet the requirements for offshore renewable energy. For example, Germany are improving onshore grids in the south of the country which are well-situated to transport renewable energy from their offshore wind farms to their areas of highest energy demand. The grid designs should contribute to identify and potentially mitigate bottlenecks in the onshore grid system and facilitate the greater integration of electricity markets in the region.

MSP will also play a major role in the future planning of grid development. Cables have a very long life (40 to 50 years) therefore the decision on their location is critical in relation to ensuring that energy resources are efficiently utilised and environmental footprints are reduced. It is therefore important that investment decisions are also made for the long term and should be thoroughly prepared and planned. MSP will also become more important as coastal space in the (southern) North Sea becomes more congested, priority planning and spatial designations (e.g. cable corridors) will be required.

The overall aim which has been the ambition for several decades is the development of a North Sea offshore grid which interconnects all NSR countries and helps meet EU targets for an integrated internal energy market, facilitating the flow of energy across borders. Due to the transnational dimension, optimal expansion of an offshore grid is best considered from a transnational perspective rather than at a national level, which is the current situation. There are some notable enabling conditions that are likely to be required for the development of such an offshore grid. Significant improvements in cross-border cooperation would be required in order to ensure compatibility and coordination of national OWE plans with the necessary grid-infrastructure. At the same time there would need to be well defined and centralised responsibility for developing the post 2020 offshore grid.

The establishment of the NSCOGI was an important first step towards increasing coordination efforts in order to establish appropriate offshore grid infrastructure for OWE and this will be continued through the Political Declaration. However, to plan an optimal grid design for OWE in the North Sea basin, knowledge is needed on the quantities and location of offshore wind parks in the medium to long term [15]. This knowledge is best acquired through an integrated planning approach based on a long term target or vision for OWE across the NSR.

There is currently no over-arching regulatory regime facilitating the association of offshore grid with offshore renewable projects across national sea basins in the NSR [15]. Whereas onshore grid networks are well established and operate with national regulations and regulatory bodies in place, offshore grid is less established. A transnational regulatory framework is needed and in establishing this, it is important to think of new solutions tailored for offshore grid development and/or attempt to extend national onshore regulatory regimes to offshore.

The level of renewable generation, in particular, the level and location of offshore renewables in projections, is likely to be the parameter with the most significant impact in determining offshore grid configurations and planning. Examples of configurations suggested by industry include: radial, meshed, hub/interconnector approach or the integrated approach [16], as seen in Figure 17.

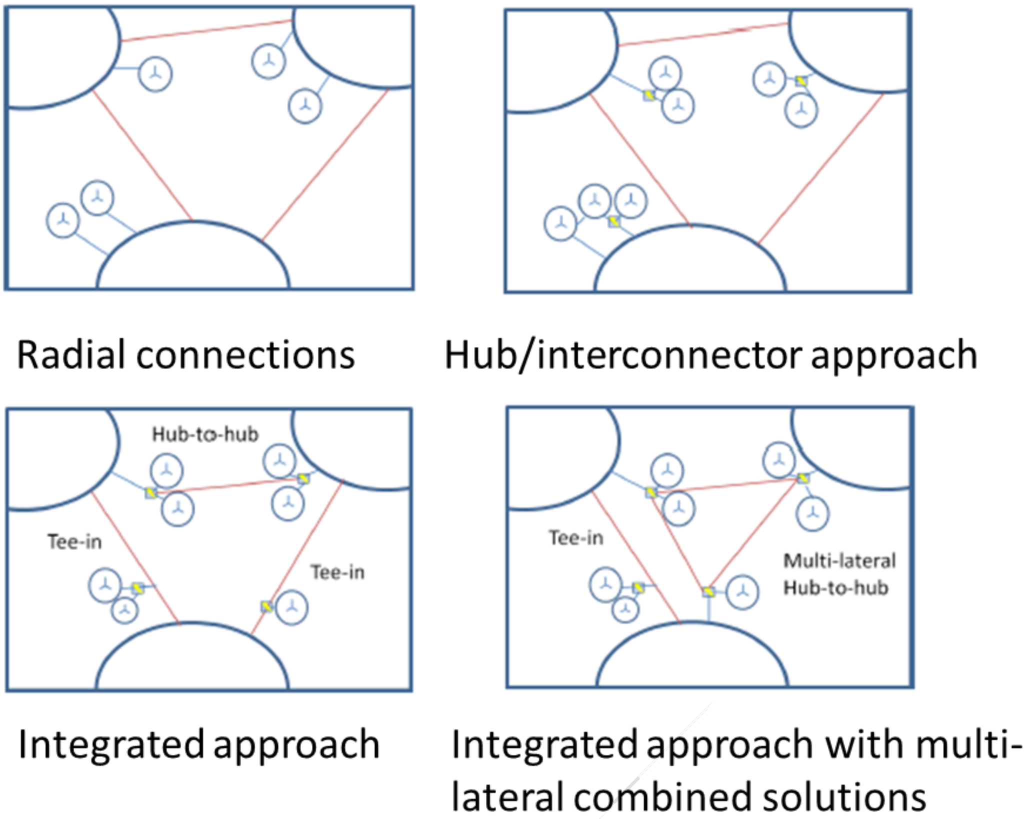

Figure 17. Approaches for a North Seas offshore grid. Source: The North Seas Offshore Grid CIEP paper 2015

To date most wind parks in the North Sea have been connected to shore by an individual electricity cable a so-called 'radial' connection. This type of connection is characterised by a limited need for coordination. The fact they are so widespread can be attributed to the *ad hoc* investment decisions in individual offshore wind projects in the past decade and their relative vicinity to shore.

