Baltic LINes

Coherent Linear Infrastructures in Baltic Maritime Spatial Plans

Offshore Wind and Grid in the Baltic Sea – Status and Outlook until 2050

22 March 2019

Interreg Baltic Sea Region

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Offshore Wind and Grid in the Baltic Sea – Status and Outlook until 2050

22 March 2019

Swedish Agency for Marine and Water Management

RISE Research Institutes of Sweden
Authors: Johannes Hüffmeier, Mats Goldberg (RISE)

SwAM, RISE

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Summary

Efficient and sustainable use of the Baltic Sea requires cross border coordination of the various activities taking place in and on the ocean. The coordination is executed through multilateral maritime spatial planning activities where countries in the Baltic Sea Region (BSR) participate. The Swedish Agency for Marine and Water Management (SwAM) is partner in BalticLINes, an Interreg project for the Baltic Sea region. BalticLINes aims to establish more coherent national Maritime Spatial Plans (MSP) in the Baltic Sea Region and thereby increase transnational coherence of shipping routes and energy corridors. The plans will prevent cross-border mismatches and secures transnational connectivity as well as efficient use of Baltic Sea space. Part of the Baltic LINes scope is to analyse future needs and opportunities for ocean-based energy from wind power and other energy sources as well as power cables for interconnection between countries. The electric power infrastructure is an important part of MSPs for the BSR.

As part of the BalticLINes project, this report described the various parameters that have been considered for deriving the 2030 and 2050 scenarios including the energy policy frameworks within the EU and in each country around the Baltic Sea for both offshore wind power and offshore power grids and the current and future market trends for offshore wind power.

Different methods have been used to collect, analyse and describe the data. A literature study has been used based on internet resources, various GIS data from trustworthy sources were collected, country-wise national experts were interviewed and asked for input. Prognoses for countries, European wide, from the industry and wind farm developers have been put together and compared to current development rates and targets. Content from other work packages in the Baltic LINes project has been adopted.

In the countries around the Baltic Sea, the energy mix and the changes in such during the last decade shows high variation. This is reflected in the 2020 EU targets as well as in the one´s for 2030. Thus, the different countries also differ in their motivation to build offshore renewable energy in the Baltic, which means for example that no dedicated offshore wind sites are planned and also that priority settings for a MSP are influenced and thus evaluation of different interests varies. The differences in ambition are affecting MSP and the possibility to approximate the various countries' plans towards a united MSP across the Baltic Sea, however, to a certain extend

harmonization of processes and targets is to be expected throughout the region, but differences between countries will remain that will affect the MSP processes.

There are good wind energy resources in the Baltic that to a large extend could be explored by using existing techniques. Other sources of energy like waves and tidal streams are showing less potential in the region due to the limited currents and a comparably mild wave climate. Additionally, the effects of ice coverage of large areas during winter season is a disadvantage. However, a combination of different sources of energy might still be of advantage for energy supply. The European Union is likely to increase the targets for renewable energy further. Also, the increased need of electricity for e.g. electrification of transport will affect the total need of renewable energy.

There is a need for more interconnection in the Baltic Sea region to ensure security of supply, lower the risk of electricity blackouts, reduce the need to build new power plants, achieve price stability and adjustment (integrate markets), and make it easier to manage intermittent and variable renewable power sources. Compared to other parts of Europe, the expected congestions in the grid are expected to be denser in the BS region and need investment and various projects that affect the MSP. The ambition of increased self-sufficiency for both EU and for single countries, whilst at the same time based on and only possible with renewable energy, however, implies an increased need for interconnection and a strengthened national grid.

The technical development within renewable energy production will have an impact on the MSP process, as required site characteristics for fitting future technology can only in a limited way be forecasted those implications are partly uncertain. MSP should for instance consider the potential technical development on a more long-term perspective. The future might not only imply bigger wind parks and turbines but also floating solutions, combined cross-national interconnectors and even airborne wind.

While the first movers Denmark and Germany are expected to slow down pace of new installations after 2025/2030, many other Baltic Sea Region countries are likely to increase their efforts to build offshore wind, resulting in development of bigger wind parks in the south eastern part of the Baltic Sea. Decommissioning of existing wind parks and re-powering of sites is expected by that time as well.

