Baltic InteGrid review: towards a meshed offshore grid in the Baltic Sea. Final Report

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Integrated Baltic Offshore
Wind Electricity Grid Development

Baltic InteGrid: towards a meshed offshore grid in the Baltic Sea

Final report

Interreg
Baltic Sea Region

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Baltic InteGrid review: towards a meshed offshore grid in the Baltic Sea

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Interreg Baltic Sea Region
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Foreword

Governments across the globe are finally recognising the urgent need to jointly address climate change. This has led to the commitments under the Paris Agreement to curb greenhouse gas emissions and keep global warming well below 2 °C. While the global energy transition is gaining momentum, there is far too little progress to stay within the 2 °C target. To accelerate the shift to a sustainable energy system, we need innovative ideas that go beyond business as usual.

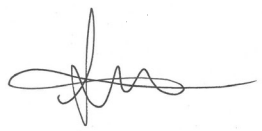
Europe has been a leader in climate policy in general, and in the development of renewable energy in particular – although other countries are quickly catching up. The European Union has set out to foster renewable energy development and further market interconnection, reducing emissions by 80% to 95% by 2050 in the process.

Offshore wind energy is crucial to this renewable energy future. Boasting a higher generation capacity and more full load hours than onshore wind, the sector has achieved remarkable cost reductions in recent years. The Baltic Sea has great potential in this regard, thanks to a range of favourable conditions like shallow waters, strong winds and short distances to shore.

With 2.2 GW of installed capacity and rising, the offshore wind market in the Baltic Sea is on the cusp of accelerated development. Now is the time to explore state-of-the-art solutions for the connection and distribution of offshore wind energy. A meshed grid is one such solution: an innovative, efficient way to link offshore wind farms while connecting electricity markets. Combining interconnector infrastructure with export cables, a meshed offshore grid in the Baltic Sea would boost system stability and the integration of electricity markets, reduce issues linked to curtailment and ensure a high utilisation rate for cable infrastructure. Moreover, the installation, maintenance and service sector that would be developed around a meshed offshore grid could help the Baltic Sea Region excel in green technologies and innovation while creating jobs for local populations.

While a meshed offshore grid has many benefits, it is also characterised by a multilateral and capital-intensive nature, the complexity of which needs to be alleviated through a guiding hand from policy-makers. Keeping in mind the long lead times of offshore wind and grid projects, it is imperative that interest in meshed offshore grids translate into bold policy-making and reinforced transnational cooperation soon, before the region is further locked into a suboptimal energy system.

The Baltic Sea Region has the potential to be a major player in innovative offshore wind technologies and grid solutions. It is high time to start planning for that future, together.



Anika Nicolaas Ponder
Project manager
on behalf of the Baltic InteGrid consortium

Publications

Policy & Regulation

- Establishing a meshed offshore grid: policy and regulatory aspects and barriers.
- European and national offshore wind energy policy in the Baltic Sea Region – A regional status report.
- Legal and policy framework for power transmission and offshore wind power generation in Finland.
- International cooperation on the expansion of offshore wind generation capacity.
- Institutional framework for the development of offshore wind
- power projects.
- Economic considerations on the regulatory framework for offshore wind and offshore meshed grid investments.

Market & Supply Chain

- Qualified overview paper.
- Market analysis of the offshore wind energy transmission industry.
- Supply chain analysis of the offshore wind energy transmission industry.
- Assessment of Baltic hubs for offshore grid development: A report for the Baltic InteGrid project.
- Baltic Offshore Grid SME business cases: A report for the Baltic InteGrid project.

Technology & Grid Design

- Offshore wind power plant technology catalogue.
- Lifetime estimation and performance evaluation for offshore wind farm transmission cables.
- Optimum sizing of offshore wind farm export cables.
- Metaheuristic-based design and optimization of offshore wind farm collection systems.
- Optimization of electrical infrastructure in offshore wind farms: A review.
- Heuristics-based design and optimization of offshore wind farms collection systems.
- Improved method for calculating power transfer capability curves of offshore wind farm cables.

Environment & Society

- Impact mitigation strategy of the Baltic Offshore Grid.
- Maritime spatial planning and the Baltic Offshore Grid: Status of the MSP process and grid variants.

Spatial Planning

- Towards a Baltic Offshore Grid: Connecting electricity markets through offshore wind farms.
- Recommendations to the ENTSO-E's Ten-Year Network Development Plan.
- Recommendations for the maritime spatial planning process.
- Paving the way to a meshed offshore grid: Recommendations for an efficient policy and regulatory framework.

Cost-Benefit Analysis

- Cost-benefit analysis for an integrated offshore grid in the Baltic Sea.

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List of abbreviations

ACER	Agency for the Cooperation of Energy Regulators
BEMIP	Baltic Energy Market Interconnection Plan
BSR	Baltic Sea Region
CBET	Cross-border energy trade
DC	Direct current
EEZ	Exclusive economic zone
EIA	Environmental Impact Assessment
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EUSBSR	European Union Strategy for the Baltic Sea Region
EWEA	European Wind Energy Association
HELCOM	Baltic Marine Environment Protection Commission
HVAC	High voltage alternating current
HVDC	High voltage direct current
LCOE	Levelised cost of energy
NGO	Non-governmental organisation
OMS	Operation, maintenance and service
PCI	Project of common interest
SEA	Strategic environmental assessment
SME	Small or medium enterprise
TSO	Transmission system operator
TYNDP	Ten-Year Network Development Plan
UNCLOS	United Nations Convention on the Law of the Sea

Glossary

Concept	Definition
Dual-purpose cable	Transmission cable which can alternatively or simultaneously act as interconnector or export cable.
Export cable	Transmission cable which connects an offshore wind farm to a (transmission grid) connection point. Traditionally, the connection is established between the power plant and the corresponding national onshore transmission grid, thus building a radial connection.
Hybrid project	Any offshore wind project which is not connected radially to the shore, or any offshore cable which does not solely act as an interconnector; that is, any project in which cables act simultaneously or alternately as interconnectors or export cables. The multiplication of hybrid projects in the Baltic Sea is expected to ultimately lead to the emergence of a meshed offshore grid.
Interconnector	Transmission cable which crosses or spans a border between Member States and which connects the national transmission systems of the Member States.
Meshed grid	In a meshed offshore grid, offshore wind farms are connected to more than one national transmission system. A characteristic of this grid architecture is the dual-purpose use of sea cables, which can serve alternately or simultaneously as interconnectors and export cables, and the possible routing of power from a given offshore wind farm to two or more national grids.

Baltic
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Integrated Baltic Offshore
Wind Electricity Grid Development

Executive summary

The Baltic InteGrid project was implemented from 2016 to 2019 to explore the potential of meshed offshore grids in the Baltic Sea Region. It was funded and conducted under the auspices of the EU's Interreg Baltic Sea Region Programme 2014-2020 with the objective to contribute to the European Union's energy policy, which aims to streamline and link the energy markets of the Member States while facilitating a safe and sustainable transition to renewable energy.

The Baltic InteGrid project analysed legal, regulatory, technological and planning issues affecting the design and implementation of meshed grid solutions, and conducted pre-feasibility studies linked to a cost-benefit analysis. **The analyses showed that a meshed offshore grid is a sound configuration for ensuring that the wind power generated offshore in the Baltic Sea in the coming decades is transported to end users in an efficient and cost-effective way.**

The major advantages of a meshed grid would correspond to the goals of the EU's Energy Union, which aims to safeguard power supply, integrate the EU energy market, help decarbonise the economy and support breakthroughs in low-carbon and clean energy technologies. Such a grid would face a number of legal, regulatory, technical, planning and acceptance challenges, however.

The main legal challenge is the establishment of a regulatory framework at the European level for the definition, construction and operation of a meshed grid, not least the problem of defining the legal status of different types of cable and regulating the power transmitted through dual-purpose cables that serve as both export cables and interconnectors.

The construction and operation of a meshed grid would, as all grid projects, be affected by spatial conflicts, environmental issues and public acceptance. Moreover, there are often concerns about perceived environment damage or a lack of transparency. These issues can be solved through careful regulatory and administrative solutions like good planning, awareness campaigns, social dialogue, financial incentives and compensation measures. A meshed grid has advantages compared to radial connections since the total space needed for the grid can be decreased, thereby reducing potential conflict with other users or maritime space.

Another major topic is technology: meshed systems are much more complex than straightforward radial ones and require advanced technical solutions. Fortunately, the relevant technology is advancing quickly, with many new solutions gradually becoming cost efficient. One of the most interesting developments can be found in long-distance

power transmission, especially high voltage direct current technology, which is generally better for transporting large amounts of power over long distances, and can be used to transmit electricity between the three different synchronous grids in the Baltic Sea Region. It is, however, still in the early stages of being applied in offshore wind farms.

The design of offshore substructures is also evolving quickly, enabling offshore wind generation and transmission facilities to be built at ever-greater depths further and further from shore. Provided they become cost-competitive, even floating foundations may be a part of future offshore designs in the BSR in the medium term.

The two pre-feasibility studies carried out by the Baltic InteGrid project aimed to measure the suitability of the meshed grid approach to the Baltic Sea in technological, market-related, environmental and economic terms. For this purpose, the studies compared a meshed-grid configuration with a radial system, considered technical designs and their costs, and provided a comparison of the costs and benefits of the various options. The results of the studies can be extrapolated to other areas of similar size and with similar conditions.

The pre-feasibility studies found that a meshed approach would be cost-efficient in most cases. Moreover, they show that meshed grids would have substantial advantages that go beyond cost efficiency. Meshed grids would mean less AC and DC cables, reducing installation and maintenance costs. They would also require fewer landfall points, potentially leading to higher public acceptance. And they would make it easier to transmit power between Estonia, Latvia & Lithuania and the other two synchronous grids in Europe, thereby strengthening security of supply.

The findings of the Baltic InteGrid project were extrapolated to the long term and across the whole Baltic Sea to formulate a vision for 2050 tentatively named the Baltic Offshore Grid. This aims to provide a realistic model for a meshed grid in the Baltic Sea in the service of EU priorities. BOG 2050 specifies a combined radial and meshed approach to existing and new offshore wind farms and transmission infrastructure. It focuses on the south-western and south-eastern Baltic Sea first, with a potential secondary hub envisaged in the northern part of the Baltic Sea, between Estonia, Finland and Sweden, and a third prospect between those two cores.

The potential of offshore wind in the Baltic is estimated to be 9.5 GW by 2030 and 35 GW by 2050.

The potential of offshore wind in the Baltic is estimated to be 9.5 GW by 2030 and 35 GW by 2050. This new capacity will require a great deal of additional generation and transmission infrastructure. If the expansion is not carefully managed and coordinated, there will be a risk of a needless proliferation of radial configurations and an accompanying glut of export and interconnector submarine cables. This might be inefficient, possibly leading to higher costs for end users, while also potentially causing significant conflicts with other marine and seaside uses.

The deployment of new offshore wind infrastructure should therefore preferably be accompanied by meaningful coordination between the countries and stakeholders involved. It is important to consider this well in advance of the coming expansion, as the lock-in effects of an inefficient grid design could be difficult or impossible to correct in the future.

To accompany the coming evolution, the Baltic InteGrid project produced several sets of concrete recommendations for the relevant stakeholders, particularly related to maritime spatial planning, policy & regulation, and the next Ten-Year Network Development Plan. These recommendations call to secure and organise maritime space for the optimised generation and transmission of offshore wind energy, ensure consistency between policies, facilitate cooperation among stakeholders, and raise awareness and acceptance among the public.

It is important to consider meaningful coordination well in advance of the coming expansion, as the lock-in effects of an inefficient grid design could be difficult to correct.

Concretely, the recommendations call for dynamic procedures that are updated whenever necessary, robust frameworks for international and inter-agency cooperation, the involvement of stakeholders from all sectors in planning, suitable legislative and administrative frameworks for the construction and operation of infrastructure, environmental protection guarantees, and advance plans for specific standalone projects that can gradually be rolled out and eventually merged into a single meshed grid linking significant portions of the Baltic Sea Region.

The horizon of this report is 2050. This may seem like a distant future, but it is one Europe needs to start preparing very soon. The Baltic InteGrid project attempts to provide some constructive perspectives, themes and avenues of thought for stakeholders and policy-makers in the Baltic Sea Region to consider and explore when formulating both an overarching vision and specific solutions in the service of laying the foundations for a better energy future.

Introduction

This report is one of the major outputs of the 'Integrated Baltic Offshore Wind Electricity Grid Development' (Baltic InteGrid) project.[i] Implemented from 2016 to 2019 to explore the potential of meshed offshore grids in the Baltic Sea Region (BSR), the project contributed important research and analyses relevant to sustainable electricity generation, further integration of regional electricity markets and security of supply around the Baltic Sea.

Funded and conducted under the auspices of the EU's Interreg BSR Programme 2014-2020, the Baltic InteGrid project was intended as an element of the European Union's energy policy, which aims to unify the energy markets of the Member States and facilitate a safe and sustainable transition to renewable energy. It also contributes to the implementation of the Baltic Energy Market Interconnection Plan (BEMIP) and has been designated a flagship project under the EU Strategy for the Baltic Sea Region (EUSBSR).

Background

A key ongoing development in Europe – which is set to rapidly accelerate in the coming decades and to which the EU has lent its full support – is the increase in the share of electricity generated from renewable sources. Wind power – increasingly offshore wind – is becoming more important across the continent, and especially its northern parts. In December 2018, 18 offshore wind farms (OWFs) were in operation in the Baltic Sea, representing a total installed capacity of 2.2 GW. Nine of these were located in Denmark, four in Germany, three in Sweden and two in Finland. Many projects are also in the planning stages (see Figure 20). For example, three new offshore wind farms are expected to be built in German waters by the end of 2022, representing an additional 733 MW of installed capacity. The coming large-scale deployment of this fast-evolving technology will require improved power transmission infrastructure, including cross-border connections, some of which will ideally cross large bodies of water.

One way to solve the issue of wind power generation and transmission in seas surrounded by land on all sides such as the North or Baltic Seas is a meshed offshore grid, which combines power generation and cross-border transmission. The EU identified a North Sea offshore grid as one of the six infrastructure priorities in its Second Strategic Energy Review as far back as 2008; many of the arguments which led to that decision also apply to the Baltic Sea.

The EU identified a North Sea offshore grid as one of the six infrastructure priorities in its Second Strategic Energy Review as far back as 2008; many of the arguments which led to that decision also apply to the Baltic.

Partners

The project was implemented by a consortium of 14 project partners from all eight EU Member States in the Baltic Sea Region: the Institute for Climate Protection, Energy & Mobility (IKEM), Rostock Business & Technology Development, Deutsche WindGuard, and German Offshore Wind Energy Foundation from Germany; the Foundation for Sustainable Energy (FNEZ) and the Maritime Institute in Gdańsk (MIG) from Poland; the Technical University of Denmark (DTU) and Aarhus University from Denmark; the Energy Agency for Southeast Sweden and Lund University from Sweden; the Latvian Association of Local and Regional Governments from Latvia; Aalto University from Finland; the University of Tartu from Estonia; and the Coastal Research and Planning Institute from Lithuania. In addition, the project consortium was supported by 35 Associated Organisations, which included, among others, transmission system operators from Poland, Lithuania,

[i] *The full list of Baltic InteGrid publications can be found in the appendix.*

Germany, Denmark and Estonia, investors in offshore wind farms, private companies, representatives of administrations from Germany, Lithuania and Latvia, and a range of agencies and institutions active in research and development.

Figure 1. Baltic Sea Region map showing project partners.

Themes and objectives

The Baltic InteGrid project focused on six themes – policy & regulation, market & supply, technology & grid, environment, spatial planning, and cost-benefit analysis – producing insights and recommendations relevant to the EU's energy policy in each. These insights include elements related to developing, interconnecting and integrating regional markets, contributing to the security of the electricity supply, fostering the diversification of energy sources to reduce the emission of greenhouse gases, and contributing to responsible economic growth by facilitating new business activities in sectors relevant to renewable energy and grid deployment.

The Baltic InteGrid project focused on six themes to develop, interconnect and integrate regional markets, contribute to the security of the electricity supply, foster the diversification of energy sources, and contribute to responsible economic growth.

This publication is divided into three main segments: a report on the current state of offshore wind generation and transmission infrastructure in the Baltic Sea; an inventory of the challenges and opportunities relevant to the development of a meshed grid in the medium term; and a description of visions and scenarios for the long term, including a future roadmap and the policies and regulations required to implement it.

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1 Offshore wind infrastructure in the Baltic Sea: present status and future potential

EU Member States have found that emission reductions can be perfectly compatible with economic growth: as part of its transition to a low-carbon society, the EU has reduced emissions by 22% since 1990, even as its gross domestic product has increased by 50%.[1] The Paris climate agreement, which took effect in 2016, has boosted public awareness of the hidden costs of overreliance on fossil fuels and the potential economic benefits of clean technologies. Accordingly, the share of renewable power consumption in EU Member States has been rising continuously over the years.

Plentiful wind, long coastlines and shallow waters make the Baltic Sea Region (BSR) a highly attractive area for cost-effective offshore wind farms. Its location at the crossroads of several Member States on the geographical edge of the EU is also linked with great potential for strategic cooperation. However, the Baltic also faces significant barriers to the integration of regional markets, including the presence of several different synchronous electrical power systems[i] and insufficient transmission infrastructure. The intermittent nature of wind furthermore means that the planned expansion of offshore wind energy in the Baltic will require substantial adjustments to the capacity and design of the electrical grids.

Meshed grids contribute to safeguarding power supply, integrating energy markets, improving energy efficiency, decarbonising the economy and supporting technological breakthroughs.

In many ways, a meshed grid is expected to be the best method to ensure that the additional power generated offshore in the Baltic in the coming decades can reach end users as efficiently as possible. Such a grid should also strengthen interconnections between the countries in the BSR, improving energy security. This double effect would correspond to the goals of the EU's Energy Union, which aims to safeguard power supply, integrate the EU energy market, improve energy efficiency, help decarbonise the economy and support breakthroughs in low-carbon and clean energy technologies.

1.1 The possibilities of meshed offshore grids in the Baltic Sea

The standard approach to transmitting power from offshore wind farms to shore is to have each installation linked to the grid of the host country (that is, the country in whose territorial waters or exclusive economic zone (EEZ) the wind farm is located) with export (park-to-shore) cables. The power is then transported to end consumers within the

[i] *A synchronous grid is a three-phase electric power grid at regional scale that operates at a synchronised frequency and is electrically tied together during normal system conditions. The three synchronous grids which converge in the Baltic Sea Region are the Nordic, Continental and Baltic State systems (see Figure 4).*

country, or exported through onshore or submarine interconnectors to another country as needed. This system has the advantage of being legally and technically straightforward; however, it is often not optimal for offshore electricity produced on a sea shared by several countries and surrounded by land on all sides.

For one thing, if submarine interconnector cables are planned to link countries on either shore, substantial savings could be achieved if they were designed, built and used to also connect any nearby offshore wind farms to both countries. Moreover, the surges in power generation which typify offshore wind often mean that more power is sometimes produced than can be consumed locally, requiring high-capacity transmission infrastructure to take the excess power to faraway consumers – and linking offshore wind farms directly to submarine interconnector cables can substantially shorten the distance involved. Finally, in many places there are significant public-acceptance issues affecting high-capacity power transmission on shore, and this problem can be partly avoided by submarine cables.

To describe different types of offshore grids, this report uses the following terminology. The business-as-usual system with limited cross-border coordination is referred to as radial connection (Figure 2). In such a system, submarine cables are always used for a single purpose: either to connect the electricity systems of two countries (as interconnectors) or to link offshore wind farms to the transmission grid of the country in whose waters they are located (park-to-shore cables or export cables). A more integrated approach, termed a meshed grid (Figure 3), involves wind farms in several countries' territorial waters or EEZs linked to each other as well as to the shore grid of several countries. In such a situation, some submarine cables have a twofold use, serving as both interconnectors and export cables.

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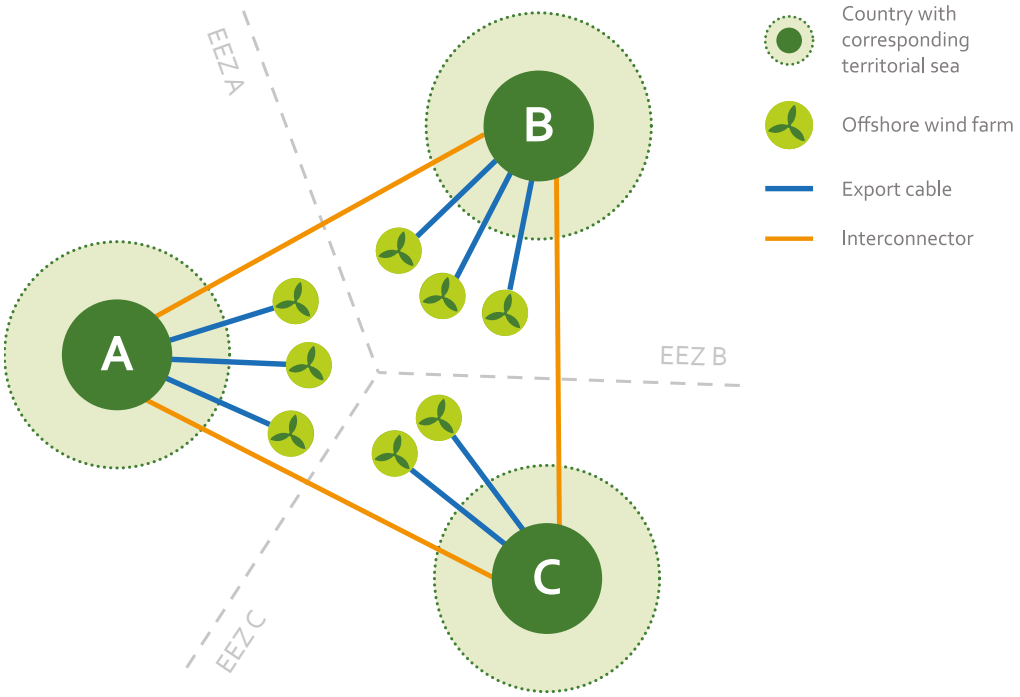

Figure 2. Radial connections.