Another approach to grid development is the 'hub/interconnector approach' which includes both radial offshore wind park connections and more coordinated form of offshore wind connections, in the form of hubs, and furthermore involves an expansion of the offshore cross-border electricity transmission infrastructure in the form of interconnectors. With the increase in the number of offshore wind projects and the fact that these are increasingly located further offshore, the need for local coordination has grown. This has given rise to the formation of hubs, which are offshore substations that connect multiple wind parks and bring their combined energy to the onshore transmission system through a single power cable. In the hub/interconnector approach, the interconnectors can be seen as the building blocks of a North Sea Offshore Grid, connecting the electricity grids of the North Seas countries with one another. The hub approach as already been implemented in the Netherlands, Germany and Belgium, though still from a national perspective with the hubs being directly connected to shore. No hubs are planned yet in the NSR where wind farms from different countries link in [23].

The second approach to developing a North Sea offshore grid is the 'integrated approach'. In addition to radial connections, hubs and interconnectors, the integrated approach also includes combined solutions, which connect an offshore wind park or hub directly to an interconnector. These are more novel and innovative solutions have gained attention, as they could potentially prove to be a more economical means of connecting offshore wind parks. Needless to say, the development of combined solutions would require a high level of international coordination.

4.2. Issues for marine planning and spatial implications

There is an increasing need to understand the current and future spatial demands for grid development and associated submarine cables in the NSR. Marine planners are faced with the need to accommodate those cable systems already in service as well as the growth of new connections and networks that are being installed to serve new and essential energy generation and distribution policies. Due to their inherent linear nature, and requirement to connect to the high-voltage grid, interconnectors pose challenging spatial questions. Cables are not as space-intensive as offshore wind farms, however they require careful routing with innovative solutions (e.g. cable corridors), they require further international attention (particularly in the cases of interconnectors), and they have an important role to play in MSP as they significantly influence (and are influenced by) where the next offshore wind developments will be sited.

Differences in planning approaches regarding cable routing and gates for transnational interconnectors between neighbouring countries ("over-planning vs "non-planning") could lead to conflicts. This is potentially the situation between Germany and neighbouring countries as Germany has strictly defined cable routes for entering their EEZ, whilst other countries have no defined gates or cable corridors. If transnational interconnectors are to be routed through the German cable gates then it has to match up with areas for cables in neighbouring countries. This may require more careful routing and may lead to more conflicts.

Restrictions on space for cables appears to cause similar conflicts around the North Sea, with some site-specific cases. The main conflicts are with fishing, shipping, renewable energy developments, mineral extraction and defence.

Fishing vessels such as trawlers and other vessels with bottom-contact fishing methods come into conflict with cables that have been surface laid and not protected by cable protection measures through snagging. This poses a significant safety risk to the vessel and can also risk asset integrity. There are also similar conflicts with shipping, where in the Netherlands, for example, ships of certain size are not allowed to anchor where there are cables or pipelines as they could damage the cable. However shipping lines should be considered in grid planning and avoided if possible.

Mineral extraction is a particularly important marine industry in the Netherlands and sand reserves are largely situated close to shore making it challenging to plan cable routes to shore. However sand is not allowed to be extracted where there are cables and pipelines located and conflict arises when cables are routed through these areas to connect to the grid. It is therefore essential during the planning process for laying new cables that efforts are made to avoid important sand extraction areas. There should also be consideration of grid connection points on land during planning to match up with preferred routes. Routing cables through some sand extraction areas is possible if they are depleted or less attractive.

There are numerous environmentally sensitive areas including protected habitats and site designations within the North Sea and routing cables around these is a major challenge. The BEAGINS study which is previously mentioned in section 1.6 which aims to ensure that environmental concerns and impacts are appropriately considered in the development of an offshore energy grid system in the North and Irish Seas, has investigated the International and European Protected Sites intersected by Radial and Meshed Grid solutions based on the different scenarios also mentioned above [23]. They compared both radial and meshed associated grid infrastructure such as grid, hub and landfall and found that all 3 meshed grid infrastructure intersected the protected sites less that the radial grid infrastructure on all accounts except for a few instances for the hub [23]. The study also found that radial connections presented the greater potential for impacts on the environment due to the lengths of cables for individual connections, a greater number of landfall points needed and no integrations of existing grid infrastructure. On the other hand, the meshed or integrated approach may require a more localised concentration of infrastructure however it would allow existing grid options to be utilised, meaning less cabling. This means that there would be less of an environmental footprint or exclusion to other maritime users. However this is dependent upon the studies proposed mitigation measures such as applying good siting and routing guidelines. These findings support the movement towards a more integrated and meshed offshore grid in the NSR.