As there are hardly any accurate targets specified for 2050 and as the need for energy and the technical development is rapidly changing, the trajectories for the long term imply higher uncertainties.

As the pathway to reach the 2-degree target as stated in the Paris Agreement is narrow, strong efforts are needed to put extensive renewable energy production into operation. Some countries must handle more limited physical space and renewable energy sources showing limited cost-efficiency. The way forward could imply green-streaming of renewable energy from probably low-densely populated regions with good energy resources to regions with high energy demand. Further development of infrastructure is needed to support this development. (The wording green-streaming, established as a contrary to the Nordstream gas pipeline, providing green energy (renewable electricity) on large scale as an export product)

As the production of electricity is going to be of more intermittent character for renewable energy sources, the exchange of energy in form of electricity will have to increase further. In order to manage security of supply in the future a different way of energy and electricity streams will be needed. Sharing of energy originating within the EU will increase tremendously so i.e. countries with a high import volume will have to rely on energy-exporting countries, taking advantage of resources for cost- and space-efficient renewable energy production. Especially Denmark, Germany and Poland, as they are characterised by high population density, energy intense industry as well as distances between production and consumption of energy, will have to invest in extending, strengthening and reinforcing their national grid. However, also all other countries will have to make significant efforts in favour of security of supply.

Table of Contents

1 Introduction

BalticLINes is an Interreg project for the Baltic Sea region. The overall objective of the Project: to increase transnational coherence of shipping routes and energy corridors in Maritime Spatial Plans (MSP) in the Baltic Sea Region (BSR). This prevents cross-border mismatches and secures transnational connectivity as well as efficient use of Baltic Sea space. Thereby Baltic LINes helps to develop the most appropriate framework conditions for Blue Growth activities (e.g. maritime transportation, offshore energy exploitation, coastal tourism etc.) for the coming 10-15 years increasing investors' security. SwAM (Swedish Agency for Marine and Water Management) has contracted RISE Research Institutes of Sweden to provide energy scenarios to the project.

To facilitate discussions in the BalticLINes project and to provide coherence in the Baltic Sea Marine Spatial Planning process spatial scenarios for offshore wind energy developments and energy grid infrastructure projections for the years 2030 and 2050 have been developed. Various parameters have been considered for deriving the scenarios including the energy policy frameworks within the EU and in each country around the Baltic Sea for both offshore wind power and offshore power grids and the current and future market trends for offshore wind power. These parameters are described in detail in this report.

Based on the current status of offshore wind power and offshore power grids in the Baltic Sea and expected future development of offshore wind power and offshore power grids in the Baltic Sea according to the permit application, planned projects and development projects of an earlier nature, the scenarios are described in this report to allow for identification and evaluation of marine spatial planning effects that promote or hinder the development of offshore wind power and offshore power grids. Future trends in electricity generation at sea in addition to offshore wind power, an assessment of whether marine energy (electricity generation from currents, waves, etc.) should be considered in the Baltic Sea's marine plans and how these can contribute to the long-term policy goals (scenario 2050) is provided. An information gap analysis, i.e. an assessment of whether the countries will achieve their goals and proposals for the necessary commitments to meet the policy objectives is given also.

This chapter describes the scenarios derived, background information on the methods, the current status and trends is provided in the following chapters. Based on the historic development of offshore wind in Northern Europe and more ambitious targets for fossil-free energy use in the Baltic Sea region scenarios have been derived for 2030 and 2050. The scenario described in the map below for 2050 corresponds to a total fossil-free energy production and consumption in the region based on a worldwide study published by Stanford (Jacobson, et al., September 6, 2017).