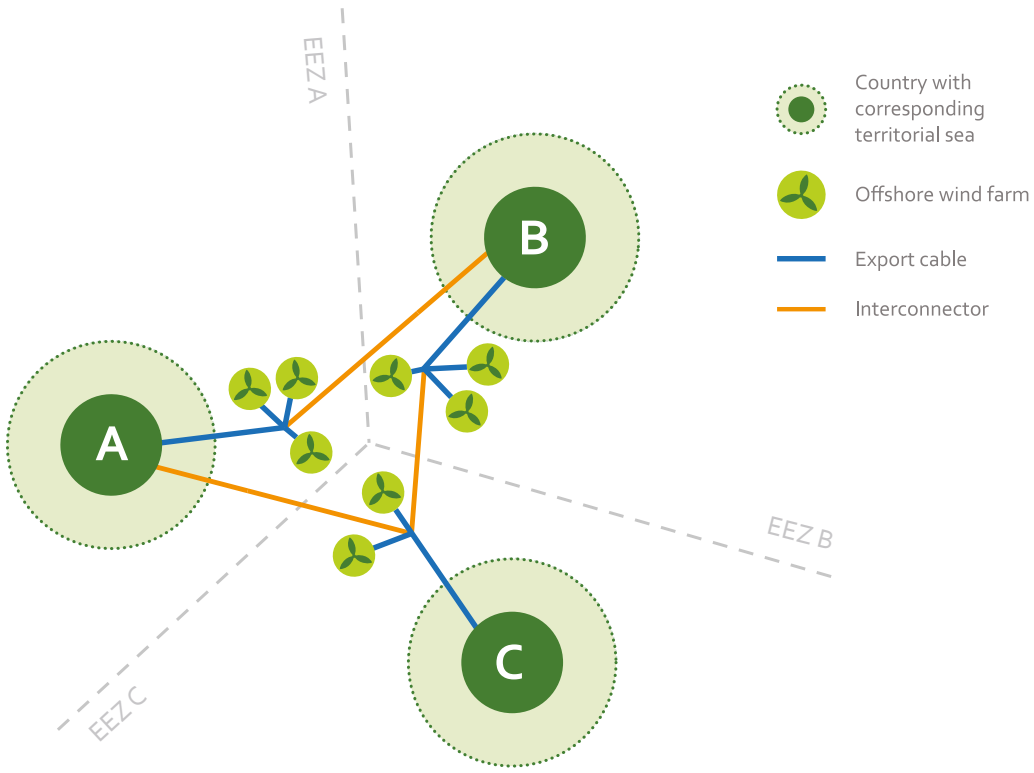

Figure 3. Meshed grid.

Studies carried out for the North Sea have shown that meshed grid configurations can bring major financial, technical and environmental benefits at a macroregional level. The Baltic InteGrid project built on this to analyse the same mechanisms for the Baltic Sea. This included legal, administrative, technological and planning issues affecting the design and implementation of meshed grid solutions, as well as cost-benefit analyses and pre-feasibility studies.

1.2 Legal and regulatory background

Offshore wind energy generation requires substantial upfront costs, and the viability of an investment can depend greatly on support schemes and the regulatory framework. Prompted both by EU initiatives and national politics, the countries in the BSR have been adapting their policies to facilitate offshore wind deployment. While such change is generally welcome, it is important to remember that it can disrupt investment plans. Germany, for instance, recently shifted to an auction process in which investors submit bids for a market premium. This reflects the tensions inherent in the ambition to make renewables more competitive while ensuring diversity among large and small investors, including members of civil society.

In 2017, the results from the first auction revealed an average weighted award price of €4.40/megawatt-hour (MWh), with price bids ranging from €0.00/MWh to €60.00/MWh.[2] The second auction in 2018 also included zero bids, but the average price (€46.60/MWh) was higher than the first tender, with the highest strike price reaching €98.30/MWh.[3] (The increase in weighted average price can be partly attributed to the auction participation conditions, which led to fewer bids being made during the second auction.)

The insights in this section are described at greater length in the Baltic InteGrid publications 'Establishing an offshore meshed grid: Policy and regulatory aspects and barriers in the Baltic Sea Region' from July 2018 and 'Qualified overview paper: Market and supply chain analyses overview and business opportunities for small and medium enterprises (SMEs) in the Baltic Sea Region for offshore wind transmission assets' from October 2018.

1.2.1 Efforts toward expansion and interconnection in the Baltic Sea Region

Today's grid design follows the pattern of yesterday's power production. Energy infrastructure in Estonia, Latvia and Lithuania, for instance, reflects their historical dependency on Russia as their sole energy provider. In Latvia, there is high power transmission capacity in the east, while the western segments of the grid are unsuited to large-scale power transmission, obstructing offshore wind power development. Moreover, three different synchronous grids meet in the BSR – those of the Nordic countries (excluding continental Denmark), the formerly Soviet Baltic States, and continental Europe.[i]

Figure 4. Synchronous grids in Europe.

A start has already been made on integrating the electricity networks in the BSR through the construction of cross-border transmission infrastructure. Existing links between Poland & Sweden (SwePol, finished in 2000) and Estonia & Finland (Estlink, 2007) announced a new era of interconnection, and were soon followed by others, with several more currently in the pipeline.

In an effort to establish a connected internal energy market and end the isolation of 'energy islands', the EU set an interconnection target of at least 10% of Member States' installed electricity production capacity by 2020 and 15% by 2030.[4] Figure 5 shows the current state of interconnection in the BSR.

In an effort to establish a connected internal energy market and end the isolation of 'energy islands', the EU set an interconnection target of at least 10% of Member States' installed electricity production capacity by 2020 and 15% by 2030.

[i] *The joint statement of the Heads of State or Governments of the Baltic States of 22 March 2018 affirmed the parties' commitment to synchronising the electricity grids of Estonia, Latvia and Lithuania with the continental system by 2025.*

Figure 5. Current and projected DC cables and interconnectors in the Baltic Sea Region.
Source: IKEM (2018)

1.2.2 International conventions

Several international conventions provide a regulatory framework for environmental protection standards and the use of the sea by sovereign countries.

United Nations Convention on the Law of the Sea

Customary international law of the sea is largely codified in the United Nations Convention on the Law of the Sea (UNCLOS), which sets common rules, establishes limits on sovereignty and specifies the activities permitted in coastal areas.[5] All eight EU Member States in the BSR are parties to the convention.

Under UNCLOS, the sea is divided into different zones of activity and competence (see Figure 6). In territorial waters, which extend up to 12 nautical miles (22.2 km) from the coast, a state has full sovereignty over the surface, seabed and subsoil, while other states still enjoy a right of innocent passage. In exclusive economic zones (EEZs), which extend 200 nautical miles (370.4 km) beyond the shore, states have sovereign rights to all economic activities involving the water, seabed and subsoil, but the surface belongs to international waters.

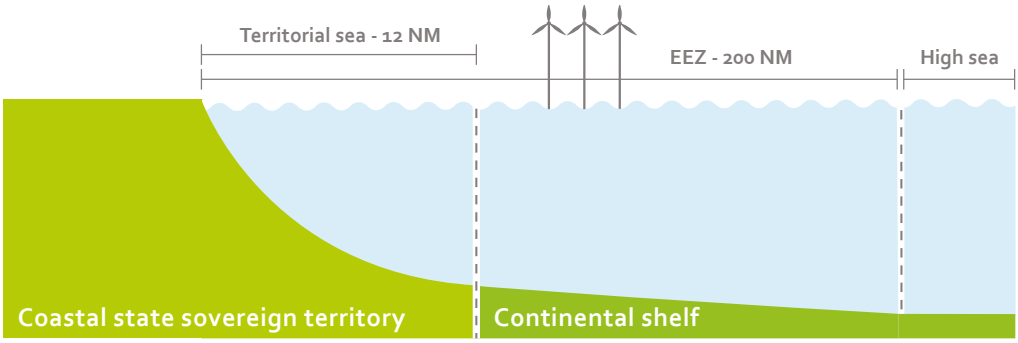

Figure 6. Maritime zones established under UNCLOS.
Source: IKEM (2018)

The sovereign rights reserved to states in their respective EEZs are enumerated in UNCLOS and comprise economic activities such as the construction of offshore wind farms and laying of export cables. The laying of interconnectors is not considered an economic activity under this definition and is permitted to other states as well as the owner of the EEZ.

The sovereign rights reserved to states in their respective EEZs comprise economic activities such as the construction of offshore wind farms and laying of export cables.

Environmental protection conventions

The Convention on Environmental Impact Assessment in a Transboundary Context (the Espoo Convention), which entered into force in 1997 and to which all eight EU Member States in the BSR are party, specifies that 'appropriate and effective measures' such as environmental impact assessments (EIAs) must be undertaken before projected major construction activities 'to prevent, reduce and control significant adverse transboundary environmental impact'.[6] In 2010, the Espoo Convention was supplemented by the Protocol on Strategic Environmental Assessment (Kyiv Protocol), which specifies that countries should undertake strategic environmental assessments (SEAs) in the early phases of the development process so potential environmental effects can be evaluated while plans are still at an abstract stage.[7] All eight Baltic Member States are parties to the Espoo Convention and Kyiv Protocol, as is the EU itself.

The Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (the Aarhus Convention), in force since 2001, establishes a public right of access to environmental information and participation in environmental decision-making as well as access to judicial review on environmental issues.

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (the Helsinki Convention) took effect in 2000. Its governing body is the Baltic Marine Environment Protection Commission (HELCOM), whose contracting parties include the eight EU Member States in the BSR as well as the EU and Russia. The Convention designates several Maritime Protection Areas (MPAs) with the goal of protecting marine and coastal flora and fauna specific to the BSR. There are currently 176 MPAs in the Baltic Sea.[8]

Other relevant conventions include the 1979 Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), which served as a model for the EU's Habitats Directive, and the 1971 Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention).

1.2.3 EU framework

Exception on state aid for renewable energy

The EU facilitates the expansion of renewable energy, including offshore wind, by allowing Member States to provide economic incentives for it as an exception to its usual prohibition on state aid to private companies. Specifically, Member States may promote energy from renewable sources as long as this contributes to the fulfilment of the EU's energy and climate targets; however, such support must not have undue negative effects on competition and trade.[9] In 2017, for example, the European Commission approved the support granted by Denmark to the Kriegers Flak offshore wind farm and concluded that the positive aspects of the project outweighed the potential distortions of competition caused by support from the Danish government.[10]

The EU's Clean Energy Package of 2016 specifies that at least 32% of EU's energy consumption should come from renewable energy by 2030.

The EU first set binding targets for sustainable power in its Member States with its Renewable Energy Directive (RED) of 2009.[11] The goal – achieving a cumulative 20% of renewable power generation by 2020 – is currently on track to be met. The new Renewable Energy Directive (RED II) of 2018 specifies that at least 32% of EU's energy consumption should come from renewable energy by 2030.[12] The EU does not set defined targets for offshore wind specifically, nor otherwise interfere in Member States' energy mix.

EU instruments and cross-border links

There are several EU instruments specific to energy in the BSR. The EU Strategy for the Baltic Sea Region (EUSBSR) is a macro-regional strategy approved by the European Council in 2009 with the objectives of saving the sea, connecting the region, and increasing prosperity. The connection goal of the Strategy addresses energy policy in particular.[13]

BEMIP

The Baltic Energy Market Interconnection Plan (BEMIP) initiative was signed in 2009 by all eight Baltic Member States and the European Commission with the aim of connecting the BSR to the EU's internal energy market and end the region's energy isolation.[14] The concrete goals of the BEMIP include setting up an integrated electricity and gas market in the BSR through the development of infrastructure projects for renewable energy and interconnections.[15] The BEMIP was updated and combined with the Energy Policy Area of the EUSBSR in 2015. The resulting revised common action plan defined measures to be implemented by 2020 in areas such as energy infrastructure, the electricity market, security of supply, energy efficiency and renewable energy.[16]

Useful support for cross-border linkages is provided by the introduction of EU interconnection targets and investment in Projects of Common Interest (PCIs)[i]; preference is given to projects in priority corridors, as identified in the Trans-European Networks for Energy (TEN-E) strategy. PCIs benefit from accelerated planning and permit granting, improved regulatory conditions, streamlined environmental assessment processes enabling lower administrative costs, and increased visibility to investors. They can also apply for funding from the Connecting Europe Facility.[ii]

EU energy law

As energy law is a field in which Member States share competence with the EU, much of the legal framework regarding offshore wind energy production and transmission represents transpositions of legal provisions set out in EU directives.

The Renewable Energy Directive 2009/28/EC establishes a framework for the development of renewable energy sources and sets technical rules for calculating the share of electricity generated from both hydro and wind sources.[iii] The Directive does not specify offshore wind objectives, but sets minimal binding targets for the share of energy from renewable sources within the Member States' gross final consumption of energy in 2020.

The Renewable Energy Directive 2009/28/EC sets minimal binding targets for the share of energy from renewable sources within the Member States' gross final consumption of energy in 2020.

Directive 2009/72/EC concerning common rules for the internal market in electricity (the Electricity Directive) establishes the rules for the organisation and functioning of an integrated and competitive electricity market in the EU and promotes regional cooperation.[17]

Other instruments relevant for the development of meshed offshore grids and considered by the Baltic InteGrid project include the Regulation on conditions for access to the network for cross-border exchanges in electricity (Electricity Regulation),[18] which lays out rules for cross-border electricity exchanges, and the EU network codes and guidelines, which are binding legal instruments establishing rules for the EU electricity market.[19]

[i] *Important infrastructure projects that link the energy systems of EU countries to help the EU achieve its energy policy and climate objectives.*

[ii] *This is a major EU funding instrument which aims to promote growth, jobs and competitiveness through targeted infrastructure investment at the European level; it supports the development of high-performing, sustainable and efficiently interconnected trans-European networks in transport, energy and digital services.*

[iii] *Following the negociations of the EU's Clean Energy Package, the new Renewable Energy Directive (Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82–209, or RED II) entered into force in December 2018. Its provisions must be transposed until 2021, when the current Renewable Energy Directive will effectively be repealed.*

Furthermore, the Regulation on guidelines for trans-European energy infrastructure (the TEN-E Regulation) provides support for the development of priority corridors and aspects of trans-European energy infrastructure, including tasks within the scope of the BEMIP initiative. In particular, this Regulation addresses PCIs and rules for the cross-border allocation of costs and risk-related incentives for those projects.[20]

Clean Energy Package

In November 2016, the European Commission published its Clean Energy Package, which consists of eight proposals to facilitate the transition to a 'clean energy economy' and reform the EU's electricity market. The proposals aim to streamline and amend the EU's Third Energy Package (a legislative package liberalising the internal gas and electricity market in the European Union which entered into force in September 2009) and set new rules for ACER, the European energy regulator. The Clean Energy Package focuses especially on strengthening cross-border cooperation and enhancing interconnection between electricity systems.

EU environmental law

The EU legal framework requires Member States to ensure that environmental considerations are not neglected in the course of the development of renewable energy infrastructure – not least in order to fulfil the EU's own commitments under international conventions. EU law cites comprehensive conditions for the assessment of the environmental impact of offshore wind developments.

The Strategic Environmental Assessment Directive (SEA Directive) of 2001 obligates Member States to ensure that environmental assessments are carried out when designing 'plans and programmes which are likely to have significant effects on the environment'. It applies to a wider range of public plans and programmes adopted by public authorities at national, regional or local levels, such as those concerning land use and the development of power plants. As a result, strategic environmental assessments (SEA) need to be carried out in an early, abstract phase of planning to assess the environmental impact not of a concrete plant project but of development in general. The SEA Directive was adopted to implement the Kyiv Protocol of the Espoo Convention into EU legislation.[21]

The Environmental Impact Assessment Directive (EIA Directive),[22] last modified in 2014,[23] applies to 'the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment'. Its provisions concern concrete project planning; the EIA is therefore performed at a later planning stage than is the SEA. The EIA Directive is the EU's tool for complying with the requirements of the Espoo Convention.

The EU also implemented the provisions of the Aarhus Convention through the adoption of the Public Participation Directive[24] and the Freedom of access to information Directive.[25] The Habitats Directive[26] and the Birds Directive[27] set standards for nature conservation in the EU and called for the creation of the Natura 2000 network of protected sites (see Figure 7).

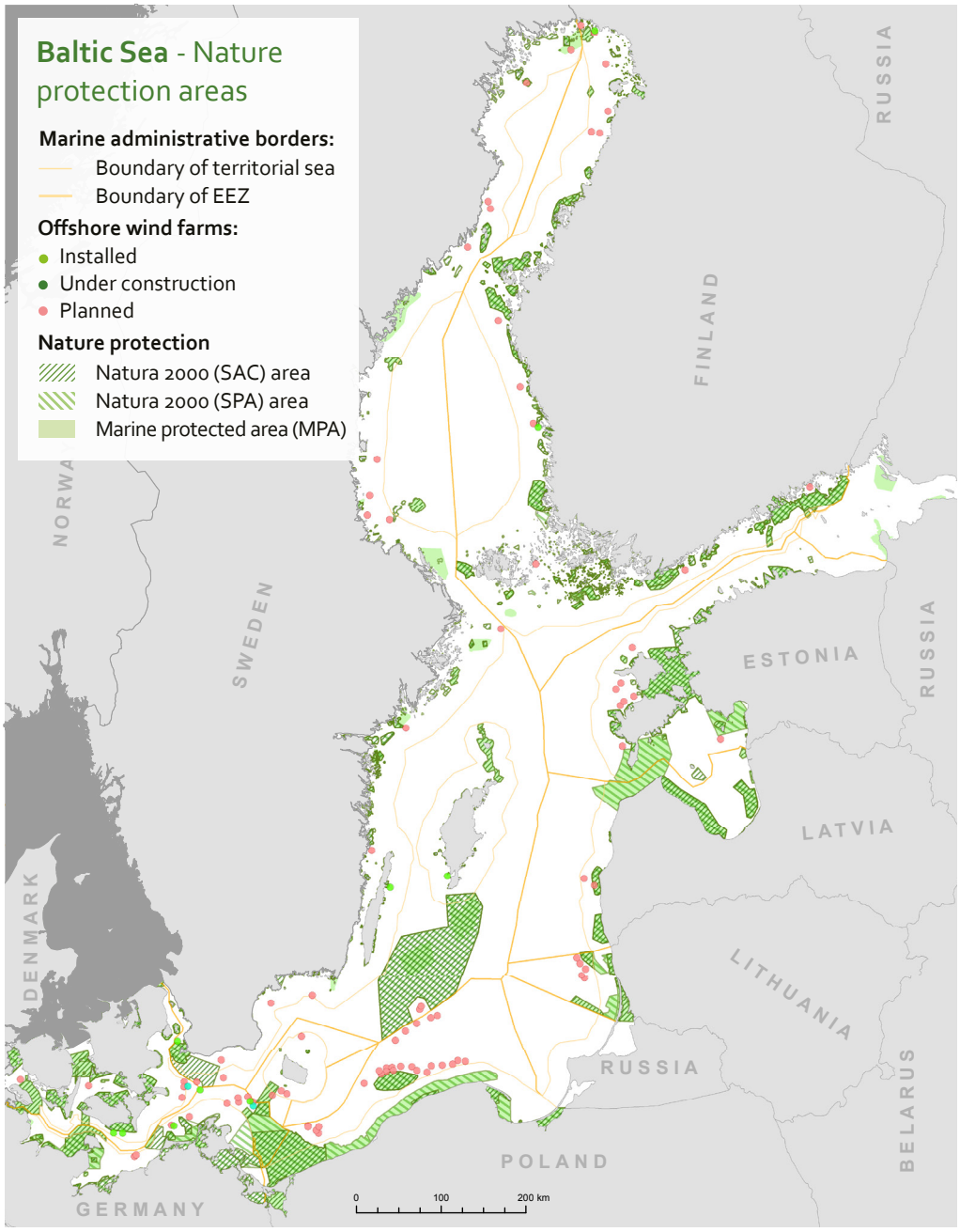

Figure 7. HELCOM MPAs and Natura 2000 areas in the Baltic Sea.
Source: HELCOM[28]

Finally, the Maritime Spatial Planning Directive requires Member States to create maritime spatial plans to coordinate activities at sea by 31 March 2021.[29] An overview of maritime spatial planning (MSP) around the Baltic Sea is available on the European MSP Platform.[30]

The Maritime Spatial Planning Directive requires Member States to create maritime spatial plans to coordinate activities at sea by 31 March 2021.

1.2.4 National actors

Public authorities

All eight countries in the BSR have ministries dedicated entirely (Lithuania and Poland) or partly (Denmark, Estonia, Finland, Germany, Latvia and Sweden) to energy policy. Offshore wind development also falls within the purview of ministries for nature conservation and environmental affairs. Moreover, each country has public agencies in charge of a range of related tasks, such as spatial planning or providing permits. Most transmission system operators (TSOs) are state-owned due to the historical monopoly of governments over power transmission.