Another issue for planning of grid in the future could be that the onshore grid connection causes a bottleneck. This might cause issues in some countries to find landing points as well as routes in the territorial sea, especially for a higher demand of offshore windfarms in the future. In some areas, e.g. the national park Wadden Sea in Germany, the possible corridors for offshore grid connections are limited and cables are already bundled to save space. This might result in some issues with transportation of energy produced from offshore to onshore. Also for consideration in some countries is the change in energy production. For example, in Germany the network expansion on land is another bottleneck. The energy transition has resulted in grid expansion from the North to the South of Germany. This shows the significance of capacity in the onshore grid to handle the higher offshore as well as in general renewable energy production. It also shows the important role that onshore grid connection as well as the onshore grid capacity plays for future grid developments.

4.3. Coherence study between offshore linear energy infrastructure and other marine users

Aim and scope

The North Sea is considered to be one of the busiest seas worldwide. As bordering states expand offshore wind as well as other renewable energy activities, the space requirements are growing in a limited space. Proper ways are needed to integrate this development into the existing marine spatial plans to minimise conflicts between different marine uses and respective users. The space has to be managed efficiently to ensure that economically reasonable uses, both existing and new ones, have sufficient space.

The aim of this chapter is to identify the interplay of components of the offshore linear energy infrastructure and other marine uses that are relevant to marine spatial planners. For this purpose, the spatial overlapping of the different uses was determined. Spatial overlapping assumes that both uses claim the same area simultaneously. Spatial overlaps were qualified with respect to given or potential inherent conflicts. Overlaps were identified for four phases of use.

The chapter deals with grid components from offshore marine renewable energies. Pipelines used for oil and gas have been excluded.

Methods

The three-dimensional marine natural space was divided into five horizontal layers comprising:

1. space above the water,
2. water surface,
3. water column,
4. seabed and
5. underground (subsurface)

In order to specify where the spatial overlapping occurs.

This study differentiates between four phases of the life cycle of the energy grid component:

Phase 1: Construction,
Phase 2: Use,
Phase 3: Maintenance and

Phase 4: Demolition

The Phases 1 (Construction), 3 (Maintenance) and 4 (Demolition) were grouped, as the grid components have the same space requirements during these phases. The space requirements during the Phase 2 (Use) differ slightly and were analysed separately.

Firstly, the space requirement (by layer) of the components of the offshore grid electricity, as well as the other activities during the phases were determined (table 1). The grid components were then compared with those of other marine uses, also indicating the number of layers affected (table 2). The interplay between the other uses was not analysed yet.

Whenever a use or action is prohibited by law, no spatial overlapping was documented. An examples is the use of restricted areas or the anchoring of boats where cables are located.

It needs to be considered that some uses are temporal and thus do not permanently overlap with grid components.

Grid components

The analysed grid components included cables and platforms. The grid components were classified according to BSH (2018)[1]

- Inter-array subsea cable defined as a cable that links groups of wind turbines to the transformer substation platform or directly to the converter platform
- HVAC subsea cable defined as a cable that connects the transformer substation platform to the converter platform. The average profile of such a cable is 590 mm².
- HVDC subsea cable defined as a cable that conducts the energy from the converter platform in DC to the shore. The average profile of such a cable is 1,250 mm².
- Interconnector defined as subsea cable systems which run through at least two countries
- Gates defined as corridors where (cross-border) subsea cable systems crossing the border between EEZ's or to the territorial sea
- Transformer substation platform defined as a platform that bundles the energy produced in one offshore wind farm
- Converter platform defined as a transmission platform on which the power arriving from the offshore wind farms' substations is bundled, transformed and converted into DC current. Current converter platforms have dimensions of approximately 65 x 105 m but require an area of 100 x 200 m in order to ensure safe installation and reliable operation.

[1] Interview with German Federal Hydrographic Agency 2018

All cables need to be buried in a depth of 1.5 m. Grid components and the affected layers they are touching in the marine can be found in table 1.

Other uses

The other marine uses were grouped into the following categories:

- Transport,
- Fisheries,
- Inorganic resources,
- Military,
- Culture,
- Recreation and tourism as well as
- Nature conservation.

<u>Transport</u>

With two of the world's largest ports—Hamburg and Rotterdam—situated on its coasts (OSPAR, 2017), the North sea is an important shipping are. Boats were divided into four categories dependent on their size (IMO, 2018)[2]

- Small crafts (< 85 m): usually maintenance vessels and other smaller boats) that can go around obstacles quite easily.
- Ships (85 – 190 m): most ships in the sea belong to this group. They are bigger, but still quite accessible.
- Panamax vessels (190 – 299 m): Example: A ship of about 200 meters in size needs about 2 NM to turn around.
- Post-Panamax vessels (299 – 400 m): Example: A ship of 400 meters in size needs 5 NM to stop after an emergency break.