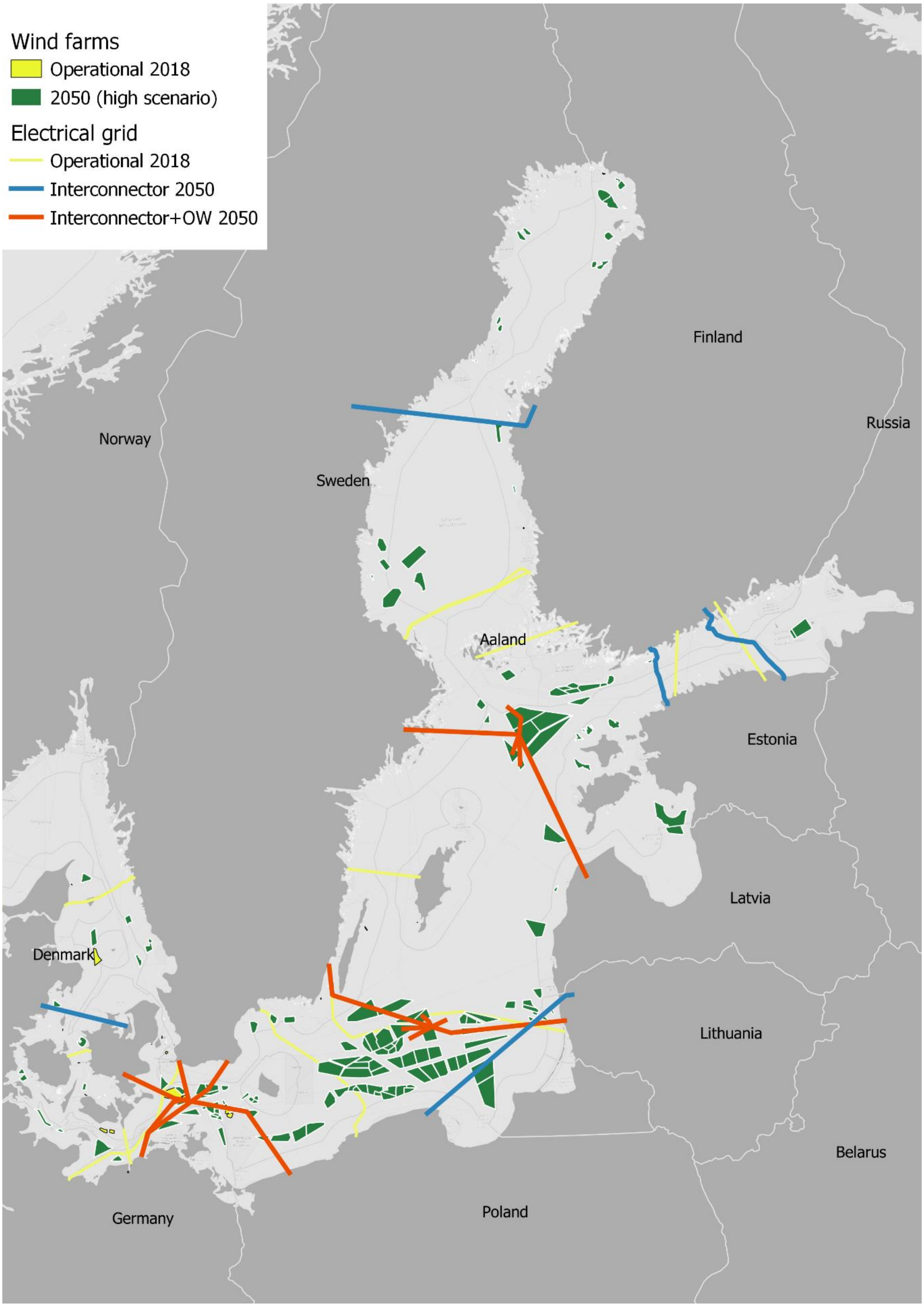


Figure 1: Overview map, energy scenario, final scenario from today to 2050 based on the high scenario in line with the Paris agreement including wind resource density

1.1 Background to the study

The Swedish Agency for Marine and Water Management is partner in Baltic LINes (Interreg Baltic Sea Region) and aims to establish more coherent national marine spatial plans in the Baltic Sea Region. The plans will ensure cross-border links, so the project is developing a framework for blue growth, which includes ocean-based energy from wind power and other energy sources. A part of the work is the analysis of future needs and opportunities for offshore wind farms and power cables in the Baltic Sea Region as well as other renewable energy sources.

The projects main goals of the Baltic LINes project include:

- Developing requirements for MSP in relation to the shipping and energy sector in BSR;
- Harmonizing BSR MSP data infrastructure for shipping routes and energy corridors, drafting guidelines for MSP data exchange and dissemination;
- Identifying and agreement on transnationally coherent planning of linear infrastructures;
- Providing recommendations for a formalized BSR agreement on transboundary consultations on linear infrastructure within the MSP process.