Regional and local authorities sometimes also play an important role in infrastructure development – in Finland, for instance, municipalities are competent for spatial planning and building permits and sometimes environmental permits.[31] In Germany, territorial competency is shared, with territorial waters belonging to the purview of the federal states and the EEZ beyond that falling under the authority of the central government.[32]

The private sector

Suppliers, manufacturers, and other actors within the energy sector have formed several industrial associations, umbrella organisations and clusters to advance their interests. These groups attempt to encourage the development of wind energy by providing relevant information, influencing legislation, reducing barriers to renewable energy, and creating a reliable long-term framework for investment. Groups active in the BSR include the Stiftung OFFSHORE-WINDENERGIE and the Bundesverband WindEnergie (BWE) in Germany, the Danish Wind Industry Association, the Estonian Wind Power Association, and many more.

Baltic Sea Offshore Forum

The wind energy associations across the BSR have joined in the Baltic Sea Offshore Forum (BaSOF), which advocates for the development of offshore wind energy and the attendant industry in the BSR to strengthen the energy transition and establish a more sustainable and efficient energy market across the region. In September 2017, BaSOF signed the Baltic Sea Declaration with the main European wind power association WindEurope. This declaration acknowledges the importance of offshore wind in the cost-efficient achievement of the objectives of the EU Energy Union and its potential to increase energy supply security and further diversify the energy portfolio in the BSR. It calls for regional cooperation in maritime spatial planning, grid development, capacity planning and support schemes.[33]

Environmental associations

International and national organisations advocating for climate and environmental protection generally have a positive view of renewable power generation. However, some environmental organisations, such as the German Nature and Biodiversity Conservation Union (NABU), have expressed caution regarding offshore wind installations and have pressed for stricter regulations to protect the environment.[34]

1.3 Current state of technology and equipment

The Baltic InteGrid project carried out an inventory of the technical components and techniques required to construct offshore wind infrastructure. This section looks at AC and DC cables, converters, filters, substructures and other relevant equipment, and analyses their advantages and drawbacks. It summarises the findings of the Baltic InteGrid publications 'Qualified overview paper: Market and supply chain analyses overview and business opportunities for small and medium enterprises (SMEs) in the Baltic Sea Region for offshore wind transmission assets' from October 2018 and 'Offshore wind power plant technology catalogue: Components of wind power plants, AC collection systems and HVDC systems' from October 2017.

1.3.1 Components

Based on site-specific constraints and generation capacity requirements, offshore wind farms and offshore transmission grids can be designed using various components; an example is shown in Figure 8. This typically includes controllable, variable-speed wind turbines, clusters of which are connected to offshore alternating current (AC) substations through medium-voltage submarine cables at voltage levels around 33-66 kV. A transformer in the offshore AC substation increases the voltage to 132-200 kV for onward transmission; this decreases the current flowing through the cables, thereby reducing the copper/aluminium content in the cables and diminishing power losses in transmission.

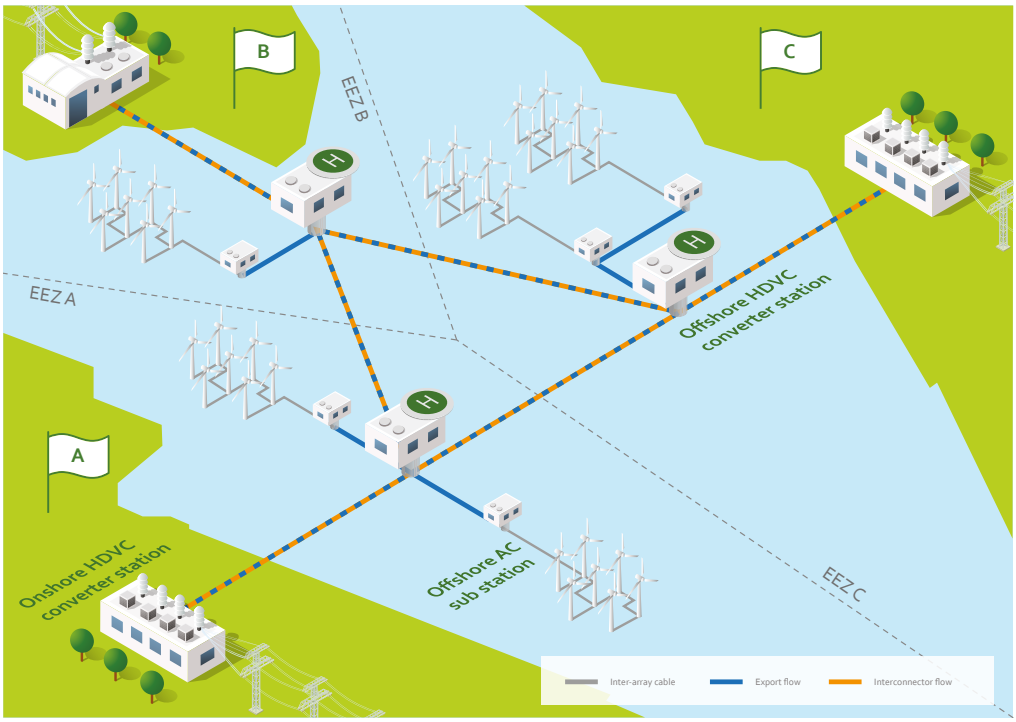

Figure 8. A meshed offshore grid.
Source: Baltic InteGrid

1.3.2 AC and DC transmission equipment

HVDC cables are more efficient than conventional HVAC for transporting large amounts of electrical power over long distances. Moreover, HVDC cables can be used to connect synchronous grids, three of which intersect in the BSR.

Near-shore wind farms use AC cables to transmit electricity directly to the onshore AC grid; in the Baltic Sea, this has so far been the most common configuration. Wind farms can, however, also be linked to the onshore grid through high-voltage direct current (HVDC) cables with HVDC converters on both ends. HVDC cables are more efficient for transporting large amounts of electrical power over long distances. Moreover, they can be used to connect synchronous grids, three of which intersect in the BSR. HVDC submarine transmission technology has also been applied on a large scale in single point-to-point connections.

There are two main types of HVDC technology. The more recent self-commutated voltage-source converters (VSCs) are more flexible than the conventional line-commutated current-source converters (CSCs) since the former allow active and reactive power to be controlled independently. This independent power flow control and increased transmission capacity can make HVDC technology preferable to conventional HVAC – despite the investment cost for a VSC-HVDC converter station generally being higher than that for an HVAC substation – as long as the transmission distance is large enough.[35] The distance at which DC is more economical depends on the project, and is typically between 80 and 120 km for offshore submarine cable connections. The decision to use AC or DC cables therefore needs to be made based on a technical and economic analysis that takes into account the line, station and losses components of costs.[36, 37]

1.3.3 Cables

HVAC

The most prevalent types of HVAC cables are cross-linked polyethylene (XLPE) cables. High-temperature-superconducting (HTS) cables are another mature technology: it is not applied on a large scale in electricity highways due to the constraints of the cryogenic systems but may be a good choice for specific projects depending on the economic conditions.

HVDC

HVDC transmission technology is mainly used when the transport of electrical power over long distances becomes uneconomical for HVAC transmission, when there is need for a high degree of control over power transmission, or to connect two synchronous networks.

Submarine HVDC cables are predominantly used to connect distant offshore wind farms to land or transmit electricity over long distance through the sea where overhead lines are technically or economically suboptimal.[38] Two main types of HVDC cable technologies are available commercially: mass-impregnated (MI) cables and XLPE cables. Self-contained fluid-filled cables are also becoming popular; however, due to hydraulic limitations they are only used for very high voltages and short connections.[39]

1.3.4 Converters

AC-DC converters

To transmit power from distant offshore wind farms through HVDC cables, AC power must be converted to DC power and vice versa. The power converters currently available on the market can be classified into two major categories: line-commutated converters (LCCs) and voltage-source converters (VSCs).[40] Both of these technologies can be used in a full HVDC scheme (AC/DC converter – HVDC cable – DC/AC converter), in a back-to-back HVDC scheme (AC/DC converter – DC circuit – DC/AC converter, with all components installed in a single station), or in a more modern configuration for multiterminal HVDC (MTDC) applications.[41]

DC-DC converters

DC-DC converters convert one DC voltage to another and are thus equivalent to transformers in an AC grid. AC transformers have greatly facilitated the capacity of AC transmission systems to operate at different voltage levels (110 kV, 220 kV, 400 kV, etc.), thereby optimising the AC grid and its components. DC-DC converters can be either isolated or non-isolated.[42]

1.3.5 Transformers

While transformer technology was invented more than a hundred years ago, the basic operating, physical and design principles remain the same today. The technology has, however, improved significantly, resulting in increased efficiency, higher power ratings, reduced weight, smaller dimensions and lower costs.

Traditionally, loads are located at some distance from the generation plants, so voltage needs to be increased substantially in order to transmit large volumes of power over long distances. The main purpose of a transformer is to increase the output voltage, resulting in reduced losses, increased transmission capacity, reduced copper/aluminium requirements, etc. Transformer technology is mature and easily available.

1.3.6 Offshore substructures

Offshore substructures are chosen based on a range of variables linked to site conditions and platform properties. The most relevant site conditions are water depth, wave height, soil type and water currents. The main properties of the platforms are size and weight.[43] The final selection is made based on structural and cost-benefit analyses. Basic types of substructures are shown in Figure 9.[44]

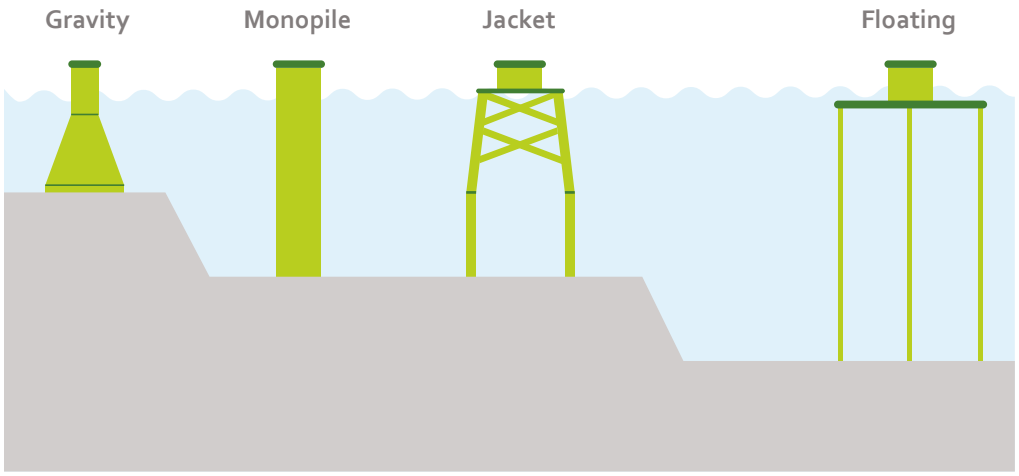

Figure 9. Offshore wind turbine foundations.
Source: Baltic InteGrid

1.3.7 Protection equipment

AC circuit breakers

Circuit breakers are the central part of air-insulated (AIS) and gas-insulated (GIS) switchgear. They are used to disconnect feeders when malfunctions are detected. High-voltage circuit breakers are mechanical switching devices which carry the nominal current in a closed position and break current circuits (operating currents and fault currents).[45] High-voltage breakers can be categorised based on the medium used to extinguish the arc. This can be bulk oil, minimum oil, air blast, vacuum, sulphur hexafluoride (SF6) or carbon dioxide (CO2). Due to environmental and cost concerns over insulating oil spills, recent circuit breakers mostly use SF_6.[46] The technology is mature, and the lifespan of each unit allows 8,000-10,000 operations.

Fault current limiters

As their name suggests, fault current limiters (FCLs) are used to limit the fault current to acceptable levels. While these devices are generally applied in AC systems, the resistance-based concept can also be used for DC systems. Generally, FCLs need to have non-linear properties in order to increase their impact on fault operation as compared to normal operation. However, linear components can also be used for limiting the fault current. FCLs are available in several types: inductors, polymeric positive temperature coefficient resistor-based FCLs,[47] liquid-metal FCLs and superconductive FCLs. The technology is mature and widely available.

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2 Concrete challenges and opportunities

Offshore wind energy is a fast-growing sector with promising applications. It is, however, beset by a number of challenges: capacity limitations of the transmission systems, issues with grid access for offshore wind farms, the intermittent nature of the power produced, high connection costs due to long distances, long lead times on the production of high-voltage cables, legal conflicts and ownership issues, to mention a few. This section looks at some of those challenges and the potential solutions that may be reached through the deployment of new legal and technical instruments or the improvement of existing ones.

2.1 Policy and regulation

Laws and regulations have major repercussions on the construction and operation of offshore grids in the Baltic Sea. This section draws heavily on the in-depth Baltic InteGrid publication 'Establishing an offshore meshed grid: Policy and regulatory aspects and barriers in the Baltic Sea Region' from July 2018.

2.1.1 Definitions of cables and their implications

Power cables are the backbone of any electric grid. In the case of a meshed offshore grid centred on a sea surrounded by land on all sides such as the Baltic, electricity produced in offshore wind farms is transmitted to land via export cables, and transported from shore to shore via interconnectors. The various submarine power cables used for these purposes have different legal status depending on their purpose, and this in turn determines the rules that apply to their laying and operation. Relevant EU legislation is largely contained in the EU's Electricity Directive and Electricity Regulation.

Cables

There are no explicit definitions in EU legislation regarding export cables, so Member States are free to determine their legal status and modalities of operation. For instance, in Finland the power generator is responsible for connecting the plant to the shore. In Germany, on the other hand, export cables are considered part of the transmission grid.[49]

The definition of interconnector used by the Baltic InteGrid project is that of the EU's Electricity Regulation, which refers to it as a 'transmission line which crosses or spans a border between Member States and which connects the national transmission systems of the Member States'.[50]

Meshed grids

Currently under construction, the Kriegers Flak Combined Grid Solution is the world's first link between offshore wind farms in two different countries' EEZs.

Meshed grids introduce questions regarding the legal status of offshore power cables. A good way to start analysing these questions is to consider simpler projects that can be assumed to be a probable first step towards a meshed grid. An example of such a project is one that involves two offshore wind farms, each located within a different country's EEZ, each connected to that country with an export cable, and both linked to each other by an interconnector. This is the concept underlying the Kriegers Flak Combined Grid Solution, which will connect the Danish and German offshore wind farms Kriegers Flak and Baltic 2 in 2019.[51] It is the world's first link between offshore wind farms in two different countries' EEZs.

It is not clear whether this solution can legally be considered as an interconnector under a literal definition of the Electricity Regulation, since the cable connects two offshore wind farms, not necessarily transmission systems as such. In its Clean Energy Package, the EU Commission proposed a common definition for interconnectors in both the Electricity Directive and Regulation, proposing to call them 'a transmission line which crosses or spans a border between bidding zones, between Member States or, up to the border of EU jurisdiction, between Member States and third countries'.[52] In this case the Kriegers Flak Combined Grid Solution would be deemed an interconnector under EU law.

2.1.2 Cable operation

It is unclear whether cross-border interconnectors are part of national transmission systems under EU legislation, as the latter are not explicitly defined. The Electricity Directive states that TSOs are 'responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems [...]'.[53] This implies that any interconnector managed by a TSO is by definition part of the relevant national transmission system. The Electricity Regulation furthermore states that factors such as independence requirements apply to interconnectors in the same way as they do for the rest of the transmission grid. At the same time, the Regulation exempts merchant interconnectors from these rules, implying that such interconnectors, at least, are not legally part of the transmission system.[54]

Dual-purpose cables

In a meshed grid, some cables will function sometimes as an export cable, sometimes as an interconnector – and sometimes even both at the same time, if part of their capacity is used to transport electricity from the offshore wind farm to shore and part to transmit power from one shore to the other (Figure 10). This situation is found at the Kriegers Flak constellation.

The differences in legal status between interconnectors and export cables – the fact that they are operated by different actors, say – can make the operation of a meshed grid quite complex, especially if a cable functions as both interconnector and export cable at the same time. A legal argument could be made that the portion of the capacity used to transmit electricity from the offshore wind farm is not open to non-discriminatory third-party access and thus in contravention of the Electricity Regulation.[55] In addition, the question of priority access or guaranteed access of renewable energy sources in accordance with the Renewable Energy Directive must still be addressed in transitional projects and meshed grids (this is very likely to be abolished with the Clean Energy Package, however).

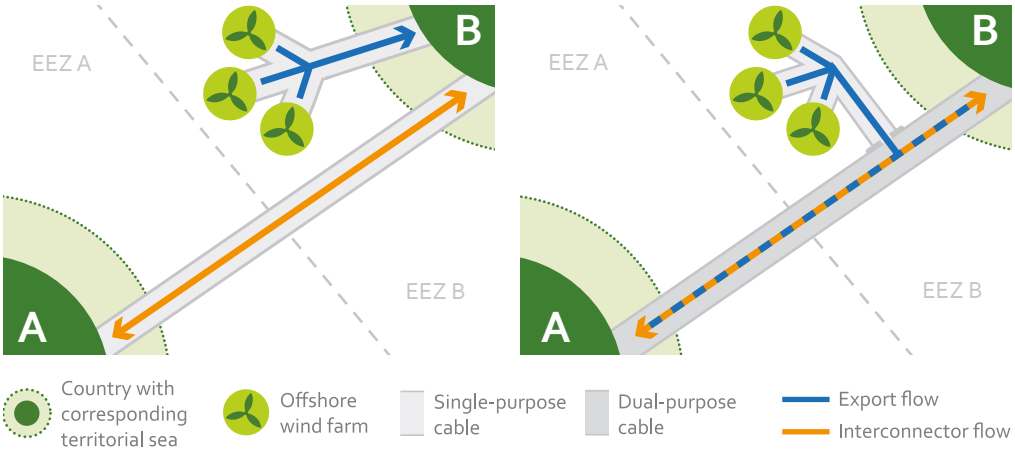

Figure 10. Dual-purpose cable in a meshed grid constellation.
Source: IKEM (2018)

In the Kriegers Flak Combined Grid Solution, which can be considered a small-scale meshed grid, the Danish national regulatory authority has determined that electricity transmitted to Denmark from the Kriegers Flak wind farm should have priority access over power arriving from Germany. The reasoning for the decision was that Kriegers Flak should be treated the same as other wind farms in Denmark, and Danish law specifies that power produced by offshore wind farms must be accommodated within the grid.[56] While the decision does not explicitly mention cross-border transmission, in practice it gives priority to power produced by the Kriegers Flak offshore wind farm to the potential detriment of the interconnector portion of the cable.

Before meshed grid developments can be more widely implemented, legal and operational uncertainty will need to be resolved, and legal definitions that can accommodate a greater number of meshed grid designs adopted.

2.2 Planning

The management of planning issues, including permits and impact assessments, is crucial to the efficient operation of a Baltic Sea offshore grid. This section builds on insights from the Baltic InteGrid publication 'Spatial planning: Spatial maps and variants of Baltic Grid component locations' from September 2018.

2.2.1 Maritime spatial planning

Offshore wind is just one of the many different interests and sectors among which maritime space is shared. Maritime spatial planning (MSP) is a crucial tool that allows maritime activities to be coordinated and sectoral interests to be balanced efficiently. This in turn facilitates more sustainable use of marine resources and the exploration of new economic opportunities. The EU Directive on MSP (2014) outlined the need for the cross-border integration and coordination of marine activities in Europe's seas.

Maritime spatial planning is a crucial tool that allows maritime activities to be coordinated and sectoral interests to be balanced efficiently.

According to the MSP Directive, all Member States must adopt maritime spatial plans by 31 March 2021. Of the countries in the BSR, only Germany and Lithuania have a national plan in place already, while those of the other countries (Denmark, Estonia, Finland, Latvia, Poland and Sweden) are still in the developing stages. The implications of maritime spatial plans for the energy sector differ among the countries in the BSR. The plans create a formal base for allocation of sea space for offshore wind farms and transmission systems, while specifying a range of legal requirements. These include specifications such as minimum distance from shore (for instance, in Estonia this is 10–12 km, and in Latvia 8 km; in Denmark it is 4 km from shore for wind farms with a capacity up to 200 MW and 20 km for larger-scale offshore wind farms[58]), minimum depth (in Lithuania this is 20 m), or the designation of areas for offshore wind energy development only within the EEZ (the case of Germany and Poland). In Sweden, the location of offshore wind farms is decided case by case and coordinated by the energy authority.

2.2.2 Permitting procedures

The permitting procedures for the construction of offshore wind farms and the laying of offshore cables are defined at the national level. In some countries, the transmission lines between the transformer substation and onshore connection point to the transmission grid are built or financed by the operator; in such cases, these cables are included in the permits.[59] In other countries they are part of the transmission grid and subject to a distinct permitting procedure.[60] This can complicate projects for developers of cross-border projects, especially foreign investors.

2.2.3 Environmental impact

Offshore wind farms are usually constructed in relatively shallow waters, which often have high ecological value and may represent important habitats for breeding, resting and migrating seabirds and other species.[61] Projects require large surface areas for components such as turbines, cables and substations. The construction, operation, and decommissioning of offshore wind farms entail significant interactions with the surrounding environment. It is important to note that environmental effects are most likely to occur during the construction and decommissioning phases.[62]

The EIA Directive dictates that the environmental impact of projects which are likely to have significant effects on the environment must be assessed.

The EIA Directive dictates that the environmental impact of projects which are likely to have significant effects on the environment must be assessed. The concrete list of projects for which an EIA is required provided by the Directive does not include offshore wind farms or submarine cables (an EIA is only mandatory for the construction of overhead electrical power lines with a voltage of 220 kV or more and a length of more than 15 km); however, a separate list of projects for which Member States are free to require an EIA list includes 'industrial installations for the production of electricity, steam and hot water', which potentially includes offshore wind farms. In practice, there is a range of different practices regarding EIAs among the countries in the BSR.

2.2.4 Challenges to permits

Challenges to the construction or operation of offshore wind and related onshore facilities can substantially slow down or complicate the construction of wind farm infrastructure. The risk and repercussions must be carefully considered in the planning phase preceding every project.