<u>Fisheries</u>

Fishing refers to the harvesting of marine fish (Blackhart et al., 2006). Gillnets, trawls and mariculture are the most common commercial fishing techniques in the North Sea[3] (BfN, n.d.-a, ICES, 2017, Animal Welfare Institute, 2018, Gabriel et al., 2005).

- Gillnets can either drift in the water column (Caddell, 2010, Nedelec and Prado, 1990) or be fixed to the ground (BfN, n.d.-c, Blackhart et al., 2006) to harvest fish that entangled themselves in the nets.
- Trawls are funnel- or cone-shaped nets towed behind one or several vessels to retrieve fish (Blackhart et al., 2006, FAO Fisheries and Aquaculture Department, 2014). Bottom trawling drags the net above the seabed and is therefore extremely destructive (BfN, n.d.-b, National Academy of Science,

[2] Interview with Directorate Shipping of Belgium 2018
[3] In accordance with MSP Challenge 2018

2002, Bradshaw et al., 2012, Palanques et al., 2001). Pelagic (or midwater) trawling drags the net through the water column (Nedelec and Prado, 1990).

- Mariculture is a marine farming system (aquaculture) for vertebrate and invertebrate animals (fish molluscs and crustaceans) and algae (Blackhart et al., 2006). Usually, cages, pens or longlines are employed to grow these organisms in a regulated environment either in the water column (Buck, 2007) or on the seabed (FAO Fisheries and Aquaculture Department, 2014).

Inorganic Resources

This category summarises all uses related to inorganic resources. Dredging refers to the extraction and relocating mineral resources, mostly sand. The most important purposes of dredging are the recovering of material for commercial purposes and to maintain shipping routes. In case of the latter sand is removed from the seabed of shipping routes in order to maintain a required depth and then released at a different location (for more information see OSPAR, 2015b, European Dredging Association, n.d., IADC, 2018).

Moreover, the North Sea is used for the exploitation of crude oil and natural gas. Once a reservoir is identified, the resources are extracted using platforms and transported to the shore using pipelines. Carbon capture and storage (CCS) is a climate change mitigation strategy which stores carbon dioxide in underground reservoirs. For this purpose, disused oil and gas platforms can be used reservedly. CCS is an emerging technology with only two operational plants in the North Sea in 2015 (in Sleipner and Snohvit, Norway) (OSPAR, 2015a, Strachan et al., 2011)

Military

Apart from restricted areas in which any use is prohibited due to potential dangers originating from unexploded ordnance, the military uses offshore space for different training purposes[4]:

- Torpedo: under water (sub surface)
- Submarine: under water (sub surface)
- Shooting: under water (sub surface) and above water surface
- Mine-hunting: under water (sub surface)
- Flight: above water surface (sea level and higher)

As more detailed information is confidential "above water surface" is defined as layer 1 (above water) and 2 (water surface); and "under water" is defined as layer 3 (water column), 4 (seabed), and 5 (subsurface).

Culture, Recreation and Tourism

[4] German Federal Hydrographic Agency 2018

Human leisure activities are divided into diving, bathing and surfing as well as recreational boating.

Underwater cultural heritage sites refer to all remnants of human existence that have been partially or totally under water for at least 100 years (UNESCO, 2017). These sites, for instance wrecks, are protected and thus limit other uses (Noordzeeloket, 2017).

Nature Conservation

In this category, areas for the protection of fish, benthic habitats, birds and marine mammals were distinguished. The definition of these protection areas assumes that the ecosystem with respective species are not influenced by the presence of components of the electricity grid (ICES, 2016). Areas for different species were included as they have varying spatial requests.

Moreover, the use for restoration purposes was included. Restoration is defined as the process of returning degraded ecosystems to their earlier good condition by human actions (see e.g. Smaal et al., 2015, CMCZM & The University of Aberdeen, n.d.).

It needs to be indicated that the analysis only refers to the spatial overlapping of uses. Further implications, like a possible sediment warming or effects of electro-magnetic fields due to subsea cables, were not included.

Spatial requests of grid components

The grid components are divided into the two categories (with different sub-categories) cables and platforms. Within these categories, the grid components have the same spatial request. During the use phase, cables are lying buried in the seabed and thus only use layer 5. During the phases of construction (i.e. cable lying), maintenance and demolition (i.e. cable removal), ships with specific appliances are used to access the cables. Therefore, all five layers are accessed during these times. Platforms are constructions accessible above water which are fixed to the ground. They are using all five layers during all four phases.

Overlapping of the different use categories with grid components

Transport

Shipping – no matter the size of the ship – does not overlap with cables during the use phase. Platforms on the other hand overlap with the transport sector in the layers 1, 2 and 3 and need to be avoided. During the phase's construction, maintenance and demolition, the transport sector spatially overlaps with all grid components in the upper three layers. Whether the overlapping indicates an incapability depends on the availability of diversions.