1.2 Aim and Scope

The aim of the work is to give input to the Baltic Sea Marine Spatial Planning process by developing spatial scenarios for offshore wind energy developments and energy grid infrastructure projections for the years 2030 and 2050. The result of this work is intended as input to the MSP Challenge computer simulation and workshops. The scope includes:

1. Analysis of energy policy frameworks within the EU and in each country around the Baltic Sea for both offshore wind power and offshore power grids
2. Analysis of market trends for offshore wind power
3. Identification and evaluation of marine planning effects that promote or hinder the development of offshore wind power and offshore power grids
4. Reporting (through maps) of the current status of offshore wind power and offshore power grids in the Baltic Sea
5. Future development of offshore wind power and offshore power grids in the Baltic Sea according to the permit application, planned projects and development projects of an earlier nature
6. Reporting (through maps and GIS files) of future development of offshore wind power and offshore power grids in the Baltic Sea, including appropriate areas, priority areas and production capacity per km2
7. Summary, including "information gap analysis", an assessment of whether the countries will achieve their goals and proposals for the necessary commitments to meet the policy objectives
8. Future trends in electricity generation at sea in addition to offshore wind power, an assessment of whether marine energy (electricity generation from currents, waves, etc.) should be considered in the Baltic Sea's marine plans and how these can contribute to the long-term policy goals (scenario 2050).

The focus of this study is the 2030 scenario as the knowledge base for the 2050 scenario are judged to be uncertain.

1.3 Related Documents

This document is part of a deliverable consisting of three reports, see Table 1. They can be read separately or together depending on the interest of the reader.

Table 1. List of documents related to this report.

Document:	Contents:
2030 and 2050 Baltic Sea Energy Scenarios	Detailed description of the 2030 and 2050 energy scenarios with some background information to put the scenarios into context.
Offshore Wind and Grid in the Baltic Sea – Status and Outlook until 2050 (including appendices appendices) (This report)	The document contains the data on which the scenarios in *2030 and 2050 Energy Scenarios for the Baltic Sea* are built, in order not to make the energy scenario report to long. It contains a comprehensive description of the current state of development for offshore wind power and offshore power grid in the Baltic Sea as well as a detailed review of energy policy on EU and national level for the countries in the Baltic sea region. There is an overview of technical developments for offshore wind power and grid.
2030 and 2050 Baltic Sea Energy Scenarios – Ocean Energy	Ocean energy (wave, tidal and current, bio masses, thermal and salinity) technology overview and scenario description for 2030 and 2050.

2 The Baltic Sea

This chapter contains an introduction to the Baltic Sea, its oceanographic properties and resources.

2.1 Oceanographic properties of the Baltic Sea

The Baltic Sea is an arm of the North Atlantic Ocean, extending northward from the latitude of southern Denmark almost to the Arctic Circle and separating the Scandinavian Peninsula from the rest of continental Europe. The largest expanse of brackish water in the world, the semi-enclosed and relatively shallow Baltic Sea has a rather low water turnover from the North Atlantic and receives mainly fresh water from the river run-offs which results in low salinity especially in the easterly and northern parts.

(Encyclopædia Britannica, 2018). The total area is 377 000km^2 to 415 000km^2 depending on where the limits are drawn in the Kattegat and Skagerrak and has including the Kattegat a volume of 21 700 km^3. The catchment area is 1 650 000 km^2, more than four times the area of the sea itself. Almost 100 million people live around the Baltic Sea (Encyclopædia Britannica, 2018). It is typically divided into sub-regions that are shown in the figure below.

The bottom types in the Baltic consists of a variety of geophysical properties. Many parts consist of sand and mud, while other parts are dominated by hard bottom complex, hard clay and bedrock. These differences have an impact on bottom fixed and moored structures and the costs connected to appropriate bottom fastening.