Affected third parties

Third parties whose subjective rights – such as physical integrity or property rights – are affected by the completion of a project can generally challenge a project permit by appealing to an administrative body to revoke the authorisation. They can also request the withdrawal of the authorisation through legal proceedings before a court. The respective general administrative laws of each country determine how these remedies and proceedings are carried out.

Environmental organisations

Another possibility to challenge authorisations is available to environmental organisations under national legislation in accordance with EU law.[63] Environmental organisations with sufficient interest are given an opportunity to challenge the legality of administrative decisions that are subject to public participation. Unlike affected third parties, environmental organisations do not need to experience a violation of a subjective right as a result of the authorisation to seek a legal remedy.

Planning and permitting procedures, especially as related to environmental impact, must be carefully considered in the early stages of any offshore wind project.

2.3 Public acceptance

Offshore wind energy projects increasingly face opposition from local populations, which delays and sometimes stops their implementation. Examples of offshore wind projects that have recently faced local opposition are the nearshore projects Vesterhav Syd and Vesterhav Nord along the west coast of Denmark. Overall, there is strong public support for transitioning to low-carbon energy systems. However, opposition to specific renewable energy projects often emerges at the local level. This illustrates the frequent gap between support for the general concept of renewables as a strategy for reducing carbon emissions on the one hand, and the acceptance of renewable energy installations in the local land or seascape on the other.

The topics explored in this section are discussed at greater length in the Baltic InteGrid publication 'Establishing an offshore meshed grid: Policy and regulatory aspects and barriers in the Baltic Sea Region' from July 2018.

2.3.1 Common objections to offshore wind projects

The local acceptance of renewable energy technologies generally depends on physical and technical issues, potential damage to the health of concerned populations and to the environment, financial factors, perceived distributional fairness, and the institutional framework, including decision-making procedures.

The physical and technical factors include the visual impacts of renewable energy installations, such as perceived aesthetic intrusion by wind turbines or flashing lights at night. Visual impact assessments are therefore often recommended as part of EIAs. Uncertainty about the health impacts of a facility can be another important contributor to local opposition. The hum of rotating turbine blades and low-frequency noise are a frequent concern. Offshore wind farms may affect property value if they are visible from shore. In some countries, such as Denmark, there are mandatory minimum distances from the shoreline or dwellings, as well as noise thresholds.

Another potential complication are the symbolic and affective aspects of renewable energy development, including perceptions of whether costs and benefits are allocated fairly. Local populations' attitudes often largely depend upon the perceived possibility to influence decision-making, and research shows that they frequently feel they have little influence on where a wind project is sited or how it is designed. If people doubt the credibility of the information they receive or their ability to influence decision-making, they are less likely to participate in consultations or support a project proposal. Critical attitudes may also be triggered by suspicion of the developer's motives, particularly if developers have no local connection, which is often the case with large national or multinational energy companies.

Local authorities need to be sensitive to local opposition and balance the negative local impacts of renewable energy projects against wider national or global benefits. This can be a challenge if the legal framework does not provide for adequate balancing of these – sometimes conflicting – interests. Local authorities may have limited resources or lack expertise to assess technical studies on wind turbine impacts. Nevertheless, developers and governments cannot avoid addressing potential conflicts with local interest groups. Failure to do so increases the risk of delay or cancellation. Meanwhile, as projects and installations increase in size, the impact on seascapes, coastal landscapes and local communities can only be expected to increase.

2.3.2 Increasing acceptance through participation

Planning procedures ensure public participation in decision-making processes. This not only improves the underpinnings of the decision-making, but also ensures local legitimacy and acceptance. It can address local mistrust of project developers, the decision-making process or the public authorities competent to approve the project.

Public participation is a core element in environmental assessment procedures, as reflected in the EIA, SEA, Public Participation and Freedom of access to information Directives. It is therefore incorporated into the planning law and procedures of the countries in the BSR. Nevertheless, countries have their own specific environmental assessment procedures.

2.3.3 Increasing acceptance through financial incentives

The possible impact of renewable energy projects can be mitigated through financial incentives, such as compensation for reductions in property value. This can lead to a fairer distribution of profits and losses and thus greater public acceptance of the project. Another possibility is to offer local populations the option to become financially involved in a project through ownership measures. Studies have shown that financial involvement of local populations in renewable energy projects increases acceptance by promoting a feeling of local control and a sense of ownership of the project. Other solutions are also possible: in the Smalininkai onshore wind project in Lithuania, for example, an agreement was made to invest a portion of the income from the local renewable energy project into improving the town infrastructure; local residents have expressed satisfaction with the arrangement.[64]

The possible impact of renewable energy projects can be mitigated through financial incentives, such as compensation for reductions in property value. This can lead to a fairer distribution of profits and losses and thus greater public acceptance of the project. Another possibility is to offer local populations the option to become financially involved in a project through ownership measures.

Opponents of offshore wind projects – mostly near-shore – are not always motivated by self-interest, fear of development or a failure to understand the importance of combatting climate change. Reasons to oppose such projects range from specific environmental concerns to a lack of transparency or inclusiveness in the decision-making processes. It is therefore important to ensure public participation and provide information in a timely fashion.

2.4 Construction issues

An offshore grid includes both offshore wind farms and transmission infrastructure – inter-array cables, export cables and transformer stations. The timeframe and deadlines for their construction, as well as relevant liability conditions, are defined by national legislation, which therefore plays an important role in the operational development of projects. The competent public authority often works together with project developers to establish a roadmap for the construction.

In the Baltic Sea, construction operations are subject to specific geological, meteorological, and infrastructural conditions that can jeopardise construction or lead to delays. For example, construction works can be significantly delayed due to challenging weather conditions. Icy conditions must also be taken into account when siting the wind farm and planning the foundation for the turbines. Other obstacles include the discovery of leftover war equipment or munitions or shipwrecks on the seabed.

The insights in this section are based largely on the Baltic InteGrid publication 'Establishing an offshore meshed grid: Policy and regulatory aspects and barriers in the Baltic Sea Region' from July 2018.

2.4.1 Grid connection

Technical requirements for plant connection to the grid are set at EU level by the Commission Regulation (EU) 2016/631 establishing a network code on requirements for grid connection of generators and HVDC network codes, while connection claims are governed at the national level. In Denmark,[65] Finland[66] and Poland[67], for instance, the grid operator is obligated to connect any wind power plant that fulfils the grid connection

Varying conditions found in different countries can represent substantial barriers to the smooth construction, operation and integration of offshore wind facilities.

requirements, and in Germany[68] and Lithuania[69] the TSO must connect renewable energy plants even if the connection requires the grid to be optimised or expanded. Meanwhile, in Estonia[70], Latvia[71] and Sweden, the grid operator may refuse to connect a plant if the grid capacity is insufficient.[72] These varying conditions must be taken into account by developers, and can represent substantial barriers to the smooth construction, operation and integration of offshore wind facilities.

2.4.2 Timeframe

A construction schedule can be set by law or by an administrative act, for example the construction permit. There is a great deal of diversity among national legal frameworks. In Latvia, for instance, construction work must begin within four months after a permit becomes non-appealable.[73] In Finland, the deadline is within three years after the construction permit or four years after the water permit is obtained; the work must then be completed within three, five, or ten years, depending on the permits required.[74] In Estonia, all work must be completed within seven years.[75]

2.4.3 Liability for delays

The liability for construction delays depends on the respective national legal framework and may or may not be set out in the tender material. In Denmark, if the TSO fails to provide the transmission infrastructure necessary to connect an offshore wind farm, it is liable for some of the losses incurred by the tenderer.[76] Liability also goes the other way: in Germany, tendered capacity is only granted after a security deposit has been paid; this deposit is kept as a penalty if the project developer misses a deadline set by the Offshore Wind Energy Act.[77]

In Latvia, the terms of the connection are set in a connection contract between the TSO and the operator of the offshore wind farm. If the plant operator breaches the agreement (for example by terminating it prematurely) and the construction has already started, it must compensate the costs incurred by the TSO. If the connection is delayed, the party at fault must pay a penalty of 0.01% of the connection fee per day up to a maximum of 10%. If the delay has lasted more than 40 days, the connection contract is deemed terminated.

Missed deadlines can also lead to the withdrawal of permits. This is the case in Poland, for example, if a tenderer does not obtain a construction permit within six years after an artificial island permit is issued, does not begin construction within three years after obtaining the final construction permit, or does not initiate operation of the offshore wind farm within five years after beginning construction. In Estonia, on the other hand, liability is not specifically prescribed by law.

2.4.4 Decommissioning

Plans for future decommissioning need to be considered during the planning stage due to the potential environmental impact of the works involved. Removing facilities usually has an adverse effect on the surrounding flora and fauna (e.g. marine mammals, sea birds, fish and crustaceans) in the form of noise and seabed disturbances. National environmental laws stipulate that the environmental impact of the decommissioning process must be minimised.

The building, grid connection and dismantling of offshore wind facilities are regulated by stringent laws and/or contractual obligations in each of the BSR countries. Contractors and operators must be aware of these rules, and differences between jurisdictions, throughout the lifecycle of their offshore facilities.

The countries in the BSR differ in the legal approach used to regulate the decommissioning of structures. Nevertheless, it is possible to discern a common framework: the decommissioning operations generally must take place under the strict control of a public agency, which is in most cases the same authority that grants the concessions or issues the construction or water permits.

2.5 Components

Europe has a global edge in offshore wind power generation and transmission, and hosts most of the relevant technology and components production in the world. The producers, suppliers and installers established in Europe include names such as Vestas, Siemens and ABB.

Europe has a global edge in offshore wind power generation and transmission, and hosts most of the relevant technology and components production in the world.

More information on these topics is available in the Baltic InteGrid publications 'Qualified overview paper: Market and supply chain analyses overview and business opportunities for SMEs in the Baltic Sea Region for offshore wind transmission assets' from October 2018 and 'Offshore wind power plant technology catalogue: Components of wind power plants, AC collection systems and HVDC systems' from October 2017.

2.5.1 Markets

Offshore wind energy is expected to play an important role in the future European energy mix. In 2018, offshore wind capacity in Europe totalled 18.5 GW.[78] The cumulative share in the BSR was 12%, with most of the capacity located in Denmark and Germany. WindEurope estimates that European wind capacity could reach 70 GW by 2030.[i, 79] According to the scenarios established by the Baltic InteGrid project, the total installed capacity in the BSR could reach 9.5 GW by 2030.

[i] *According to the medium-expansion setting (high expansion would entail a potential of 99 GW of installed capacity by 2030, whilst low expansion would involve 49 GW for the same year).*

2.5.1.1 Submarine cables

HVAC cables

Figure 11 shows the demand forecast for HVAC cables in the Baltic Sea in the high and low-expansion settings defined by the Baltic InteGrid project. High capital intensity and expertise requirements, as well as the increasing demand for turnkey solutions, are significant barriers to entry for new suppliers. Manufacturers are expected to be able to adjust their supply to meet the increasing demand. However, rising demand may put a strain on the available fleet of installation vessels. New cable manufacturing facilities are unlikely to be established in the BSR in the medium term due to the relatively small market size. SMEs may find business opportunities in the operations, maintenance and service (OMS) segment, however.

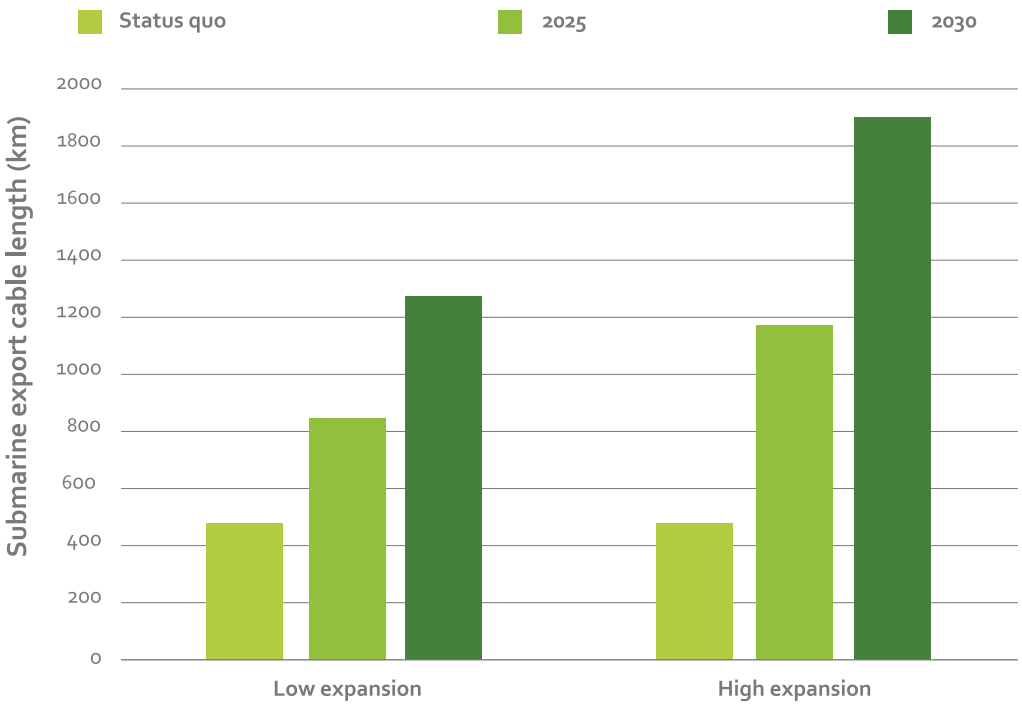

Figure 11. Cumulative demand for HVAC submarine cables forecast in the Baltic Sea.
Source: Baltic InteGrid

HVDC cables

Figure 12 shows the demand for HVDC submarine cables in the Baltic Sea until 2030 based on development scenarios calculated by the Baltic InteGrid project. There is more demand expected in the low-expansion setting than the high-expansion setting because the former would be based on more radial connections, whereas the latter assumes clusters of offshore wind farms.

While HVDC cables are likely to be applied more and more in the industry, and their price is bound to fall over time, uncertainty and risks associated with the technology make it challenging to predict demand with precision. If demand does increase rapidly, current production capacity may be insufficient to avoid shortages – but any gap is likely to be filled by the established manufacturers.

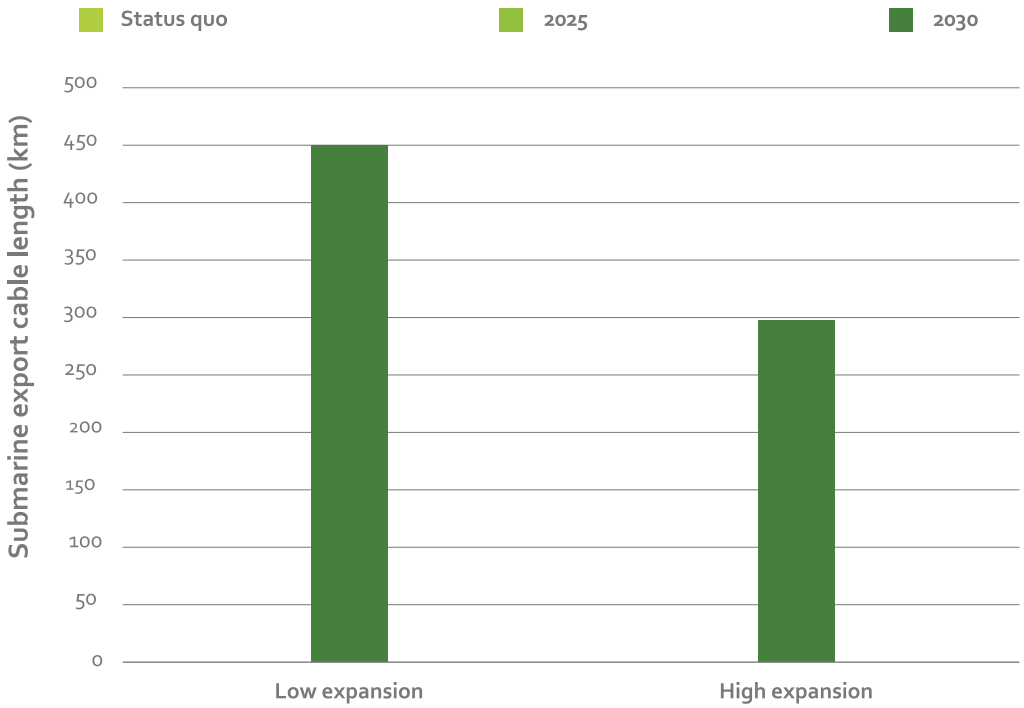

Figure 12. Cumulative demand for HVDC submarine cables forecast in the Baltic Sea.
Source: Baltic InteGrid

2.5.1.2 Substation components

Transformers

The market for transformers in the BSR is expected to continue to grow, and further innovations are anticipated – Figure 13 shows the demand forecast for the low and high-expansion settings. Track record requirements are likely to make it challenging for new arrivals to enter the market. Potential bottlenecks may appear in the supply of tap changers and copper windings. While offshore power transformers are expected to increase in capacity, their prices will remain relatively stable, leading to improvements in power density but not in capital expenditure.

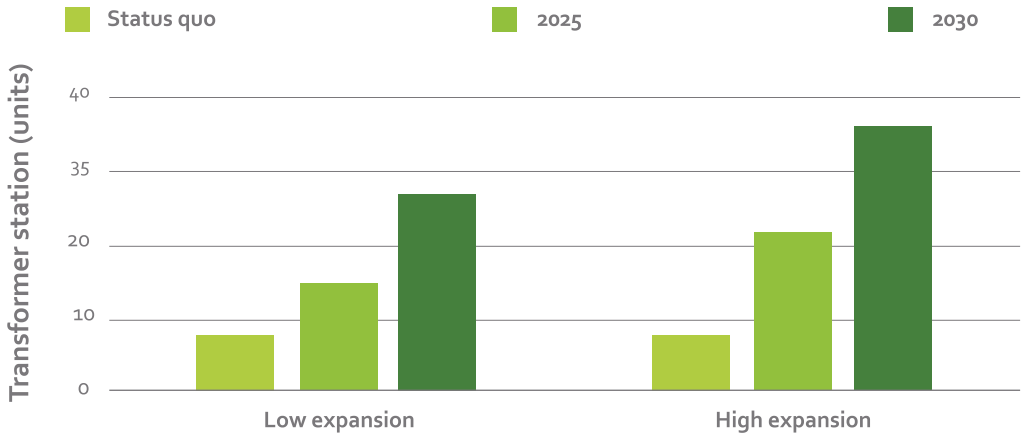

Figure 13. Cumulative demand for offshore transformer stations forecast in the Baltic Sea.
Source: Baltic InteGrid

DC technology

The use of HVDC for submarine connections of meshed offshore grids is currently hampered by limitations in the technology, as much of the relevant technology – circuit breakers especially – is not yet commercially mature. The potential applications are highly promising, however.

DC-DC converters

There are substantial variations in the DC voltage used in various systems – for example, several different DC voltage levels are currently used in offshore wind integration in Germany. There have been efforts to standardise voltage levels, thereby eliminating the need for DC-DC conversion. The fast progress in converter and cable technology means that significantly higher voltages can be expected in the future, however, so agreeing on a standard now could waste possible benefits from improved voltage ratings in the future.

While DC-DC conversion can be carried out by using a DC-AC converter and an AC-DC converter, it would be least expensive and most efficient through DC-DC converters.

While DC-DC conversion can be carried out by using a DC-AC converter and an AC-DC converter, it would be least expensive and most efficient through DC-DC converters. The latter would also have the advantage of regulating the current or power flow, which would help in the operation of a theoretical meshed DC grid. They could even be applied for this purpose only, connecting two buses of the same voltage level.[80] If a common DC voltage is not agreed, DC-DC converters will continue to be required in the medium and long term, not least for the smooth operation of a hypothesised large-scale future HVDC grid (a so-called super grid).[81, 82] In this sense they would play the same part as transformers do in the normal AC grid.

Only one converter station is expected to be installed in the BSR by 2030 in both the high and low-expansion settings. Recent technological developments are leading to reductions in surface area and size, reducing the cost of installation and OMS. Key factors that may hamper the installation of converter stations in the future include transmission congestion and instability, high initial costs, lack of grid infrastructure investments and lengthy approval processes. Requirements in terms of track record and the small market size mean that the converter market will continue to be the preserve of large, established companies for the foreseeable future.

DC circuit breakers

In future HVDC grids, DC breakers would be needed to isolate faulty segments during earth faults (other kinds of malfunctions could be handled by converters or slower DC switches). Generally, DC breakers have to quench fault currents with very fast rising times, since, unlike AC circuits, DC circuits operate without a natural zero crossing current. Electronic breakers can operate very quickly but have relatively high on-state losses. Hybrid breakers have a mechanical bypass path to reduce losses to near zero (60 kW at 320 kV DC) while maintaining clearance time.[83]

DC circuit breaker technology is not yet commercially available or ready for large-scale deployment. Although manufacturers like ABB and Siemens have developed and tested DC circuit breakers for HVDC applications, these have not been implemented inpractice yet.[84, 85] This makes it difficult to estimate how much they will cost; however, the expenditure is expected to be in the range of tens of millions of euros.

Foundations

Figure 14 shows the demand for substation foundations forecast for the Baltic Sea in the low and high-expansion settings. The market is mature, with high barriers to entry due to the capital intensity and know-how requirements of the industry. No major bottlenecks are foreseen, and prices are expected to decrease with technological improvements and increased experience. Furthermore, some experts have reported that they foresee an increase in non-European supply. Increasing demand for wind farms built in greater water depths is contributing towards the development of floating foundations, which could enable the installation of offshore wind farms at depths surpassing 100 metres in the medium term.