Fishing

When cables are sufficiently buried, i.e. using only layer 5 and not layer 4, fishing does not interfere with them during the use phase. The different fishing methods overlap with platforms in the upper three or four layers, depending on the method.

During the phase's construction, maintenance and demolition, fishing spatially overlaps with all grid components in the upper three or four layers, depending on the method. Whether the overlapping indicates an incapability depends on the availability of diversions.

Inorganic Resources

As the use of inorganic resources is connected to the use of the seabed or subsurface reservoirs with the aid of ships or platforms, all uses within this category overlap with all grid components: During the use phase they overlap with cables in layer 5 and during the other three phases they overlap with cables in all five layers. Inorganic resources and platforms are overlapping in all five layers during all four phases.

Military

As any use within restricted areas is prohibited, per definition no overlapping of uses occurs in these areas. However, these areas of course need to be considered during the planning process as they exclude all other uses.

The torpedo, submarine and mine-hunting training areas occur in layers 3, 4 and 5 and thus overlap with cables in layer 5 during the use phase and in all other cases in the layers 3, 4 and 5. Shooting training occupies all layers and thus overlaps with cables in layer 5 during the use phase and in all other cases in the layers 1, 2, 3, 4 and 5. Flight training overlaps during the use phase only with platforms in layer 1 and 2. During the other three phases, flight training may interfere with all grid components in layer 1 and 2.

Areas of dumped explosives pose a threat to other activities happening on or in the seabed. They therefore overlap with cables in layer 5 and with platforms in layer 4 and 5 during the use phase; and with all grid components in layer 4 and 5 during the three other phases.

Culture, Recreation and Tourism

Recreational activities overlap with platforms during the use phase and with all grid components during construction, maintenance and demolition in the layers 1, 2 and 3. Diving additionally occurs in layer 4. Cultural heritage sites occupy space in layers 3, 4 and 5.

Nature Conservation

Areas for the protection of benthic habitats and restoration areas are the only nature conservation uses that overlap with cables in layer 5 during the use phase. All other protection areas only overlap with platforms during the use phase: areas for the protection of fish in layer 3 and 4, area for the protection of benthic habitats in layer 4 and 5; areas for the protection of birds in layers 1, 2, 3 and 4; areas for the protection of marine mammals in layers 2, 3 and 4; and restoration an all layers. The overlapping during construction, maintenance and demolition equals for all grid components the overlapping with platforms during the use phase.

Overlapping of different uses within each layer

Layer 1: above water

All uses in the categories of transport, fishing and inorganic resources as well as shooting and flight training areas, recreational activities, areas for the protection of birds and restoration occur in layer one where they overlap with platforms during the use phase and with cables and platforms during the three other phases.

Layer 2: water surface

All uses in the categories of transport, fishing and inorganic resources as well as shooting and flight training areas, recreational activities, areas for the protection of birds and marine mammals and restoration occur in layer two where they overlap with platforms during the use phase and with cables and platforms during the three other phases.

Layer 3: water column

All uses in the categories of transport, fishing, inorganic resources and culture, recreation and tourism as well as torpedo, submarine, shooting and mine-hunting training areas, areas for the protection of fish, birds and marine mammals and restoration occur in layer three where they overlap with platforms during the use phase and with cables and platforms during the three other phases.

Layer 4: seabed

All uses in the categories of inorganic resources and nature conservation as well as trawling and mariculture, torpedo, submarine, shooting and mine-hunting training areas, areas for dumped explosives, diving and cultural heritage sites occur in layer four where they overlap with platforms during the use phase and with cables and platforms during the three other phases.

<u>Layer 5: subsurface</u>

All uses of inorganic resources, torpedo, submarine, shooting and mine-hunting training areas, areas for dumped explosives, cultural heritage sites, areas for the protection of benthic habitats a d restoration occur in layer five where they overlap with cables and platforms during all phases.

Conclusion

During the use phase, transport and fishing is not overlapping with cables, but with platforms. In case of the latter enough space for diversions needs to be assured around each platform.

The use of inorganic resources is always overlapping with the grid components.

Apart from flight training areas which are only above water, all military uses overlap with all grid components in all four phases. (The only exception are restricted areas as any other use is forbidden in these areas.)

Recreational activities overlap with platforms, but not with cables during the use phase. Cultural heritage sites also overlap with cables during the use phase.

During the phases of construction, maintenance and demolition, all other uses overlap with grid components at least in one layer. (The only exception are restricted areas as any other use is forbidden in these areas.) Whether this overlapping equals an incompatibility of the different uses needs to be determined for each situation.

The water column (layer 3) is the layer where most uses overlap with grid components during all four phases. Subsurface space (layer 5) is occupied by the least other uses during all four phases.

During the planning process, not only spatial overlapping within one area should be regarded. Blue corridors and habitat connectivity need to be considered as well to ensure the protection of marine ecosystems. Natural conditions or the availability of resources that influence the implementation of some uses, such as suitable depth for transport or fish stocks, need to be considered when assigning spaces to different uses as well.