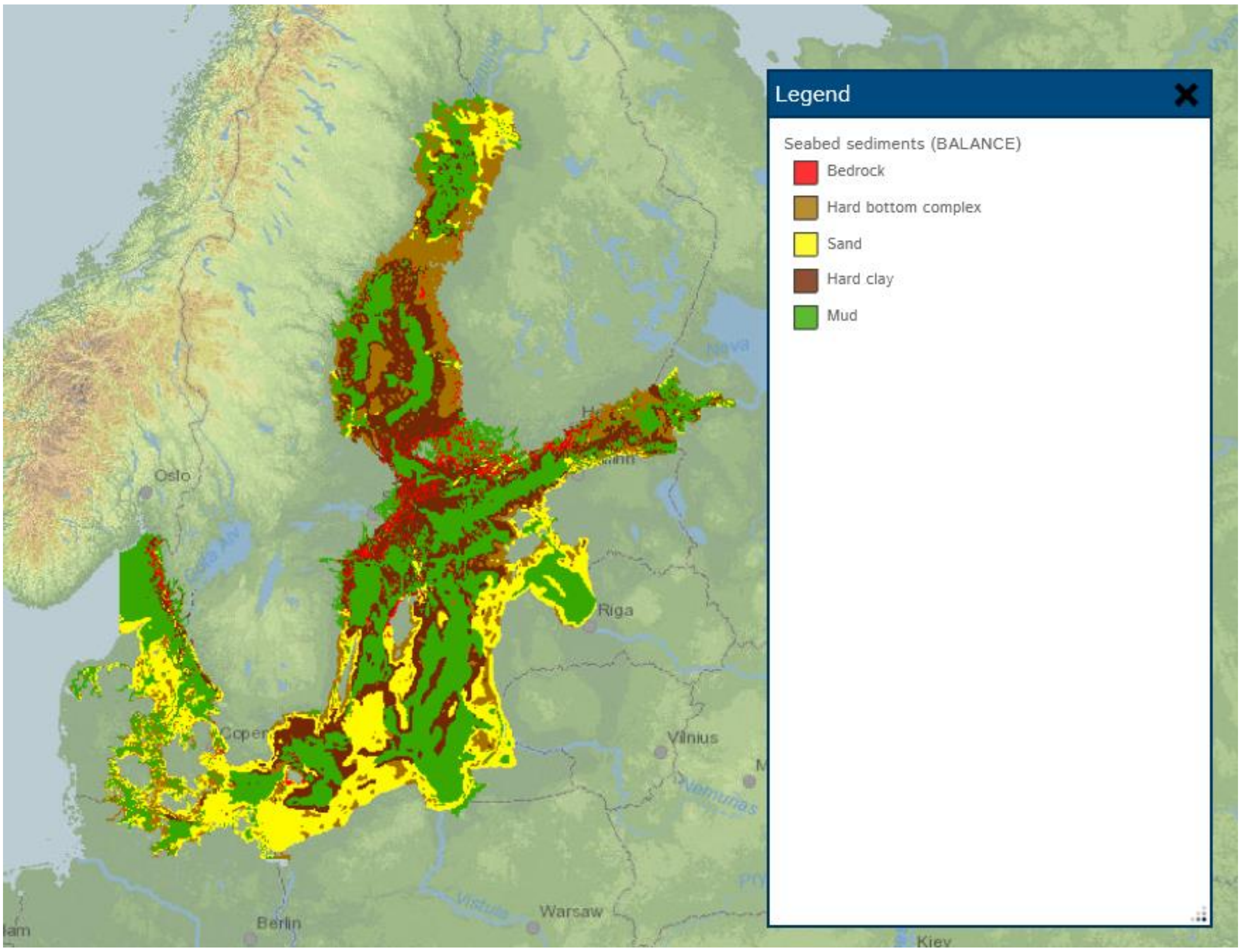


Figure 2: Seabed sediments in the Baltic Sea. Data Source: HELCOM

The water depth in the Baltic is up to about 500m in depth in the Baltic Proper east of the island of Gotland and contains rather shallow parts around the Danish islands and in the Gulf of Finland. Where there are sandy bottoms the water depth is often shallower, while in the deeper parts, mud and hard clay is prevailing. Especially in the Finnish and Swedish archipelagos the bedrock bottom is present together with hard clay or hard bottom complex.