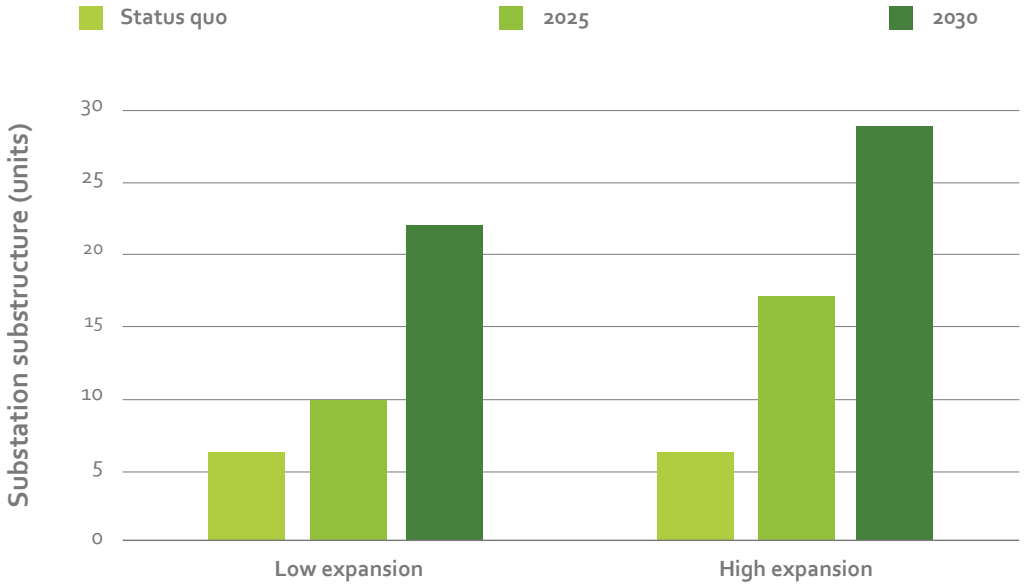

Figure 14. Cumulative demand for substation foundations forecast in the Baltic Sea.
Source: Baltic InteGrid

2.5.1.3 Operation, maintenance and service

The OMS market is expected to provide expanding opportunities to a wide range of established companies and new market entrants. There will be space for new players to compete as long as they offer cost reductions. Future savings are expected to emerge from developments such as further improvements in weather forecasting; remote monitoring, inspections, and repairs; condition-based monitoring; offshore logistics; and a holistic approach to OMS strategy. Condition-based maintenance is expected to be applied to HVAC technologies in the early 2020, and to other system components by 2030. Provision of services by third parties is also expected to grow. Additionally, there has been an increasing trend towards the entry of large manufacturing companies that offer new OMS products such as turnkey solutions.

Future savings are expected to emerge from developments such as further improvements in weather forecasting; remote monitoring, inspections, and repairs; condition-based monitoring; offshore logistics; and a holistic approach to OMS strategy.

2.5.2 Supply chains

2.5.2.1 Submarine cables

Manufacturing submarine cables requires highly specialised facilities, since they are produced in very long lengths to reduce the number of joints. This involves special production techniques, such as vertical continuous vulcanisation (VCV) or catenary continuous vulcanisation (CCV).

Market entrants face high costs associated with the building of new manufacturing facilities, the recruitment of skilled workers, the acquisition of specialised cable-laying vessels and the development of specialised expertise. It is more difficult and riskier to produce HVDC cables than HVAC cables, as the technology underpinning the former is less well-established.

The demand for offshore wind export cables is expected to increase, and interviews with major European suppliers have shown that manufacturers are ready to adjust their production capacity to avoid bottlenecks. However, some respondents pointed out that rising demand may lead to insufficient capacity in terms of the installation vessels available.

2.5.2.2 Substation components

Converters, transformers and protection equipment

The use of converters within the offshore wind industry is relatively new, with only eight installed until today (all in German waters in the North Sea). The technology is associated with high costs and implies a level of risk that only large companies can generally bear.

Foundations

Market entry by SMEs in this segment remains difficult due to the high capital intensity of the sector. Larger companies could consider entering the market by creating a subsidiary and drawing from expertise already existing in the field. An example of this is Steelwind Nordenham, an established steel producer that is part of the Dillinger Group.

2.5.2.3 Operation, maintenance and service

There is an increasing trend in the industry towards condition monitoring, since this allows the continuous observation of assets to detect wear or corrosion in a timely manner. This technology can potentially extend the service life of components and help avoid costly production losses.

Manufacturing companies are increasingly offering maintenance and servicing solutions. Subcontracting of OMS activities is also often observed in the industry and represents a promising business opportunity for local SMEs.

Service activities can include end-of-service-life solutions in which manufacturers provide solutions for or take over the decommissioning process as well as the disassembling of the products. Furthermore, manufacturing companies are increasingly offering maintenance and servicing solutions. Subcontracting of OMS activities is also often observed in the industry and represents a promising business opportunity for local SMEs that wish to enter the offshore wind supply chain.

Technical developments relevant to offshore wind in particular – especially in long-distance power transmission – are ongoing, and are likely to make the related processes more efficient and streamlined. Even so, there are still questions about the degree of integration that can be expected in offshore grids in the Baltic Sea in the future, and which technologies and procedures will turn out be the most cost-effective.

2.6 Technology

Most of the components necessary for the development of an offshore grid are available today or will be in the near future. The main uncertainty lies with the lack of operational experience with some of the components, most notably the DC breakers.

Since the offshore grid is most likely to be developed in stages, rather than all at once, the capability of converters from different vendors to operate with each other (their interoperability) will be the main relevant technological challenge. Ensuring interoperability will also pave the way towards harmonisation, and then standardisation, of the requirements for offshore grids.

A substantial portion of capital investment in a meshed grid is related to electrical infrastructure and grid connection costs. The Baltic InteGrid project therefore considered various ways to minimise these costs, especially the optimisation of export cables for transfer of power from offshore wind farms to the onshore grid.

Export cable optimisation

The size of export cables is typically determined according to the CIGRE and IEC standards. However, these standards consider steady state conditions under rated operation, that is, a continuous conductor temperature equal to 90°C and nominal electric field. The limitation of the conductor temperature at this value is due to the close contact with the insulation material, which represents the most critical element in a cable. This criterion may be too conservative considering that offshore wind farms present a typical capacity factor of around 0.4-0.5. A range of different concepts therefore need to be combined to develop a methodology capable of estimating the lifespan of cables operating under real conditions, such as time-varying cyclic power generation, thermal and electrical stress, thermal transients, capacity currents and failure probability.

The Baltic InteGrid project developed a six-step methodology to optimise the design of export cables based on site-specific data such as power generation and seabed temperature. (Further details on the methodologies can be found in the project research publications.) A case study realised within the project looked at an offshore wind farm with a total capacity of 456 MW[i], 89 km of export cables, a nominal voltage and frequency of 275 kV and 50 Hz respectively, an aggregated power factor of 1, and no compensation units. The IEC criterion would dictate a cable of 1200 mm² for such a windfarm, but the study found that a cable of 800 mm² would suffice to satisfy all the operational constraints and ensure a secure, reliable, and effective operation for the duration of the project.

Decreasing the cross-section of export cables was found to reduce the LCOE share related to export cables, providing savings of approximately 5%.

Decreasing the cross-section of export cables reduces the levelised cost of energy (LCOE) share related to export cables ($LCOE_{es}$), providing estimated savings of approximately

[i] *With 38 wind turbines of 12 MW.*

5%. A comprehensive sensitivity analysis of this case study has shown the importance of gathering accurate data related to thermal properties of the soil (thermal resistivity and capacitance) and seabed temperature.[86]

2.7 Assessment of Baltic hubs for offshore grid development

An evaluation of Baltic ports was carried out in the framework of the Baltic InteGrid project to determine their suitability as potential future hubs for activities related to the construction, operation and maintenance of offshore wind facilities. This involved creating an overview of the existing supply chain capability in the BSR and then drawing up a list of opportunity ports. These were selected from a list of 306 Baltic ports based on water depth, the ability to accommodate vessels used in the offshore wind transmission market, proximity to current and future offshore wind projects, accessibility, availability, and synergies with existing supply chains.

This resulted in a shortlist of 14 opportunity ports, each of which was assessed for port infrastructure relevant to export cables and substations at each supply chain lifecycle stage: manufacture, installation and maintenance. The assessments used publicly available information, with support provided with the relevant port authorities where necessary.

This process is described in more detail in the Baltic InteGrid publication 'Assessment of Baltic hubs for offshore grid development' from February 2018.

2.7.1 Existing capability

Export cables

The primary opportunities for Baltic hubs are expected to be in the short-term storage of cables prior to installation, long-term storage of spare parts and accommodation of vessels for cable survey and repair.

The primary opportunities for Baltic hubs are expected to be in the short-term storage of cables prior to installation, long-term storage of spare parts and accommodation of vessels for cable survey and repair, where current port infrastructure is likely to be adequate. Several cable suppliers and installers in the BSR also have the capacity to provide cable service work packages.

Substation structures

New infrastructure would be required to accommodate the large vessels used in major substation component replacement and repair; however, there is little demand for this activity in the BSR. There are companies in the region with the capacity to perform minor maintenance on substation structures.

Substation electrical equipment

The current port infrastructure is likely to be adequate for the supply of electric components to substations, as this does not require high-specification ports or dedicated infrastructure. Owner-furnished equipment, primarily power electronics, can be brought to substation structure fabrication yards from outside the BSR by truck, rail, barge or ship. Crew vessels are required to access the substations for the installation of high-voltage electrical equipment; however, demand is low, and such work does not require highly specialised infrastructure at any rate. Some specialist electrical work packages can be performed by companies in the BSR.

Figure 15. Location of Baltic InteGrid opportunity ports.
Source: Baltic InteGrid

2.7.2 Opportunity ports

The 14 opportunity ports identified for further assessment are listed in alphabetical order and their location in the BSR is shown in Figure 15. Assessments for each port were made considering the port authority area as a whole rather than specific facilities or locations within it.

2.7.3 Findings

The BSR is well positioned for the manufacturing and installation of export cables thanks to its strong existing supply chain, including port infrastructure at the point of supply. There are a high number of cable manufacturing facilities in the BSR due the regional demand for interconnectors. This means there is no clear demand for major new manufacturing and installation infrastructure in the BSR. Some ports are likely to benefit from nearby manufacturing facilities or offshore wind farms for the provision of vessel services or short-term cable storage, for instance.

The BSR has sufficient port infrastructure in place to meet demand for substation structure and electrical supply and installation. While there is some capability for the production of substations, demand is low, and supply is likely to come from outside the region. There is also not much demand for new supporting infrastructure for the manufacture and installation of substations or electrical equipment.

Opportunities

There are many ports in the BSR with the capacity to become hubs for the maintenance supply chains of offshore transmission assets.

There will be more opportunities for BSR hubs in the OMS segment than in the manufacture and installation of offshore transmission components. There are many ports in the BSR with the capacity to become hubs for the maintenance supply chains of offshore transmission assets. As these operations do not require specialist port infrastructure, ports that are yet to develop experience in the offshore sector, such as those in the eastern Baltic, may have an opportunity to establish themselves in this field. Offshore transmission maintenance supply chains are also more sensitive to distance from the installed transmission system, and so need to function locally.

BSR ports can capitalise on their experience in areas such as cargo handling and logistics to improve their position in the manufacturing, installation and maintenance of transmission infrastructure. Moreover, hubs around specialised facilities can further drive economies of scale and co-location.

Challenges

The main barriers to developing the optimal port infrastructure in the BSR are competition from outside the region and the relatively low level of demand. There is also competition for space and quays from within the port areas themselves. Publicly owned ports are more likely to accept a new industry entering the port authority based on the economic benefit for a wider municipal area than privately owned ports, which will assess a change to the utilisation of port infrastructure purely on financial merit. There is also lack of certainty about the dates and total volumes of transmission grid that will be needed, which is a risk to ports considering investing in further infrastructure.

Future developments

German ports and supply chains will likely continue to serve the offshore transmission sector in the BSR beyond projects installed in German waters.

Current BSR transmission supply chains are predominantly located in Denmark and Germany. Although Denmark has the highest installed capacity within the BSR right now, Germany is anticipated to install a greater volume by 2030. German ports also have the most infrastructure, thanks in part to their strong connections to continental European industries. German ports and supply chains will likely continue to serve the offshore transmission sector in the BSR beyond projects installed in German waters.

For all these reasons, the ports likely to develop into and remain hubs for the offshore transmission sector are mostly found in Germany. Ports in countries whose offshore wind sectors are in their infancy, such as Poland, Lithuania, Latvia and Estonia, will thus have to compete against the experience and track record of German hubs once their own offshore wind projects are ready to be developed.

2.8 SME business cases

The Baltic InteGrid project studied the offshore wind transmission market across three supply chain areas: export cables, substation structures and substation electrical systems. A four-stage lifecycle was further considered for each supply chain, covering development, manufacture, installation and maintenance. Thirty-seven work packages that could be delivered by SMEs were identified, with the largest potential contract estimated to be worth up to some €10 million.[87]

Each of the 37 work packages was further assessed for future demand growth, required investment size, synergies with other sectors, level of competition, complexity of interfacing, and relevance of proximity of customers. These assessments, along with five case studies of SMEs located in the BSR that have won subcontracted work packages, were used to draw conclusions about the challenges and opportunities facing SMEs entering the offshore wind energy transmission market.

The SME work packages are explored at length in the Baltic InteGrid publication 'Baltic offshore grid SME business cases' from February 2018.

2.8.1 SME work packages

The 37 work packages identified by the study that could be delivered by SMEs are summarised in Table 1. Some packages – such as diving services, crewing services, and crew transfer vessel services – are contracted across several supply chain elements or lifecycle stages.

	Export cables	Substation structure	Substation electrical
Development	Cable design	Structural design analysis	System design
	Cable ancillaries design	Logistic analysis	
	Cable route engineering	Sea fastening design	
Manufacturing	Factory jointing	Architectural steel	Busbars
	Cable ancillaries manufacture	Secondary steel	Heating, ventilation and air conditioning
	Equipment servicing	Signage	Fire detection and suppression
	Transport and storage	Sea fastening manufacture	Lighting
		Cable routes and trays	
		Cranes	
Installation	Cable protection	Port services	
	Route clearance and pre-lay grapnel run	Crewing services	
	Unexploded ordnance survey and removal	Crew transfer vessel services	
	Remotely operated vehicle services		
	Diving services		
	Cable termination and testing		
	Cable surveying		
	Trenching tools		
Maintenance	Repair jointing	Asset inspection services	Safety checks
	Fault monitoring		

Table 1. The 37 SME work packages considered in the study.
Source: Baltic InteGrid

2.8.2 Findings

Offshore wind developments in the BSR are expected to lead to an increase in demand across most of the work packages identified in the study. The size of demand will vary depending on the supply chain element and lifecycle stage. The strongest growth is likely to be found in crew services and crew transfer vessel services that are required in both the installation and maintenance of offshore transmission assets. While almost all work packages will grow at least a little, it is unlikely that an SME located in the BSR can form a business case for entering the offshore wind transmission market based on serving this industry alone. Work packages with the lowest barriers to entry for SMEs will tend to be ones with lower growth opportunities.

The strongest growth in demand for work packages that could be delivered by SMEs is likely to be found in crew services and crew transfer vessel services that are required in both the installation and maintenance of offshore transmission assets.

Challenges

The criteria used to assess the challenges for the entry of SMEs into markets related to each work package show that the greatest challenge will be existing competition. Many work packages require highly specialised skills or an established track record, which can be difficult for SMEs to obtain. These packages are most likely to be kept in-house by the primary fabrication or installation contractors and may only become available to SMEs when the contractor has insufficient in-house capacity to fulfil multiple contracts at once. When subcontracting opportunities do arise they are likely to be won by large companies.

Prospects

An SME looking to enter these highly specialised areas should look to recruit experienced individuals from competitors. Companies that have experience supplying similar industries, such as oil and gas, are more likely to be able to transition into the offshore wind energy transmission market. To demonstrate a credible track record within offshore wind and compete with experienced suppliers, SMEs must highlight their technical, commercial and logistical experience in applications relevant to offshore wind. Gaining a detailed understanding of the technology, supply chain and contracting approaches is essential to identifying key potential customers.

For more specialised packages, partnerships with existing offshore wind suppliers can help establish credibility and will often be an effective way to enter the sector. Similarly, an SME considering entering the offshore wind market should consider that its potential customers may also be in parallel sectors thanks to synergies with other markets.

Many work packages can be contracted as single packages to reduce interfacing complexity and risk to the end client. Some work packages – such as offering both design and manufacturing work – will still be better provided in combination, however. SMEs in the BSR who have been successful in entering the offshore transmission sector tend to demonstrate capability in multiple areas.

Large-scale supply chains

Although demand will increase significantly in the BSR by the end of 2030, offshore wind infrastructure will also be installed in significant volumes across the North Sea and at more moderate levels in the Atlantic and Mediterranean. Offshore wind functions within a truly integrated European supply chain, and many tasks are carried out by suppliers who are not located near their sub-suppliers or end clients. SMEs should consider their capability to export goods and services to the wider European market. Once some capability and experience has been gained, there may also be opportunities to expand into emerging markets, such as in North America and Asia, who will look to European suppliers until their domestic supply chains are established.

The importance of relationships

The scale and importance of offshore transmission assets means that a high level of trust is required in any SME subcontracted to undertake most of the described work packages. An SME that has developed a relationship with a large contractor should look to secure a framework agreement to enhance the likelihood of further opportunities. Some of the advantages of framework agreements include:

- Strengthening the working relationship between client and supplier
- Cost efficiencies of delivering multiple contracts
- Increase in company confidence, allowing re-investment into the company, or expansion into other work packages and markets, and
- Standardisation of supply.

Framework agreements often 'split' larger packages into smaller items, which are more accessible for SMEs with low experience or ability to take on risk. SMEs in the BSR have found success in securing framework agreements with major offshore wind contractors.

Investments

Many SMEs have the equipment or infrastructure in place to supply the offshore wind energy transmission market without significant further investment. Expanding capabilities so as to win additional work packages may require further investment in capital assets, and in some cases also in training or certification due to the high skills required for many work packages.

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3 Mapping the future

While a large-scale expansion of offshore wind in the BSR in the coming decades is making good progress, many of the exact ways in which it will take place remain to be determined. A full or partial meshed grid in the Baltic Sea, which the Baltic InteGrid project was formulated to explore, will be a promising solution for many of the challenges raised by this expansion, and the most efficient and cost-effective answer to many of the EU's priorities in this field. However, it will also require substantial international coordination, legislative innovations and deployment of a number of as-yet novel techniques.

The Baltic InteGrid project has carried out an analysis of the situation expected on the ground in 2030, followed by study cases of potential meshed grid solutions in the Baltic Sea that could be implemented during the timeframe 2025-2045. A tentative vision for a realistic meshed grid configuration in 2050 was formulated based on these estimates.

3.1 Offshore wind in the Baltic Sea in 2030

Just like the North Sea, the Baltic offers excellent conditions for offshore wind development, with the added benefits of relatively shallower waters, smaller waves, weaker tides and more potential sites close to shore, all of which result in lower manufacturing, installation and servicing costs for generation and grid infrastructure.

Offshore wind power naturally forms part of any diversified and sustainable energy future, certainly in the high latitudes of northern Europe. It is playing an increasingly important role in the EU's energy mix. Offshore wind capacity in Europe totalled 18.5 GW in 2018, the vast majority in the North Sea.[88] Just like the North Sea, the Baltic offers excellent conditions for offshore wind development, with the added benefits of relatively shallower waters, smaller waves, weaker tides and more potential sites close to shore, all of which result in lower manufacturing, installation and servicing costs for generation and grid infrastructure.

While the Baltic had an installed capacity of just 2.2 GW in 2018, it is expected to host up to 9.5 GW by 2030 and up to 35 GW by 2050.[89] Figure 16 shows the projected installed capacity of offshore wind per country in the BSR until 2030, according to the high and low-expansion settings elaborated within the Baltic InteGrid project.[i] Some countries have binding targets, while others are simple objectives.

[i] *WindEurope offshore wind capacity estimates for the Baltic Sea include wind farms located along the east coast of Denmark. The present study is using a different definition of the Baltic Sea Region, based on maritime spatial planning, and excludes wind farms located in the Kattegat area. The offshore wind status quo capacity presented in Figure 16 is thus lower than what is reported by WindEurope, and this can be justified by the different area definitions.*

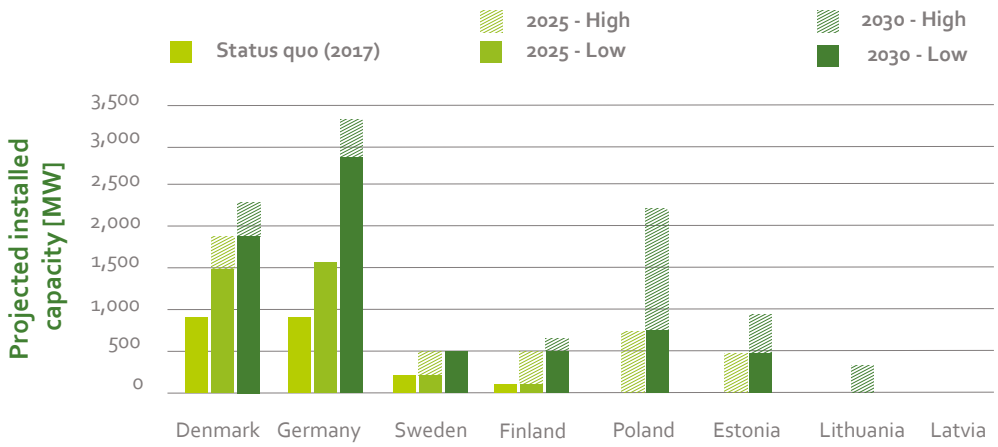


Figure 16. Offshore wind energy development scenarios in the BSR until 2030.
Source: Baltic InteGrid

The Baltic InteGrid scenarios estimating potential offshore wind deployment to 2030 were based on predictions developed by WindEurope in 2015 (when it was still called the European Wind Energy Association or EWEA) and 2017, and the European Network of Transmission System Operators (ENTSO-E) in 2017.[90] Some of these scenarios did not differentiate between the North and Baltic Sea deployments by Member States with coastlines on both seas; in these cases, capacity assumptions were based on historical developments and the current political framework of the respective countries.