4.4. Planning solutions and proposals for routes, gates and land fall points

MSP is a crucial tool in the process of proposing routes for cables and locations for gates and land fall points. Not only because it takes into account the current *status quo* of offshore energy and grid development but also any future trends and scenarios. It can also facilitate planning solutions to spatial conflicts. However route proposals need to be site-specific to take into account the different planning processes and criteria in the NSR countries, as well as country or site-specific spatial obstacles. Planning and proposing routes and locations for grid infrastructure requires marine planners to work in close collaboration with industry and other stakeholders in order to find effective routes and gates for interconnectors. Industry stakeholders, for example, can advise on future energy trends and technology advancements which will influence planning. This coordination and stakeholder involvement needs to occur at an early stage in the planning process.

In terms of proposals for land fall points, in general the NSR needs more landfall points in order to meet future needs. The requirement for more landfall points goes hand in hand with the requirement for increased electricity and interconnection demand. Most landfall points are already over-capacity for example, in Scotland and in Germany. As a general observation, there are more landfall points in the Southern North Sea compared to the Northern North Sea which reflects the geographical distance between the UK and the rest of Europe. There is especially a lack down the east coast of the UK, in particular Scotland's east coast and also on Germany's North Sea coast. These areas could be proposals for more landfall points, especially because the UK and Germany are two of the main producers of offshore wind energy. However the location and number of landfall points is related to the grid solution or configuration applied, with generally more land fall points being required for radial compared to meshed or integrated grid. Therefore more landfall points are required now because of the fact that most North Sea wind farms are currently radially connected to shore, however this may change in the future if and when a more coordinated and integrated offshore grid is implemented.

With reference to gates, so far only the German MSP authorities have implemented gates as a method for planning cable routes. It has not been explored if this method is also effective for other NSR countries but the German Spatial Offshore Grid Plan is certainly an example of best practice for grid planning and there is potential for it to be replicated in other countries such as Scotland.

In terms of proposing interconnectors in the NSR, the UK and Germany require more interconnectors in order to meet the 2020 and 2030 interconnection targets and therefore these should be a priority for the benefit of a more interconnected NSR. Considering route proposals for interconnectors, Germany along with Belgium and the Netherlands already have designated cable corridors or priority areas within their marine plans, but Scotland does not have any designated routes for interconnectors.

There is currently less demand for space in Scotland's marine area of the Northern North Sea, and therefore interconnector route proposals are of less importance at this time. However there is interest in Scotland to develop an offshore grid plan to compliment it's National Marine Plan and therefore this can act as a mechanism for proposing interconnector routes to boost Scotland's interconnection levels. In order for marine planners to propose effective routes for current and future grid requirements, they could benefit from industry reports on route proposals.

With regards to grid solutions and configurations, many studies have debated radial versus meshed or integrated offshore grid in the NSR. An initial findings report produced by NSCOGI in 2012 aimed to evaluate grid configuration and the long-term development of an offshore grid structure in the North Sea [2].The report weighed up the options of continuing to 'go it alone', or by 'doing it together'. This means that NSR countries either continue with nationally connected offshore generation or move towards a type of shared or integrated grid design which supports cross-border flows of energy and transnational cooperation. Possible electricity transmission system designs (as seen in Figure 17), grid simulations and scenarios such as the 'reference scenario' are discussed in great detail and with future predicted changes to electricity energy requirements at the forefront. The report leans more in favour of the benefits of a meshed grid, however it also highlights the unknown risks associated with meshed grid. The report also includes chapters called 'country-specific comments' which discuss some industry proposals for interconnector routes and grid connection points on land which are useful from a planning perspective. These or similar studies could be used as an indication of routes in conjunction with spatial conflict analysis studies to further refine cable routes.

There is also the BEAGINS study which compares radial versus meshed grid solutions from an environmental point of view. The study recommended a meshed grid solution as the reduced footprint of nearshore cabling utilising the meshed solution has greater potential, in combination with sensitive siting, to reduce habitat displacement and avoid sensitive coastal sites [23].

Overall, it appears that the best practice proposal for grid solutions is a meshed or integrated offshore grid from a coordinated planning, increased transnational interconnection and environmental point of view. However it is also noted in the NSCOGI report that despite the quantifiable costs and benefits associated with meshed approach to grid design, there are less quantifiable implications such as added complexity, increased technology risk, challenges of operating an integrated DC grid and the need for significant regulatory adaptation [2]. Nevertheless, there is still the EU ambition for an integrated single energy market which may be the over-riding driver in the development of an integrated North Sea offshore grid.