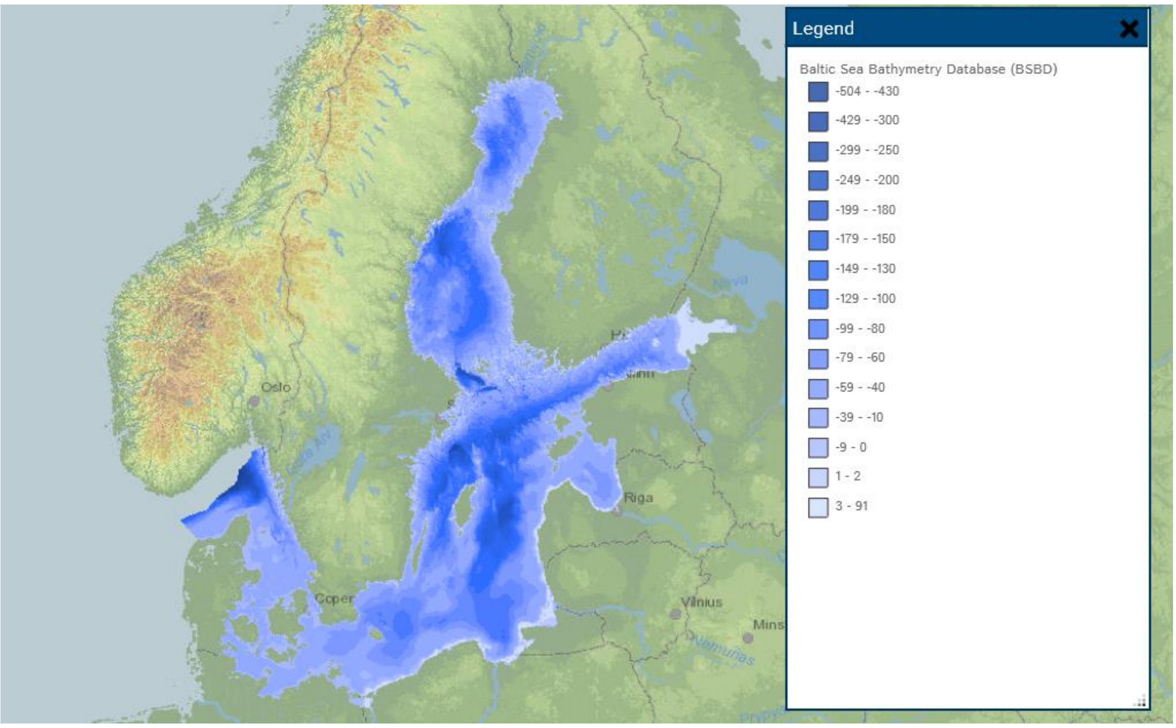


Figure 3: Water depth in the Baltic Sea [m], Data Source: HELCOM

2.2 Wind energy profiles and resources in the Baltic Sea region

This chapter describes the wind energy profiles and resources available in the Baltic Sea. The resources can be split into wind, waves, tidal and stream currents, temperature and salinity. There is a dependency between these resources, but they are described separately anyway in "*2030 and 2050 Baltic Sea Energy Scenarios – Ocean Energy*".

Wind resources are typically numerically modelled based on satellite images and wind measurements. They have different resolutions in time and space. Important is to know the wind content in the area at various heights, the variability of the wind, seasonality and sensitivity to distance to coastlines and other obstacles. The assessments made in this study are based on *coastDat* data[1]: *coastDat is a model-based data bank developed mainly for the assessment of long-term changes in data sparse regions. A sequence of numerical models is employed to reconstruct all aspects of marine climate (such as storms, waves, surges etc.) over many decades of years relying only on large-scale information such as large-scale atmospheric conditions. The approach was developed over more than 10 years and has been applied successfully to various issues in the North Sea including, amongst others, assessments of the effectiveness of political measures to reduce chronic oil pollutions or changes in wind and storm surge climate. The coastDat data set is used by more than 100 users with about 40% of them located in economy, 15% in authorities and 45% in research institutes.*

[1] https://www.coastdat.de

The wind energy content is than typically calculated based on representative power curves for wind turbines, that describe the energy production for various wind speeds. In this work, the data from the coastDat projects have been used to calculate the average wind speeds and the wind power content. All wind speed statistics in the database show a reasonable agreement between observations and model results: Mean values as well as inter-annual variability of the different indices appear to be reasonably reproduced by the coastDat model. (Weisse, Feser, & Storch, 2005). The spatial and time resolutions are satisfactory for the scope of this study.