The costs associated with offshore wind turbine technologies, as well as the installation, operation and maintenance of European offshore wind farms have fallen sharply over the last years. This can be explained by improved technologies, higher capacity factors, more experience, increased competition, low interest rates, and reduced cost of capital.

Recent tenders for offshore wind farms in the United Kingdom, Germany, Denmark, and the Netherlands – the four largest European offshore wind markets – revealed significant price decreases.[91] In the UK, the lowest clearing price in the 2017 offshore wind auction (£57.50/MWh) represented a 50% price decrease over the lowest bid awarded during the previous auction in 2015.[92] In Germany and the Netherlands, recent auctions received the first 'zero-bids' for offshore wind projects yet seen in Europe. In Denmark, the capital expenditure requirement per megawatt has decreased by 15-25% between the Horns Rev 3 (early 2015) and Kriegers Flak (end 2016) projects, while the unitary bid price halved.[93]

Recent tender results in Europe showed significant price decreases, with clearing prices falling by up to 50% and the appearance of the first 'zero-bid' for offshore wind projects.

Costs associated with offshore wind developments are predicted to continue to decrease in the coming decades thanks to new technological and financial solutions, evolutions in the supply chain and economies of scale achieved through increased deployment.[94] The drop in LCOE is expected to continue until 2030, with some of the largest reductions originating in reduced perceived risk and thus lower financing costs. Another important factor will be turbine technology innovations, which will enable greater power output and higher reliability without increasing cost per MW. And a third major element will be increasing competition and greater long-term market visibility.[95]

3.2 Baltic InteGrid case studies

A major component of the Baltic InteGrid project consisted of two pre-feasibility studies, which aimed to measure the suitability of the meshed grid approach to the Baltic Sea in technological, market-related, environmental and economic terms.

A major component of the Baltic InteGrid project consisted of two pre-feasibility studies, which aimed to measure the suitability of the meshed grid approach to the Baltic Sea in technological, market-related, environmental and economic terms. For this purpose, the studies compared a meshed-grid configuration with a radial system, considered technical designs and their costs, and provided a comparison of the costs and benefits of the various options. The results of the studies can be extrapolated to other areas of similar size and with similar conditions.

The pre-feasibility studies were carried out for three proposed degrees of integration, two levels of expansion and two hypothetical meshed grid areas – a south-eastern one linking Lithuania, Poland and Sweden and a south-western one between Sweden, Germany and, in the high-deployment scenario, Denmark (see Figure 17). The areas were chosen based on high development prospects and an existing pipeline of projects, as well as potential for useful cross-border infrastructure. The proposed connections were also discussed with relevant stakeholders such as TSOs.

The case studies are described in detail in the Baltic InteGrid publication 'Towards a Baltic Offshore Grid: connecting electricity markets through offshore wind farms; pre-feasibility studies report' from September 2018. Only the high-expansion settings are considered here for both study case areas.

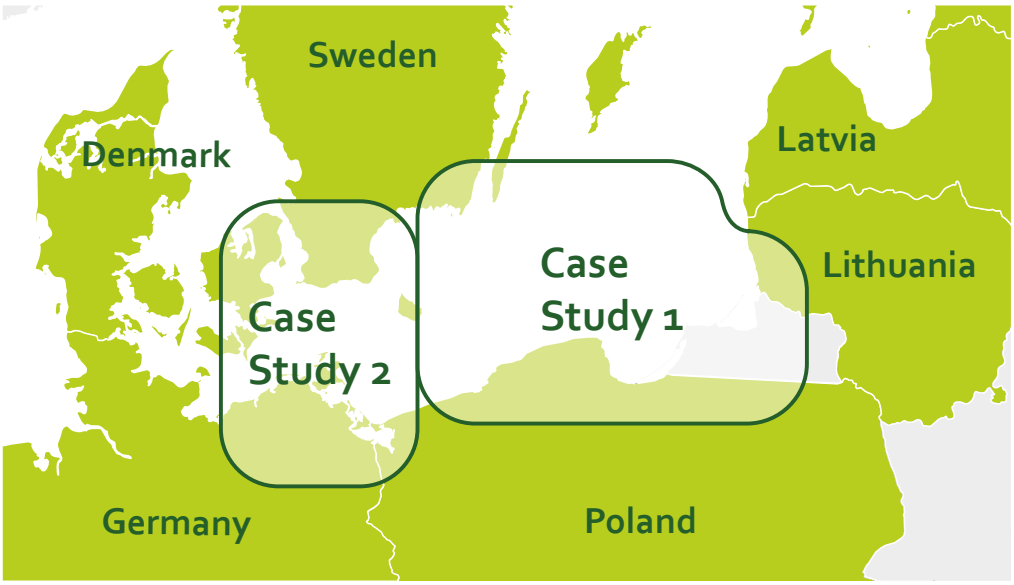


Figure 17. Baltic InteGrid case study areas.

3.2.1 Case study 1

The first case study covered the south-eastern Baltic Sea. This region was selected for several reasons: there are numerous offshore wind projects planned in the Polish EEZ and several in the Swedish EEZ, and many of those will be close to the border between the two on the Southern Middle Bank. There are also existing submarine interconnectors between Poland and Sweden and between Lithuania and Sweden.

The Southern Middle Bank area contains some 2000 km² of water shallower than 40 m. The Słupsk Bank further south within the Polish EEZ comprises a Natura 2000 area, but there are plenty of areas outside this zone with shallow waters suitable for offshore wind development. The distance to shore is also relatively short. Accordingly, many wind farms have already been proposed for this area. There are also significant suitable regions in the Lithuanian EEZ in which authorities have started reserving zones for offshore wind projects. Its south-eastern section is one of the largest surfaces of unobstructed water in the Baltic Sea, so there are significant wind resources there.

The meshed grid scenarios for the pre-feasibility study considered only offshore windfarms located near the route of a potential interconnector. The high-expansion setting comprises all projects with valid and expired permits in Polish waters, all projects with ongoing and potential permits in Swedish waters, and all projects that have received an initial permit in Lithuania (some of which would require the onshore grid to be reinforced before they were connected).

3.2.2 Case study 2

The site of the Baltic InteGrid project's second case study was the south-western Baltic, chosen based on the significant number of offshore wind projects planned in the German portion of the Baltic Sea and the projects under consideration in the Swedish and Danish EEZs close to the border with Germany. Moreover, the Swedish and German TSOs are building an additional interconnector (one has been in place since 1994) named Hansa PowerBridge between the two countries which is expected to be commissioned in 2025. A third link (Hansa PowerBridge 2) is under consideration.

Most of the area considered by the pre-feasibility study lies within the Arkona Basin between Sweden and Germany, with Danish waters west of Bornholm included in the high-expansion setting. The maximum water depth in the region is 50 metres, and the wind is stable – in other words, the conditions are ideal for offshore wind farms.

A disclaimer

Areas where wind farms are complete or under construction, such as Kriegers Flak to the west and the German wind farms off the island of Rügen, were excluded from the study, as were some regions where wind farms are already planned or under construction. This concerns mostly German waters, partly due to the fact that the pre-feasibility study was carried out before the results of the latest offshore wind tender in Germany became known at the end of April 2018. Case study 2 did not take this latest development into account – however, it does not significantly affect the main conclusions drawn in this report.

There is a great deal of uncertainty linked to any predictions about offshore wind expansion in the south-western Baltic. The Swedish and Danish projects are only in the very early stages of planning, while Germany expects to install 3.3 GW in the Baltic by 2030 as per the offshore grid development plan by the TSOs and BNetzA (existing and awarded projects so far place the country on track to achieving 1.9 GW by 2025).

Germany expects to install 3.3 GW in the Baltic by 2030 as per the offshore grid development plan by the TSOs and BNetzA.

3.2.3 Scenarios

No integration

This scenario is not very complex in terms of technology or coordination. The wind farms and interconnectors would be planned and built separately. The only projects that would require some coordination would be the wind farms around the Southern Middle Bank in the south-eastern Baltic – as these locations are relatively distant from the closest onshore connection point (farther than 120 km), the offshore wind facilities would be clustered close together and the power aggregated among them before transmission to shore. The high-expansion setting would also require some reinforcement of the German and Swedish onshore grids in the south-western Baltic. The overall result in both cases would be longer total cable routes, low levels of redundancy and a low utilisation rate of farm-to-shore links.

Partial integration

This approach attempts to strike a balance between technical and organisational complexity, economic feasibility and power-flow flexibility. It assumes a partially integrated system that incorporates both radial and meshed connections – offshore wind farms close to shore would be linked radially with AC technology while more distant ones are integrated via HVDC interconnectors. (The Danish offshore wind farms built south-west of Bornholm in the high-expansion situation in the south-western Baltic would also be connected to HVDC converters, since they cannot be linked to Bornholm itself).

This configuration would use a VSC-HVDC system and require a substantial level of cooperation among the project planners, implementers and stakeholders both in the construction phase – likely resulting in longer planning times – and during operation. The solution would offer high flexibility, utilisation rates, trading capacity and cost-sharing opportunities. The earliest functional DC grid could be operational in 2035, leaving some 15 years of development and piloting before implementation.

Maximum integration

The maximum-integration setting would require heavy and early cooperation between countries, and a great deal of research into technical specifications for components, modularity options for future extensions, grid codes and security standards. Major efforts in terms of regulation and maritime spatial planning would also be required. DC protection equipment would be needed in several nodes within the system.

Several offshore HVDC converter stations would have to be built in the regions of both the south-western and south-eastern grids. In the latter case, the complexity of the system would require most or all of the offshore wind farms within a given area to be commissioned at the same time.

The benefits of maximum integration would include high redundancy, optimal flexibility of the power flow, high infrastructure utilisation rates and substantial cost-sharing opportunities between interconnector and offshore wind farm connection.

3.2.4 Considerations

Dimensioning faults

An internal dimensioning fault in the framework of an offshore grid system is defined as the largest difference in delivered power caused by the failure of a single component at maximum load within the system. This was not found to be a major risk in the Baltic InteGrid case studies. A failing AC link in the zero-integration scenarios only affects the connected offshore wind farm, while systems are designed with overcapacity in the partial and maximum-integration cases so as to accommodate a larger cross-border energy trade (CBET) potential – in other words, a failing DC link would still not preclude a significant amount of offshore wind power reaching shore. An external dimensioning fault is defined as a single outage contingency (N-1) criterion according to the TSOs requirement at the onshore connection points.

Cross-border energy trade potential

The scenarios with high expansion, high integration, or both include very substantial capacity for cross-border trade. However, this capacity has to be shared with the power produced by offshore wind facilities. Even though forecasting models for wind generation are improving, wind remains by its nature a volatile resource. The CBET of the systems therefore fluctuates. At any rate, carbon-neutral offshore wind energy is expected to be granted priority over additional trading capacity in the grid access.

The viability of a meshed grid in the south-eastern Baltic was confirmed by the Polish Institute of Power Engineering in an expert opinion which determined that it would increase CBET capacity and contribute to meeting export/import capacity targets set by the EU for 2030.[96]

Spatial conflicts

In both low and high-expansion settings, more integration means less risk of spatial conflicts thanks to the lower number of cable corridors. While the difference in the use of space between no integration and partial integration is highly significant, the gains are proportionately lower when moving from partial to maximum integration.

In both low and high-expansion settings, more integration means less risk of spatial conflicts thanks to the lower number of cable corridors. While the difference in the use of space between no integration and partial integration is highly significant, the gains are proportionately lower when moving from partial to maximum integration.

There are potential conflicts between offshore wind infrastructure and other sea uses, namely navigational routes, fishing areas and environmental protection areas. In practice, cables do not cross areas with a high priority for fishing carried out with bottom-contact fishing gear in any of the scenarios – most cables run through areas of low interest for fisheries, and there are intersections with a few medium-priority areas (priority in this sense is determined by HELCOM's Vessel Monitoring System (VMS)). Conflicts may also arise in the vicinity of shore connections due to onshore environmental protection areas, settlements and tourist activities.

In cases where there are overlaps with other activities. mitigation measures such as cable burial, concrete mattresses and safety zones may need to be applied. A scenario with no integration but high expansion would involve cables crossing a traffic separation scheme (TSS), for instance, which may require deeper burial than other navigational routes.

Environmental impact

Most identified environmental effects are likely to occur on a local scale, with the exception of underwater noise emissions during the installation of offshore foundations, which may be detectable on a regional scale. Nevertheless, actual injuries to fish or mammals are expected to occur only very close to the noise sources. This should be avoidable by means of mitigation measures such as bubble curtains and ramping-up of noise to scare off animals from the vicinity before works begin in earnest. The environmental impact of wind turbines was not assessed.

3.3 The way forward

As indicated above, the potential of offshore wind in the Baltic Sea is estimated to be 9.5 GW by 2030 and as much as 35 GW by 2050. This new capacity will require a great deal of additional transmission infrastructure. If the expansion is not carefully managed and coordinated, there will be a risk of a proliferation of radial configurations and an accompanying glut of export and interconnector submarine cables. This would be inefficient, possibly leading to higher costs for end users, while also potentially causing significant conflicts with other marine and seaside uses.

The deployment of new offshore wind infrastructure should therefore be accompanied by meaningful coordination between the countries and stakeholders involved. It is important to consider this well in advance of the coming expansion, as the lock-in effects of an inefficient grid design could be difficult to correct in the future. The Baltic InteGrid project has produced a set of policy recommendations for the implementation of meshed grids in the south-western and south-eastern Baltic Sea in the medium term.

This section builds largely on the Baltic InteGrid publications 'Recommendations to the ENTSO-E's Ten-Year Network Development Plan' from September 2018 and 'Cost-benefit analysis for an integrated offshore grid in the Baltic Sea: Comparison of different levels of grid integration based on case studies' from August 2018.

3.3.1 South-eastern Baltic grid

The pre-feasibility study covering the south-eastern Baltic ascertained a great deal of potential for a meshed grid linking Lithuania, Poland and Sweden. Such a grid would make economic sense in both high and low-expansion settings for offshore wind in the Baltic Sea, with benefits outweighing the costs in all cases.

In the high-expansion setting – assuming 11.2 GW of capacity added to the Baltic Sea between 2025 and 2045 – the grid costs would be €3.27, €2.96 and €3.5 billion for the no, partial and maximum-integration scenarios, respectively.

In the case of the south-eastern part of the Baltic Sea, the partial-integration scenario appears to be the most efficient.

Maximum integration would result in substantial benefits compared to partial integration, but even higher costs – in fact, the maximum-integration scenario is the least favourable for the proposed south-eastern Baltic grid. The partial-integration scenario is also more realistic, as the first projects to come online in Poland can be expected to be close to shore and therefore connected radially.

A partial-integration system in the south-eastern Baltic would incorporate radial AC connections for near-shore offshore wind and integrated links through new HVDC interconnectors for wind farms farther offshore (in Polish and Swedish waters). (The existent HVDC lines NordBalt and SwePol are not considered for integration with offshore wind farms.)

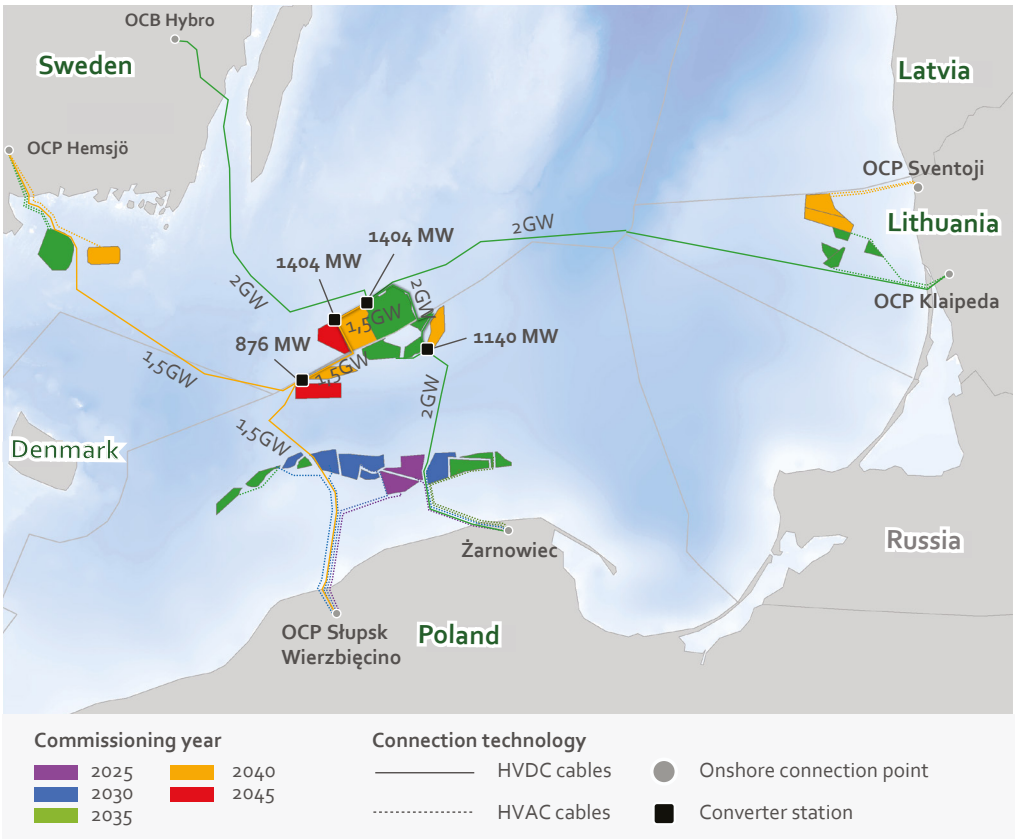


Figure 18. Offshore wind capacity development for the proposed south-eastern Baltic grid in the high-expansion, medium-integration scenario.
Source: Baltic InteGrid

Practical considerations

The implementation of the south-eastern Baltic meshed grid would require further actions, including a detailed feasibility study, establishment of a working group, and discussions among the TSOs and investors involved. The respective governments would also need to make strategic commitments and review their legislative frameworks to enable the construction and operation of cross-border connections. The meshed grid should be nominated for inclusion as a project in the TYNDP 2020[i], which would open the way for obtaining Project of Common Interest status and unlocking financing and other support from the EU.

The meshed grid should be nominated for inclusion as a project in the Ten-Year Network Development Plan (TYNDP) 2020.

[i] *The Ten-Year Network Development Plan (TYNDP) is a non-binding policy instrument prepared by ENTSO-E which outlines the needs for investment in grid infrastructure that comply with EU policy objectives and serve as a guideline for plans drafted by TSOs on a national level.*

3.3.2 South-western Baltic grid

In the case of the south-western part of the Baltic Grid, the maximum-integration scenario appears to be the most efficient.

Assuming a given critical mass of generation capacity in the south-western Baltic Sea, a meshed grid would be substantially more favourable than radial connection of offshore wind farms. In the high-expansion setting – assuming 3.7 GW in the whole Baltic Sea added in 2025-2045[i] – grid costs would be €1.37, €1.75 and €1.32 billion for the no, partial and maximum-integration scenarios, respectively. The best scenario overall is that of maximum integration; once the benefits are taken into account, gains over the no-integration baseline would be €1.81 billion.

Under the maximum-integration scenario, all offshore farms in the south-western Baltic would be linked to an HVDC offshore grid with two HVDC offshore converter stations. This would require major efforts to coordinate international energy infrastructure and sea use planning, as well as extensive technological know-how regarding multiterminal systems. The benefits would be high infrastructure utilisation rates and cost-sharing opportunities between interconnectors and offshore wind farm connection infrastructure.

Moreover, high integration would reduce the number of subsea cables and landfall sites six-fold – a critical benefit in terms of impact on other sea users, public acceptance in tourist areas and environmental protection.