Chapter 4 Summary

- The role of MSP for grid development involves effective routing to avoid spatial conflicts and match up offshore energy resource to suitable grid connection points on land.
- Transnational cooperation and MSP knowledge exchange between NSR countries is necessary for optimal grid expansion in the NSR.
- Cable planning requires a strong link between marine and terrestrial planning to link up offshore energy generation to landfall points.
- There is currently no over-arching regulatory regime facilitating the association of offshore grid with offshore renewable projects across national sea basins in the NSR.
- Most NSR wind parks are connected to shore by radial connections, however a switch to more integrated and hub connections will facilitate more cross-border electricity transmission.
- Conflicts can arise from differences in transnational interconnector planning e.g. over-planning versus non-planning.
- Main conflicts between grid development and marine activities are: fishing, shipping, renewable energy developments, mineral extraction and defence.
- Coherence links between cables and grid systems and other marine users within the NSR are studied. The term coherence relates to the spatial overlap of different users where they share the same space. Fishing, shipping and recreation don’t overlap with cables when properly buried or protected but sediment extraction and cultural heritage do overlap.
- In terms of proposals, in general the NSR needs more landfall points in order to meet future needs, Scotland and Germany need more interconnectors to meet interconnection targets and the German Spatial Offshore Grid Plan is considered best practice.

5. Conclusions

5.1. Main findings

- **Current grid and linear energy infrastructure is nationally focused and largely disconnected with only some transnational coordination.**
  This transnational coordination is in the form of integrated connection of a number of offshore wind parks and between nations in the development of interconnectors. As stated by WindEurope in their wind energy scenarios, in order to meet 2030 renewable energy and climate change targets, there will need to be efficient and improved power interconnections between Member States. This will require extensive coordination between NSR countries for the dream of a North Sea offshore grid to become a reality.

- **The main transnational drivers that are relevant for NSR countries are interconnection demand and increased grid connection points. The main barriers are grid connectivity and grid integration.**
  The drivers will facilitate not only the flow of offshore renewable energy back to National onshore grids but also flow of energy across borders. There are also numerous benefits of an offshore grid such as allowing countries such as the Netherlands, Germany and the UK, to develop portions of their EEZ's that are further from shore, increasing their potential installed capacity. The barriers are caused by lack of transnational grid development, interconnectors and landfall points, which are already at full capacity.

- **Denmark currently has the most interconnector cables in the NSR and Belgium has the least. This has important implications for energy security and stability but is also dependent upon current energy requirements and future demand.**
  Due to Denmark having the most interconnectors, it can therefore be deemed to have a higher level of energy security. The least interconnected country is Belgium with the fewest existing and planned interconnectors between countries. Sweden and Norway are beginning to catch up in the medium term and the UK and Germany have more planned interconnectors in the future.

- **Differences exist in the level of established grid planning including planning provisions between NSR countries.**
  Germany has a more established and focused approach to grid planning where they currently have an offshore grid development plan. However this only covers installations until 2025, and then this will be replaced by the spatial

offshore grid plan which will be a more comprehensive planning tool to bring spatial and chronological planning of offshore wind farms and grid connections together. However, the Netherlands and Scotland's approach to grid planning is less established than the German approach and only features as a chapter rather than a dedicated grid plan. Considering MSPs under preparation, for example Sweden and Denmark, not all plans include regulations for offshore energy cables. Swedish MSP has a more guiding character and therefore does not include any spatial rules for electricity cables. Denmark is at a very early stage of their MSP and have not yet decided how to treat electricity cables in their national MSP.

- **Third party and generator TSO models are better suited to support the evolution towards larger scale offshore wind farms that are increasingly developed farther out to sea, while the TSO model is better suited to support the evolution towards cross-border offshore grid projects.**
  There needs to be a trade-off between the two as there are currently no existing regulatory models that can fulfil all the requirements. It was suggested by the author that this trade-off has to be made at the regional or EU level because different national regulatory frameworks are incompatible when applied to a cross-border offshore grid project.

- **Differences exist between NSR countries in terms of planning criteria and between criteria being Government-led or Industry-led.**
  Grid planning differs between North Sea countries, with Germany having well-established planning criteria compared to limited criteria in other NSR countries. There is also a difference between criteria being Government-led or Industry-led. For example, in Germany, the Government have defined planning principles and criteria for both offshore wind farms, grid connection systems and for interconnectors in their designated Spatial Offshore Grid Plan, however they both follow similar principles. On the other hand, in Scotland planning principles are classed more as 'rules of thumb' by Industry and adherence to the principles is dependent on risk.

- **UK and Germany have not yet reached the 10% interconnection target for 2020 and the UK may not meet the 15% interconnection target by 2030.**

Although NSR countries demonstrate considerable differences in terms of their energy mix, size of energy market and geographical location, which influence their interconnectivity potential and needs makes it challenging to determine future interconnector demand, this evidence suggests that the UK in particular needs to increase its interconnector capacity. It is the aim of PCI's such as, for example, the NorthConnect and North Sea Link interconnectors to help meet the target for the UK.