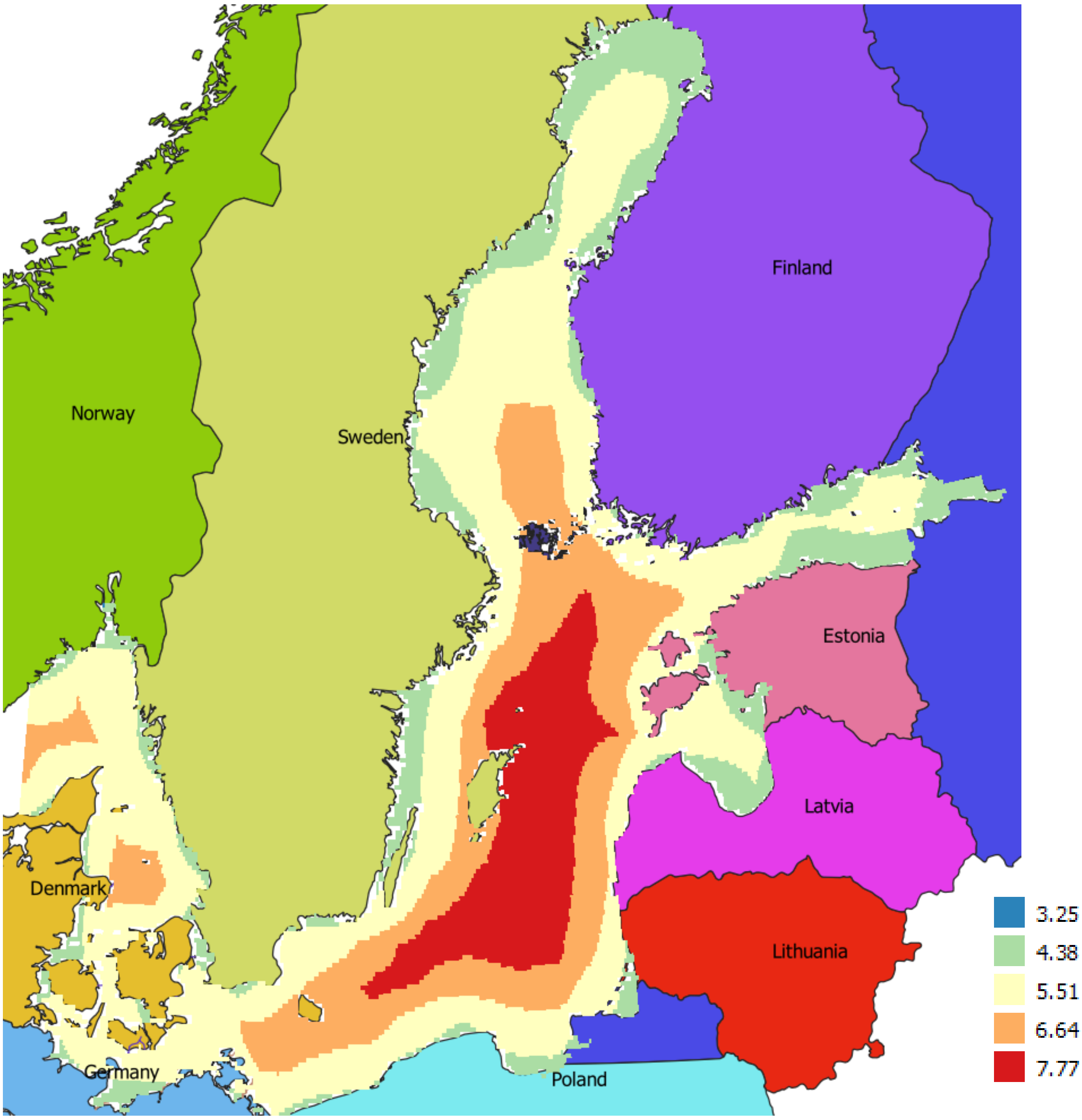


Figure 4: Average wind speeds [m/s, one hour mean] in the Baltic Sea based on numerical simulated data from coastDat