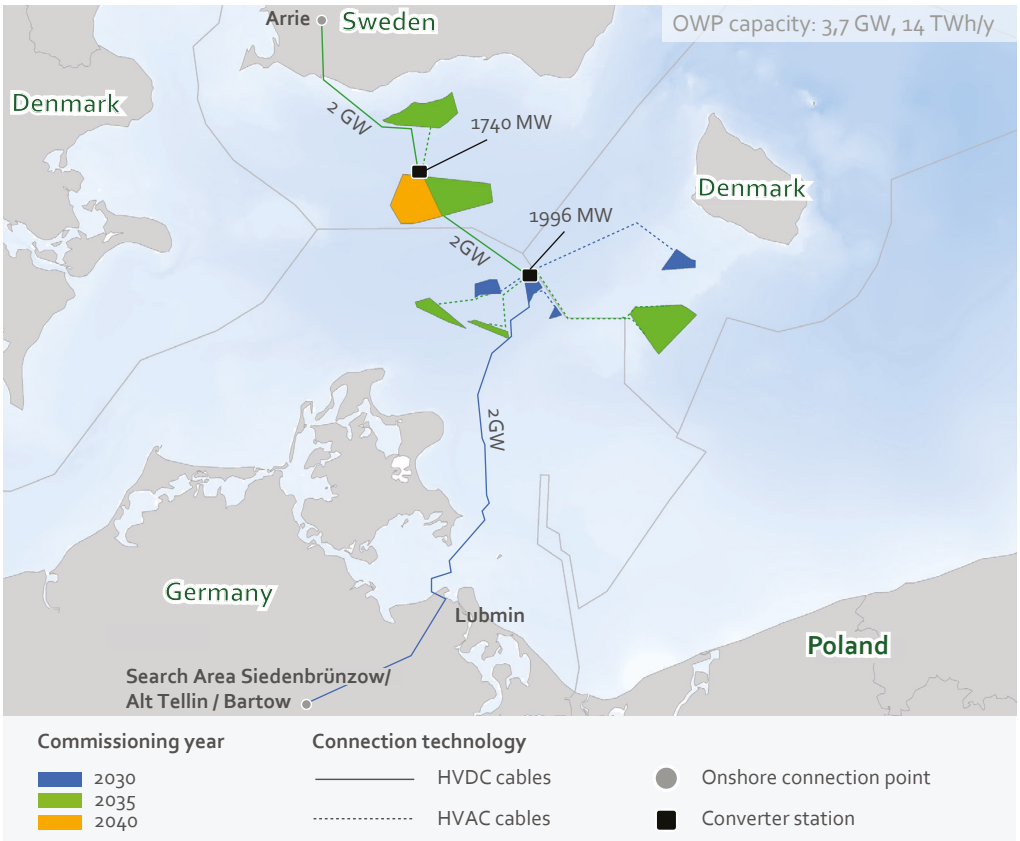


Figure 19. Offshore wind capacity development for the proposed south-western Baltic meshed grid in the high-expansion, maximum-integration scenario.
Source: Baltic InteGrid

[i] *As noted elsewhere, this estimate was formulated before Germany's latest offshore tender, so it excludes several projected developments in Germany.*

3.3.3 Technical and strategic issues

Local meshed grids in the south-western and south-eastern parts of the Baltic Sea would have substantial advantages beyond cost efficiency. Adequacy analyses show that the system would have enough capacity available in all proposed scenarios; however, higher integration would provide more flexibility with regard to the adequacy rate. It would also lead to shorter combined length of AC and DC cables and therefore lower installation costs; however, integration would require some application of relatively costly HVDC technology and more converter stations (on and offshore).

Integration would promote the process of linking Estonia, Latvia and Lithuania to the synchronous grid of Continental Europe and strengthen security of supply. For instance, the system could fulfil the ambition stated in Project 170 of the latest TYNDP), which calls for a submarine HVDC connection between the grids of Continental Europe and the Baltic States via Poland and Lithuania. As the first elements of the proposed south-eastern Baltic meshed grid would be built around the same time, in the period 2030-2035, the connection of the two grids could instead be realised close to the Southern Middle Bank.

Integration would promote the process of linking Estonia, Latvia and Lithuania to the synchronous grid of Continental Europe and strengthen security of supply.

Similarly, a second connection between Poland and Sweden to supplement SwePol – which was commissioned in 2000 – was considered for the TYNDP 2016, as it showed potential benefits related to price differences. The TSOs eventually chose to not nominate it for a range of reasons. Integration with offshore wind farms in the framework of a meshed grid could improve its feasibility and make it a more cost-effective solution.

Finally, the lower number of cables and landfall points (only one third as many in the maximum-integration scenario as in the baseline situation) in a meshed system would potentially lead to higher public acceptance than could be expected for a radial grid.

3.4 The Baltic Offshore Grid concept (BOG 2050)

A concept for a meshed grid in the Baltic Sea has been developed within the Baltic InteGrid project. Tentatively named the Baltic Offshore Grid (BOG 2050), it is based on the findings of the various groups of activities, especially the study cases, extrapolated to the long term and across the whole Baltic Sea.

BOG 2050 aims to provide a realistic model for achieving a meshed grid in the Baltic Sea. This would entail an improvement of the connections between offshore wind farms in the Baltic Sea and strengthening of cross-border links in the service of EU priorities such as increasing the share of renewables in the regional energy mix, enhancing the security and diversity of the energy supply, reducing the energy isolation of Member States in the BSR, unifying the local markets, and reducing energy costs.

BOG 2050 would also enable the development of innovative offshore technologies, with intensive research and development carried out to achieve ever-larger, more efficient and cheaper turbines and increased transmission voltages, and the training of multidisciplinary staff in relevant engineering, planning and research programmes, international law, and national regulations.

Much of this section is based on the Baltic InteGrid publication 'Impact mitigation strategy of the Baltic Offshore Grid' from July 2018.

3.4.1 Background: the Baltic Sea in 2050

Its complexity and long-term perspective mean that BOG 2050 is not a roadmap, but rather indicates future orientations and options for streamlining and enhancing offshore wind development in the BSR. For instance, there are no official predictions for generation capacity in the BSR in 2050; the Baltic InteGrid therefore made its own estimates, supported by BVG Associates, based on the detailed study cases made by the project and focused on the areas that offshore wind developers had shown interest in exploiting across the whole Baltic Sea. These are marked by coloured points on the map in Figure 20.

The total volume of offshore wind expected to be installed in the Baltic Sea in 2050 was estimated by BVG Associates to be 35 GW. This figure is derived from the '80% renewable energy sources scenario' of the 2050 EU Roadmap, which proposes that offshore wind should provide 758 terawatt-hours (TWh) per year of electricity across the EU, of which 145 TWh per year in the Baltic Sea; the capacity required to produce this is approximately 35 GW.

Next, the levelised cost of energy (LCOE) was mapped for the entire Baltic Sea based on wind conditions, sea depth, distance to grid connection, potential conflicts with other sea uses, etc. Additional likely locations of future wind farms in 2050 (marked by black points on the map in Figure 20) were determined based on LCOE and input from partners.

Based on analyses conducted by the Baltic InteGrid project, the total offshore wind capacity expected to be installed in the Baltic Sea in 2050 is estimated to be 35 GW.

Expected energy production was calculated for each wind farm based on the expected technology characteristics for average wind farms reaching completion in each decade and the wind speeds at each location. It was assumed that wind farms operational before 2021 would be repowered between 2041 and 2050, so technology characteristics for this decade were used for the calculations. The results are shown in table 2 below.

Country	BIG 2030 Upside cumulative total	Additions 2030-2045 under the high- expansion setting 2045	Further additions before 2050	Cumulative total in 2050
Denmark	1,696	648	2,000	4,344
Germany	3,305	204	1,000	4,509
Sweden	472	6,048	4,500	11,020
Finland	616	0	1,500	2,116
Poland	2,232	3,076	2,000	7,308
Estonia	900	0	1,000	1,900
Lithuania	300	1,548	500	2,348
Latvia	0	0	1,500	1,500
Total	9,521	11,524	14,000	35,045

Table 2. Derivation of total installed capacity in MW by 2050 and breakdown by country.
Source: Baltic InteGrid, BVG

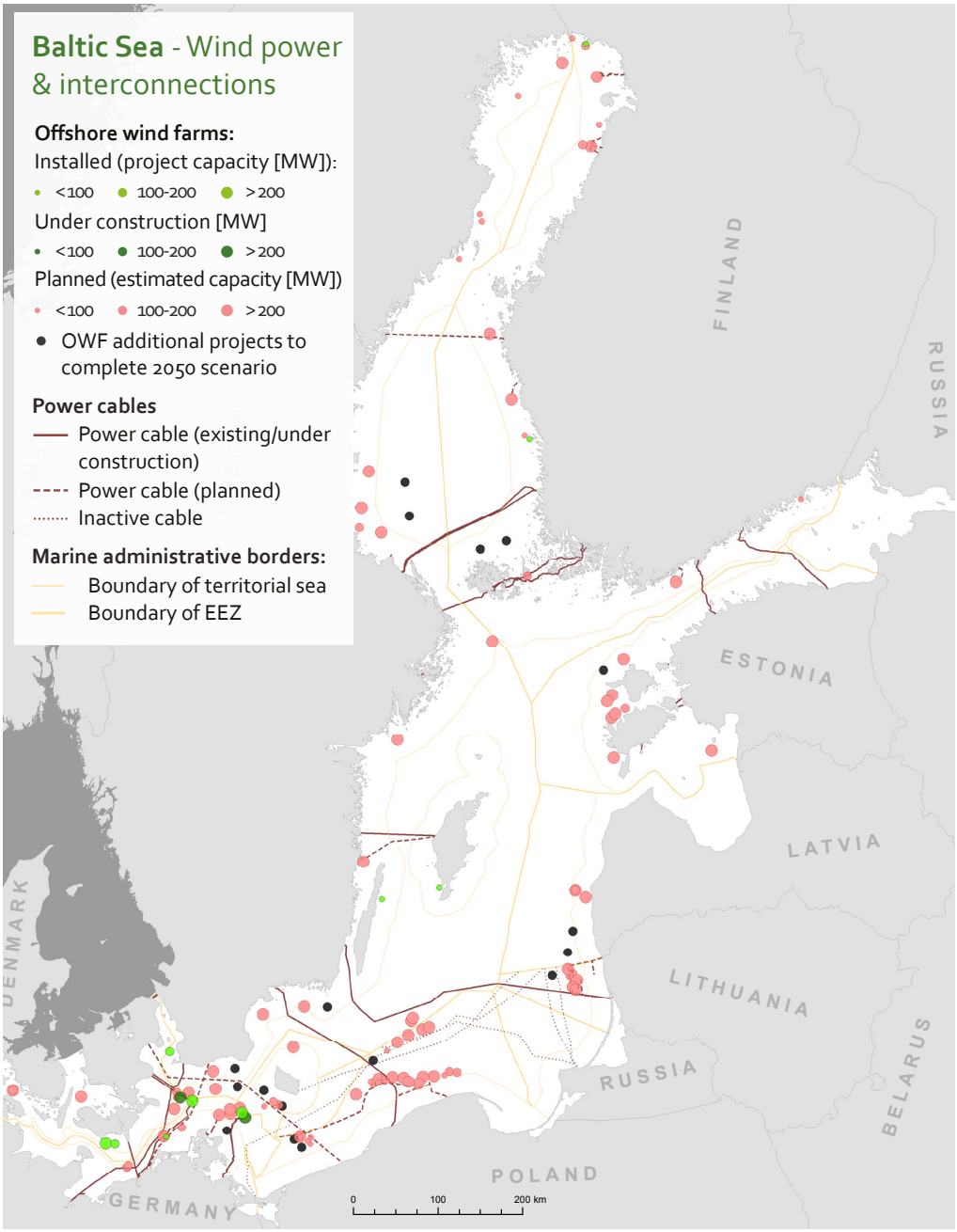


Figure 20. Map of existing and potential offshore wind farms and interconnection projects in the Baltic Sea by 2050.
Source: Baltic InteGrid | Image: MIG

The concrete design of the BOG 2050 must also take into account the various other maritime uses of the Baltic Sea and possible spatial constraints brought by them. Figure 21 below shows the diverse maritime uses in the Baltic Sea as of 2019.

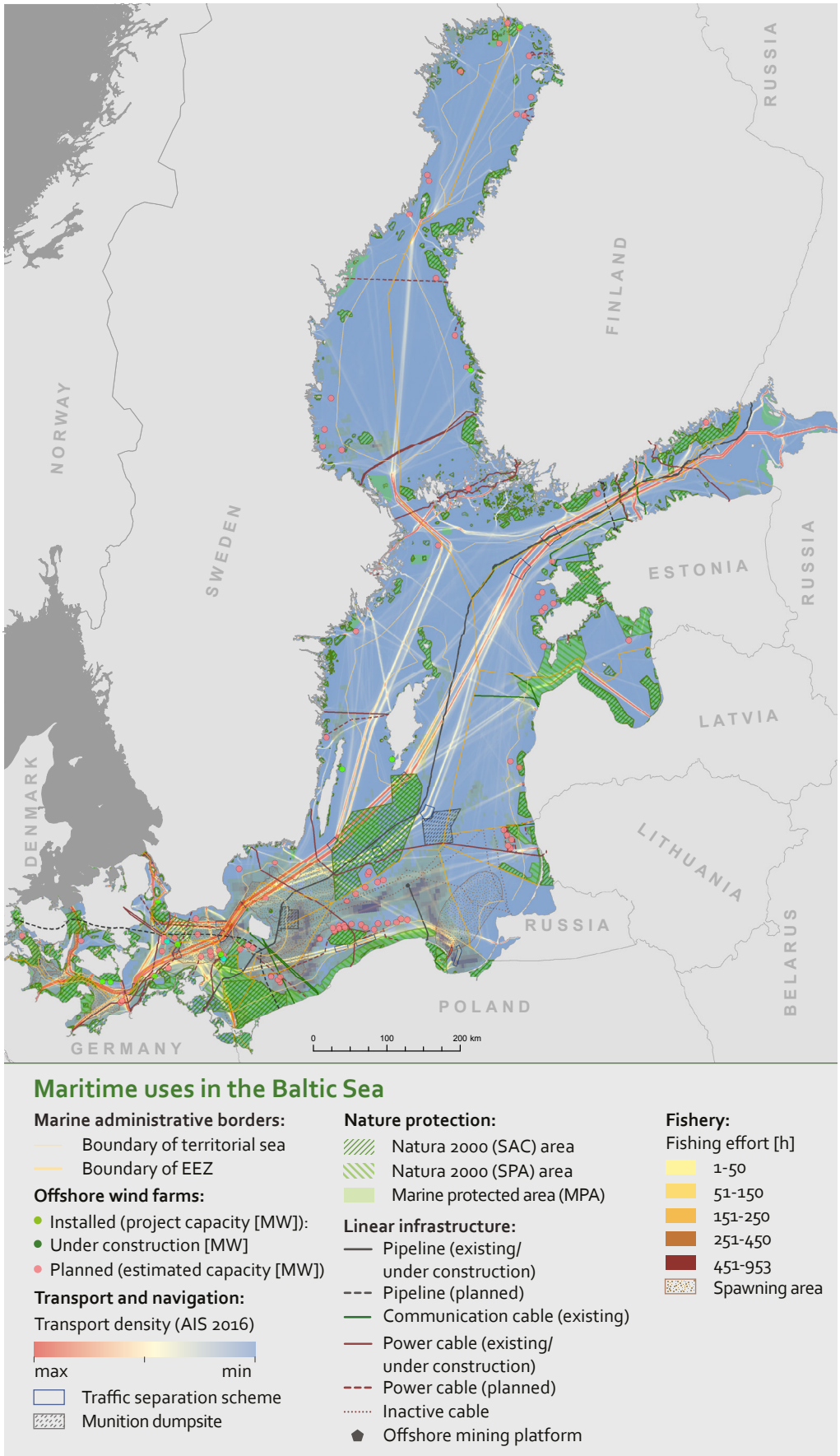


Figure 21. Map of different maritime uses in the Baltic Sea.
Source: Baltic InteGrid | Image: MIG

3.4.2 Description and variants

Given current plans for the installation of offshore wind farms and interconnectors, the main component of BOG 2050 would be a combination of the south-western and south-eastern meshed grids explored in the study cases above. As the study cases indicated, wind farms close to shore would mainly be expected to be connected radially, while the integrated section of the grid would realistically be deployed for wind farms at some distance from shore. A potential secondary focus could be envisaged in the northern part of the Baltic Sea, between Estonia, Finland and Sweden. And a third prospect could be considered to link the northern and southern systems through a configuration situated off the coast of the Baltic States. Figure 22 below shows the proposed development corridors of BOG 2050 together with planned and existing interconnectors and offshore wind farms.

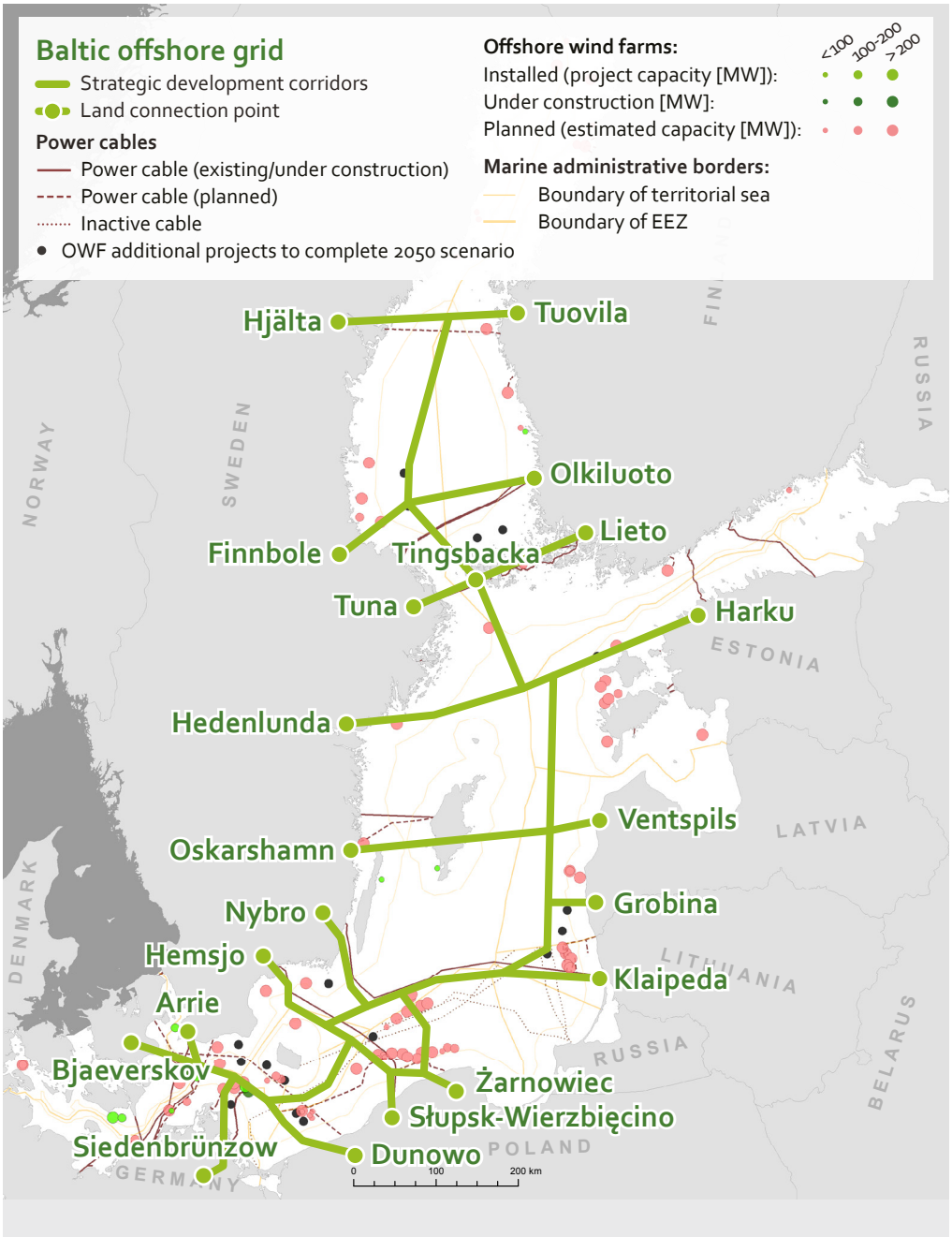


Figure 22. The Baltic Offshore Grid (BOG 2050) concept.
Source: Baltic InteGrid | Image: MIG

Which of the BOG 2050 segments are executed will depend on the balance of costs and benefits, which will in turn largely be determined by the distances involved and the availability of transmission technology. It will also be highly dependent on which offshore wind farms are built and when. While general indications for cable corridors are included in the concept, the concrete planning and implementation of individual cross-border interconnectors will be determined by the TSOs and their coordination within ENTSO-E via the TYNDP.

3.4.3 Implementation

As a meshed grid, BOG 2050 will involve numerous submarine cables serving as interconnectors and export cables simultaneously, allowing a given offshore wind farm to transmit electricity to two or more different countries depending on need. The cables will be laid by or on behalf of grid operators or offshore wind farm operators, who should seek the status of projects of common interest (PCIs) for this activity in order to receive investment support from EU funds.

The Baltic InteGrid has developed guidelines and identified good practices for strategic environmental impact assessments related to the offshore investments assumed for BOG 2050. This included establishing standards for environmental and socioeconomic impact analysis, analysing the potential offshore and onshore impact of the new infrastructure, and providing assumptions for surveys within the environmental impact assessment (EIA) process. An impact mitigation strategy was also formulated.

Geographic information software (GIS) was used to perform quantitative analyses of selected phenomena and mutual correlations between environmental (e.g. distribution of protected areas, including Natura 2000 sites) and social (e.g. shipping routes, restricted military areas, fisheries) factors and offshore wind generation and transmission.

Potential issues

The Baltic InteGrid project considered all risks of irreversible deterioration of the environment or its components potentially caused by the implementation of BOG 2050. The cumulative effects of all the components of existing and planned projects in the Baltic Sea were considered, as were possible cases of noteworthy residual impact likely to remain after measures to mitigate primary problems would be implemented.

Environment

Most of the identified environmental effects are expected to be limited to the near proximity of the grid components and be associated with the construction stage of individual projects and therefore temporary in nature. However, effects like habitat loss or alteration due to electromagnetic fields and heat emission from cables may persist in the longer term.

In general, it is not expected that the development of BOG 2050 would cause a significant effect on the environment.

In general, it is not expected that the development of BOG 2050 would cause a significant effect on the environment, as long as all individual projects are planned and implemented taking into account existing environmental and social conditions, especially the presence

of particularly sensitive areas, like spawning grounds of rare and protected fish species. The technical installations built as part of BOG 2050 may affect up to 82 Natura 2000 sites, and a potentially significant impact on these sites cannot be excluded out of hand. To ensure that environmental issues are properly considered during the planning stage of individual projects, the Baltic InteGrid therefore recommends that environmental impact assessments (EIAs) be required in the licensing procedures.