- **Further development of oil and gas pipelines expected in Scotland, Norway and the Netherlands with decommissioning well underway but still the extension of new pipelines. However, the number of new pipelines is expected to stabilise after 2020.**
  The decommissioning of oil and gas pipelines has given rise to an opportunity which can be used to help combat climate change. CO_2 can be captured and stored in decommissioned pipelines, a technique called Carbon Capture and Storage (CCS).

- **The role of MSP in grid development involves identifying areas of least constraint to locate cable corridors which match up offshore energy resource to suitable grid connection points on land, whilst carefully routing around environmentally sensitive areas.**

- **MSP will become more important as coastal space in the (southern) North Sea becomes more congested, priority planning and spatial designations (e.g. cable corridors) will be required.**

- **There is currently no over-arching regulatory regime facilitating the association of offshore grid with offshore renewable projects across national sea basins in the NSR.**
  Whereas onshore grid networks are well established and operate with national regulations and regulatory bodies in place, offshore grid is less established. A transnational regulatory framework is needed and in establishing this, it is important to think of new solutions tailored for offshore grid development and/or attempt to extend national onshore regulatory regimes to offshore.

- **The level of renewable generation, in particular, the level and location of offshore renewables in projections, is likely to be the parameter with the most significant impact in determining offshore grid configurations and planning.**

- **To date most wind parks in the North Sea have been connected to shore by an individual electricity cable, a so-called 'radial' connection, but a meshed, hub/interconnector or integrated approach may be the way toward achieving transnational coordination of a North Sea offshore grid.**
  Radial connection is characterised by a limited need for coordination and ad-hoc investment. In the hub/interconnector approach, the interconnectors can be seen as the building blocks of a North Sea Offshore Grid, connecting the electricity grids of the North Seas countries with one another. The integrated approach is a more economical way to create a combined approach, however

the development of combined solutions would require a high level of international coordination.

- **Differences in planning approaches regarding cable routing and gates for transnational interconnectors between neighbouring countries ("over-planning vs "non-planning") could lead to conflicts.**
  This is potentially the situation between Germany and neighbouring countries as Germany has strictly defined cable routes for entering their EEZ, whilst other countries have no defined gates or cable corridors.

- **In terms of coherence links between cables and grid systems and other marine users within the NSR and spatial overlap, fishing, shipping and recreation don't overlap with cables when properly buried or protected but sediment extraction and cultural heritage do overlap.**

- **NSR needs more landfall points in the Northern North Sea order to meet future needs and more interconnectors are required in the UK and Germany to help them achieve their 2020 and 2030 interconnection targets. However, despite higher interconnection demand in the future, there might be less of a requirement for landfall points if a meshed or more integrated grid solution is implemented.**
  As a general observation, there are more landfall points in the Southern North Sea compared to the Northern North Sea which reflects the geographical distance between the UK and the rest of Europe. There is especially a lack down the east coast of the UK, in particular Scotland's east coast and also on Germany's North Sea coast. These areas could be proposals for more landfall points, especially because the UK and Germany are two of the main producers of offshore wind energy. However the number of landfall points is related to the grid solution applied and generally radial connections require more landfall points compared to meshed or integrated grid connections.

5.2. Recommendations

Energy and grid

- Establish a dedicated transnational regulatory framework for offshore grid.

- Identify current and future areas of large energy generation offshore and energy demand onshore and match them up.

- Designate a well-defined and centralised responsibility for developing post 2020 offshore grid.

- Ensure any new cables are effectively buried or protected and the locations are accurately recorded on navigational charts.

<u>NSR countries</u>

- Maintain continued pledge to the Political Declaration on energy cooperation in North Sea countries.

- Prioritise the development of interconnections with those neighbours that are below any of the thresholds (e.g. UK and Germany) in a spirit of solidarity and cooperation.

<u>MSP</u>

- Develop a Spatial Offshore Grid Plan which takes into account energy and climate change targets, current and future energy industry trends, spatial planning principles and criteria and integrates cable corridors and gates.

- Facilitate stakeholder involvement in offshore grid planning and consult a wide range of relevant stakeholders in the marine planning and licensing process at an early stage.

- Designate cable corridors in areas of least constraint, especially in congested near shore areas.

- Identify new areas for landfall points.

- Identify viable grid connection points and terrestrial sites for land-based converter stations early on in the planning process to enable cable efficient routing.

- Connect terrestrial land planning to MSP when it comes to offshore wind farms, grid development, onshore converter stations and land fall points.

- Consider optimal expansion of offshore grid from a transnational perspective rather than at a national level.

- Facilitate more transnational coordination and cooperation in offshore grid planning between all North Sea countries.

- Consider geographical locations of offshore energy generation, in particular floating or deep water offshore wind farms, in relation to onshore grid connection points.

- Consider grid connectivity when planning areas for wave and tidal energy developments and support their needs.

Future energy industry trends

- Encourage and support more transnational grid configurations such as the integrated approach.

- Continue to decommission old and unused cables and pipelines where environmentally feasible to avoid spatial conflicts with other marine users.

- Explore and invest in Carbon Capture and Storage opportunities in decommissioned pipelines.

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7. Annex 1 – Country profiles