None of the technical elements of BOG 2050 (offshore cables and converter/transformer stations) are cited by the EIA Directive as components likely to have significant effects on the environment. Even so, to minimise any harmful effects of the implementation of BOG 2050, it is crucial to find optimal locations for cable corridors and substations. They will have to minimise contact with ecologically sensitive areas, especially Natura 2000 sites and – in the case of facilities that require piling – regions important to noise-sensitive species. Where cables cross habitats of marine species sensitive to electromagnetic fields (e.g. especially fish and marine mammals) and temperature change (e.g. some benthic organisms) they should be buried, if possible, to minimize the impacts.

Location

Other sensitive areas to avoid include contaminated locations (to prevent the release from sediment of substances harmful to marine organisms), places of historical interest, unexploded ordnance sites, mineral deposits and fishing areas. Shipping lanes should be avoided as much as possible by leaving them free of substations and by minimising the number of intersections with cables; where intersections are necessary, they should be perpendicular to the lanes as much as possible.

Social considerations

The successful implementation of BOG 2050 would require robust social dialogue to avoid delays, cost creep, refusal of permits or loss of credibility. This should rest on solid knowledge of the environmental and social context, the type and area of potential impact and the positions of stakeholders, as well as on honest engagement with the concerns of stakeholders and their involvement throughout the process, including through awareness-raising measures and meetings.

Baltic InteGrid impact mitigation strategy

An impact mitigation strategy developed by the Baltic InteGrid project for BOG 2050 shows that deployment of a highly integrated meshed grid would be better for the environment than equivalent expansion without integration. This effect rests upon the smaller number of cable corridors and of landfall points and transformer stations on land, which causes less interference with coasts. Better integration of spatial planning and less transmission infrastructure mean that BOG 2050 is superior to the baseline also in terms of its effects on economic activities on and offshore, and less likely to interfere with prospective undersea mineral deposits of economic value, the tourist potential of coasts, or on and offshore areas of cultural interest.

3.5 Recommendations: roadmap towards 2050

The Baltic InteGrid project has produced several sets of recommendations for the stakeholders within its fields of focus. These feature in separate publications; a summary of the recommendations related to maritime spatial planning, policy & regulation, and the next TYNDP is presented here.

3.5.1 Maritime spatial planning recommendations

As maritime spatial development plans formally assign marine space to specific uses, they are a crucial element in the development of offshore wind energy. The maritime spatial planning (MSP) recommendations within the framework of the Baltic InteGrid project focus on policy, information-sharing and management matters related to MSP. The target groups are the various authorities in charge of both formulating and implementing maritime spatial plans as well as the energy operators. The overarching goal of the recommendations is to streamline the MSP process and make it more apt to facilitate offshore wind energy development in the BSR. More explicitly, this means:

The overarching goal of the recommendations is to streamline the MSP process and make it more apt to facilitate offshore wind energy development in the BSR.

- securing marine space for the generation and transmission of offshore wind energy,
- ensuring the consistency of relevant policies,
- facilitating the stakeholder integration process,
- encouraging and securing data exchange,
- raising awareness of the benefits of offshore wind energy to facilitate its acceptance, and
- encouraging synergies and co-existence with other uses.

Few of the countries in the BSR have established maritime spatial plans: as of September 2018, only Lithuania and Germany had national plans covering their maritime areas. The first draft plans are at the consultation stage in Sweden, Latvia, and Poland, while Finland, Estonia and Denmark currently have their plans under development. The plans should be complete in all countries by 2021. A detailed overview of the current status of maritime spatial planning processes in the countries in the BSR is presented in the Baltic InteGrid report 'Maritime Spatial Planning and the Baltic Grid. The Status of MSP and the development of grid variants' of November 2018.

The MSP recommendations are the following:

1. Maritime spatial plans should be revised in a timely manner in response to major changes in national policies and strategies and industry-wide technological evolutions.

2. Robust frameworks should be established to ensure fruitful international cooperation in the service of producing the most useful maritime spatial plans for the BSR. There should be a unified approach to defining the priorities of the different sectors in the BSR and the same methodologies should be developed and applied across countries for the evaluation of the productivity of marine space.

3. Policy makers and public authorities should ensure that the OWE sector has a clear political mandate on the national and international level with well-defined OWE targets in the short and long term. The targets should be communicated properly at the local and international levels.

4. OWF and grid operators should consider setting up pan-Baltic associations/clusters (or strengthening existing ones) to represent their interests.
5. OWF and grid operators should consider organising face-to-face and/or online discussions within each sector before joining cross-sectoral MSP consultations.

6. To support international meshed offshore grid development, **there should be cooperation between national MSP authorities and energy authorities from bordering countries to locate corridors and transfer gates for interconnectors.**

7. Multi-use applications to encourage synergies between OWE and other sea uses should be enabled by MSP authorities on the basis of input from OWF operators and investors.

8. MSP authorities should enable early stakeholder engagement in the MSP process and face-to-face consultations/dialogue with the presence of principal decision-makers from the energy sector and maritime authorities.

9. MSP authorities should facilitate formalised coordination across the entire range of government institutions and authorities involved in maritime topics.

10. MSP authorities should ensure that they have at their disposal all the crucial information in terms of allocating space for OWE, and OWF and grid operators should provide this information regarding all potential constraints.

11. The public authorities involved in producing and implementing MSP policy should establish efficient data and information management systems at the scale of the BSR.

12. Public authorities should create agreed mechanisms together with the OWE sector to enable the broader use of commercial monitoring data collected for the purpose of OWE investments, including data collected for EIAs.

3.5.2 Recommendations related to policy and regulations

The research conducted by the Baltic InteGrid project in the fields of policy and regulation aimed to identify barriers to the realisation of a meshed offshore grid in the Baltic Sea. The obstacles identified included issues with public acceptance of wind energy facilities, insufficient grid capacity (including on shore) to accommodate offshore electricity production, ever-changing legislation related to support for electricity from renewable sources, and complex administrative procedures concerning the permitting of grid and generation projects.

Policy and regulations should be adapted to deal with issues of public acceptance, insufficient grid capacity, shifting legislation regarding support to energy from renewables, and complex administrative procedures.

Other factors, such as a lack of political will to develop the sector – often based on outdated cost information and reflected in the absence of specific offshore wind targets in most of the EU Member States in the BSR – as well as a shortage of adequate incentives to invest

into offshore wind technology, may deter investors. The Baltic InteGrid project therefore developed concrete recommendations addressed to stakeholders on the EU and national levels which propose ways to eliminate these identified barriers. They fit within three overarching thematic groups.

1. It is necessary to provide an adequate regulatory framework for investments in offshore wind farms and grid projects.
The allocation of connection costs for offshore wind farms in the Baltic Sea should be harmonised by adopting a so-called super-shallow approach, with TSOs bearing the entire costs for connecting wind farms to the onshore grid. This would avoid distortions among market actors while freeing project developers to choose the best location regardless of connection costs. In order to limit overcosts in network expansion and reinforcement, a taskforce bringing together maritime spatial planners, regulatory authorities, TSOs and the energy sector should be established at a regional or EU scale to identify the most suitable locations for offshore wind and grid development. Offshore wind power targets should be set at the national level, and reliable remuneration for offshore wind power should be provided. TSOs must also be incentivised to invest in and operate meshed offshore grids. Incentive packages for TSOs should be adopted to promote innovation and mitigate the investment risk associated with meshed grid project development. TSOs' profits should be coupled to the expected benefits of a meshed grid. Finally, cross-border network development expenses in meshed offshore grids should be allocated between the TSOs involved using an adapted methodology in a fair, cost-efficient and transparent way. This will require a high degree of cooperation between TSOs and the relevant authorities in the definition and implementation of jointly agreed cost allocation methods.

2. Policy-makers should be incited to provide an adequate legal framework for the construction and operation of a meshed offshore grid.
The legal feasibility of hybrid projects (solutions that are neither radial nor meshed, but somewhere in-between) must not be hindered by permitting requirements that assume radial connections to national onshore grids. This would be the case if, for instance, construction permits for offshore wind farms were conditioned to the project developers winning a capacity auction and having the obligation to feed the allocated capacity into the national grid. Once the meshed offshore grid is built, there must be adequate regulation to allow it to operate properly. Specific definitions and provisions for dual-purpose cables and meshed infrastructures, as well as clear operation rules, must be provided at the EU level. This should include capacity allocation rules for offshore wind farms connected through dual-purpose cables and clear priority rules for the energy transmitted from offshore wind farms and from across the border. Finally, the multilateral nature of the meshed offshore grid means that it might best be supervised by an overarching regulatory authority at the EU or regional level encouraging TSO cooperation.

3. It is essential to guarantee environmental protection and increase public acceptance in order to ensure positive attitudes. Already at the MSP stage, SEAs should be performed as accurately and comprehensively as possible in order to shift the main assessment of possible environmental hazards caused by a meshed offshore grid to an earlier planning stage. As for administrative permits for offshore wind farm and grid construction, a single EIA should be conducted as soon as all the parameters of the project (turbine model, pattern, number of turbines, etc.) are known, and its results reused at each new procedural stage when several permits are needed for the realisation of a project. Public acceptance issues can further be mitigated by encouraging public participation as early as possible in the different grid and maritime planning processes. Flexible schemes and mechanisms that involve local communities in projects, as is the case in Denmark, for instance, have the potential to increase public acceptance and foster a sense of community around offshore wind projects.

3.5.3 Recommendations to TYNDP

The Ten-Year Network Development Plan (TYNDP) is a policy instrument formulated by the European Network of Transmission System Operators for Electricity (ENTSO-E) for the purpose of orienting, streamlining and coordinating a pan-European approach to electricity system planning. The TYNDP is updated regularly: the Baltic InteGrid project has formulated several recommendations for inclusion in the next edition, due in 2020.

The next TYNDP should endorse meshed solutions and include proposals related to concrete hybrid and meshed projects in the BSR.

1. The interconnectors planned in the Baltic Sea under TYNDP 2018 should be examined for possible integration with offshore wind farms in order to build hybrid systems.
The following projects in TYNDP 2018 should be considered for this purpose:

- Project 179: 'DKE-DE (Kontek2)' between eastern Denmark and Germany,
- Project 234: 'DKE-PL1' between eastern Denmark and Poland,
- Project 239: 'Fenno-Skan1 renewal' between Sweden and Finland, and
- Project 267: 'Hansa PowerBridge II' between Germany and Sweden.

Failing to conduct such an analysis in good time before the construction of a meshed offshore grid may result in locked-in solutions that rule out integration of offshore wind farms in the future, reduce the potential offshore wind energy in the future, or cause the region to miss out on cost reduction opportunities.

2. The results of the Baltic InteGrid case studies carried out in the south-eastern and south-western Baltic should be applied in practice.
First, a Polish-Swedish-Lithuanian interconnection should be integrated with planned offshore wind farms as a project candidate in the next TYNDP 2020; this connection should be considered independently from the Polish-Lithuanian link currently under development and due to be commissioned in 2025. Second, Hansa PowerBridge II should be conceived as a meshed solution integrating offshore wind farms in Germany, Sweden and Denmark (Bornholm), similar to the TYNDP project 260 'New Great Britain-Netherlands interconnection'.

3. Formal support for the integration of meshed-grid solutions with offshore wind farms should be included in the TYNDP.
Such integration would bring several benefits:

a. Lower system costs,
b. Creation of new north-south connections that would allow intermittent wind energy to be balanced with hydro resources in the Nordic countries,
c. Improved security of energy supply to the Baltic States in the Lithuania-Poland-Sweden scenario,
d. Lower price differences between continental and Nordic energy markets,
e. Higher utilisation rates, since the capacity of the cable not used for exporting electricity from wind farms can be used for CBET,
f. Lower risk of local acceptance issues (fewer cables and less linear infrastructure),
g. Higher flexibility of the system and reduced electricity prices thanks to cheap renewable energy and – in times of no wind – CBET.
h. Facilitated communication between stakeholders, with active roles given to ENTSO E and TSOs.

3.6 Conclusion

The horizon of this report is a future many of us will live to see. The world in 2050 will be characterised by several major changes, not least a large-scale transformation of the energy system.[97] The roadmap described in this chapter aims to provide a blueprint for the establishment of a meshed electrical grid in the Baltic Sea connecting offshore wind farms with the onshore grids of the surrounding countries. This will enable electrical supply from offshore wind farms to reach end consumers more quickly and efficiently, while also establishing interconnections between countries to balance demand and supply in different regions.

While a meshed approach has been shown to be beneficial from a range of perspectives, especially in terms of cost efficiency and the environment, it is accompanied by challenges linked to legal frameworks, planning, market & supply and technology, as described in chapter 2. These will need to be taken into account and thoroughly incorporated in the objectives and analyses linked to the future deployment of a meshed grid.

The vision described above shows how a tentative construction of a meshed grid in the Baltic could look in the medium and long term. It will be crucial that the EU and its Member States define clear goals subdivided into realistic sub-goals that can be implemented and monitored over a reasonable timeframe. If this is not done properly, there will be a risk that deviations are identified late in the process, making corrections or alterations slow, difficult or impossible.

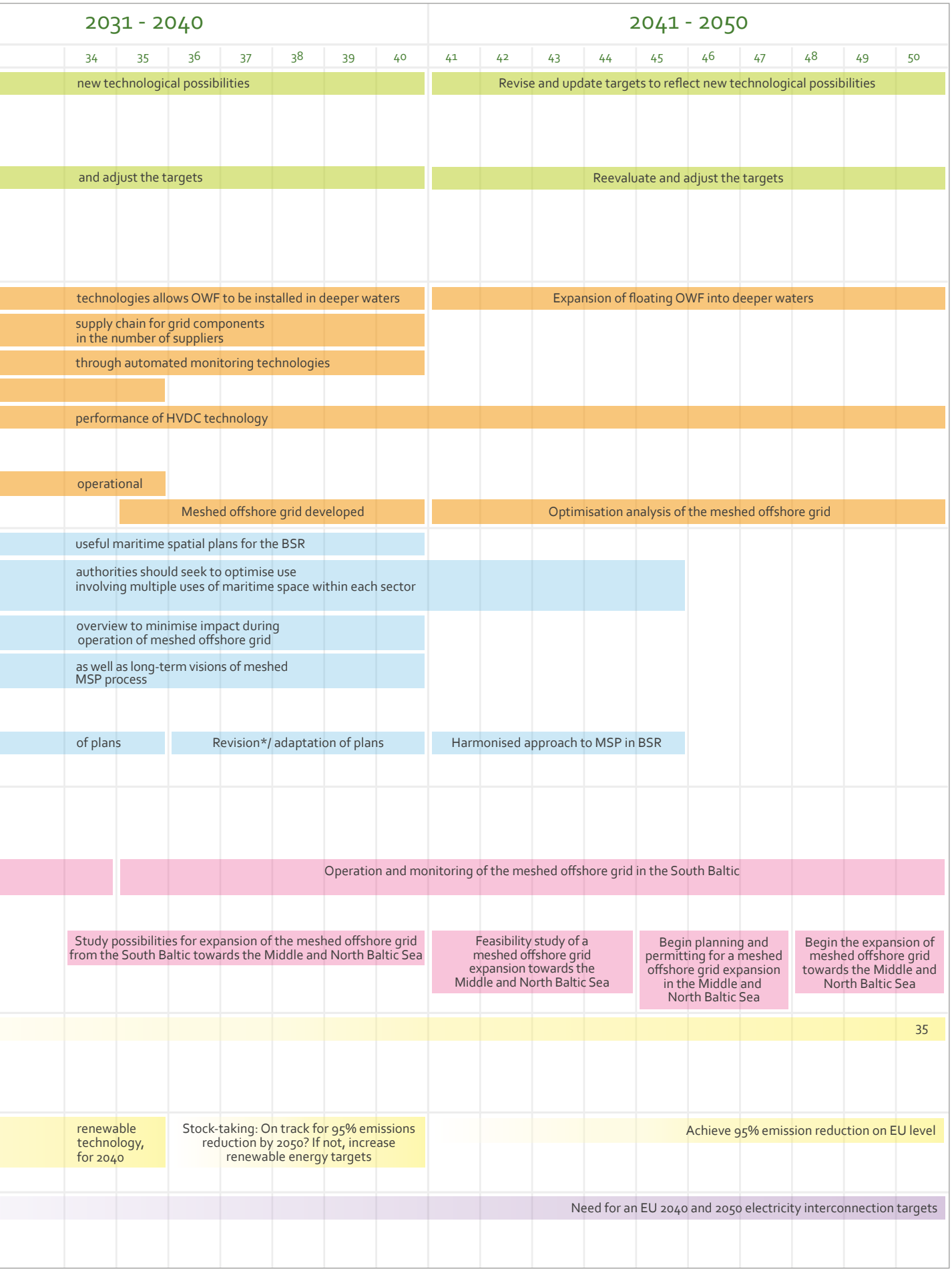
The Baltic InteGrid project has carried out an estimate for offshore wind energy in the Baltic Sea for 2030, as well as a vision for 2050 based on the volumes of renewable electricity production needed to achieve CO_2 reduction and climate targets. The investments needed are massive and the potential for regional development large. The roadmap in Table 4 shows a summary of the main actions needed to enable a meshed grid as a part of the BOG 2050 vision.

While 2050 may seem distant now, it is important to remember that the lead time for an offshore wind energy project often exceeds a decade. A meshed grid combining several such projects as well as complex new grid infrastructure will require a great deal of planning and coordination. It is crucial that this process be thoroughly prepared and integrate the full range of valuable input from experts and stakeholders, and that proposed solutions be planned and implemented in a timely and well-structured way.

	2019-2020		2021 - 2030												
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Policy & regulation			Adopt regional and national offshore wind energy targets					Revise and update targets to reflect							
			Adopt rules for the operation of meshed offshore grids at EU level												
			Develop an EU framework for the transnational coordination of OWE planning												
			Set targets and provide incentives for hybrid and meshed offshore grid projects, in line with interconnection and renewable targets										Evaluate		
			Develop harmonized CBA guidelines and cost allocation methods for meshed offshore grid connections												
			Create regional socio-economic benefits by incentivising developers to establish local service, maintenance and training centres												
Technology & market development			HVDC technology price decrease										Progress with floating		
			Install the first offshore converter station in the Baltic Sea										Diversification of the and increase		
			Further implement of automated condition-based maintenance technologies for subsea infrastructures										Achieve cost reductions		
			Integrate SMEs in the service & maintenance sector of meshed offshore grids												
			Enhanced efficiency and												
								Establish the price span and development of DC circuit breakers							
													First MTDC grids become		
Environmental & spatial planning			Establish a robust framework to ensure international cooperation in the service of producing												
			Develop channels for cooperation and data-sharing between MSP agencies, actors from the wind energy industry, and stakeholders from other maritime uses (e.g. fishing, shipping, etc.), at an early planning stage										MSP agencies and public through solutions		
			Prioritisation of the different activities in the BSR based on an unified approach										Develop best-practice construction and		
	Maritime spatial plans are adopted and legally binding in all Member States in the BSR			Ensure that the siting of OWF is done in a way that considers intermediate requirements transmission systems at an early stage of the											
				Establish a transnational organisation responsible for regional MSP, together with national authorities											
				Revision*/ adaptation of plans in response to changes in national policies or industry trends				Revision*/ adaptation of plans					Revision*/ adaptation		
Grid planning & construction	Revise the new TYNDP 2020-2022 to integrate planned interconnectors with offshore wind farms														
				Perform a full feasibility study for a meshed offshore grid in the South Baltic as optimal starting point for a regional grid, connecting Poland, Sweden and Lithuania, and Germany and Sweden.				Begin planning and permitting procedure for a meshed offshore grid in the South Baltic			Start integrating offshore wind farms in a South Baltic meshed offshore grid				
Offshore wind energy capacity in the BSR (GW)	>2.2											9.5			
EU renewable energy targets		20%		Revise targets for 2030 for from 32% to 35%				Achieve 35% renewable energy target					Revise and update targets based on new set new target		
**EU electricity interconnection targets		10%										15%			

* The MSP Directive dictates that the Plans must be revised/adapted at least every 10 years. Countries are free to set shorter time intervals.
**EU interconnection targets refer to interconnection capacity in relation to installed electricity production capacity.

Table 3. Baltic InteGrid roadmap for the future.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new technological possibilities
Revise and update targets to reflect new technological possibilities
and adjust the targets
Reevaluate and adjust the targets
technologies allows OWF to be installed in deeper waters
Expansion of floating OWF into deeper waters
supply chain for grid components
in the number of suppliers
through automated monitoring technologies
performance of HVDC technology
operational
Meshed offshore grid developed
Optimisation analysis of the meshed offshore grid
useful maritime spatial plans for the BSR
authorities should seek to optimise use
involving multiple uses of maritime space within each sector
overview to minimise impact during
operation of meshed offshore grid
as well as long-term visions of meshed
MSP process
of plans
Revision*/ adaptation of plans
Harmonised approach to MSP in BSR
Operation and monitoring of the meshed offshore grid in the South Baltic
Study possibilities for expansion of the meshed offshore grid
from the South Baltic towards the Middle and North Baltic Sea
Feasibility study of a
meshed offshore grid
expansion towards the
Middle and North Baltic Sea
Begin planning and
permitting for a meshed
offshore grid expansion
in the Middle and
North Baltic Sea
Begin the expansion of
meshed offshore grid
towards the Middle and
North Baltic Sea
35
renewable
technology,
for 2040
Stock-taking: On track for 95% emissions
reduction by 2050? If not, increase
renewable energy targets
Achieve 95% emission reduction on EU level
Need for an EU 2040 and 2050 electricity interconnection targets

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