The usable power input is calculated according to the standard methods used for wind atlases.[2]

---

[2] http://drømstørre.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/powdensi.htm

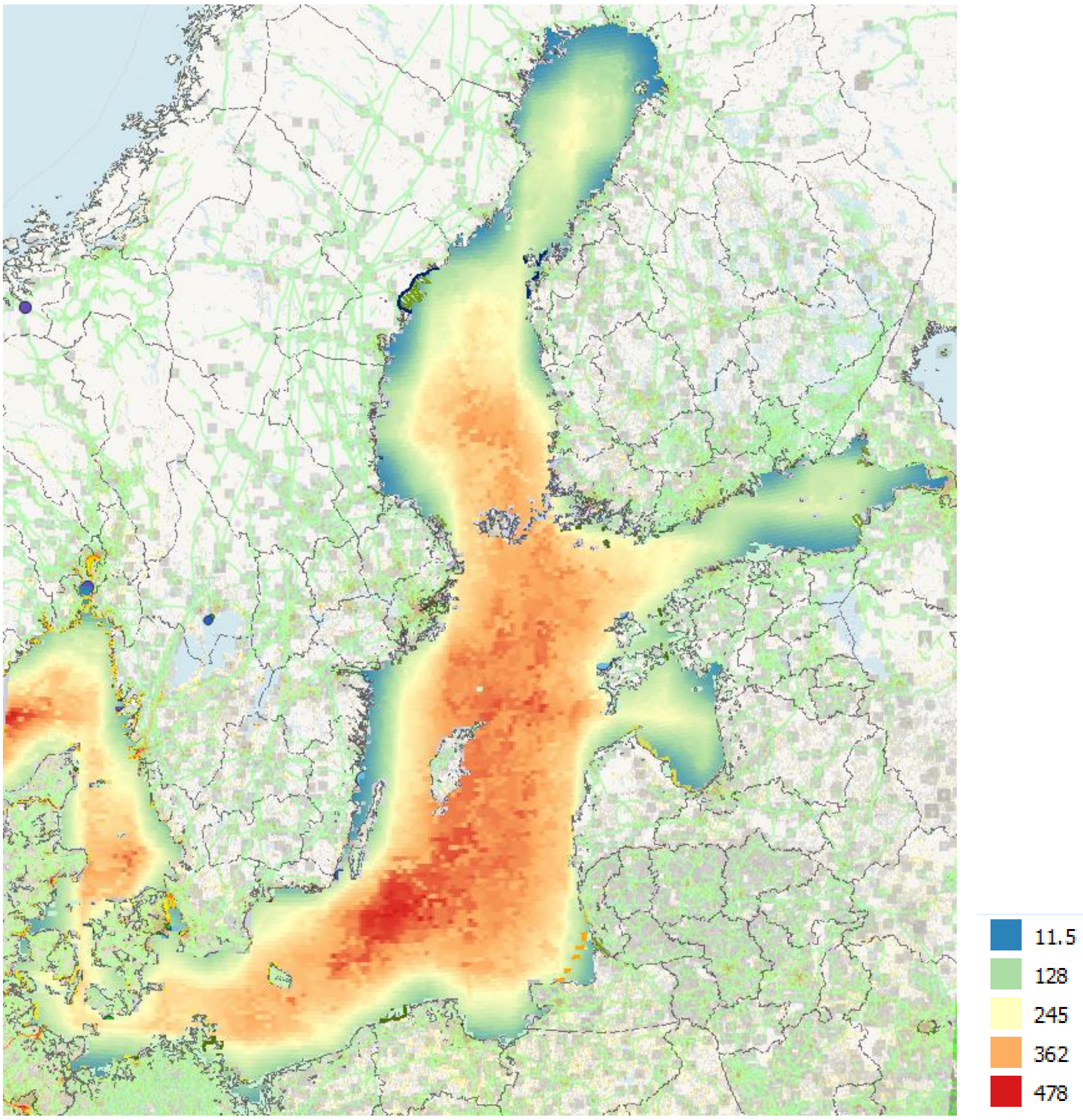


Figure 5: Usable power density [W/m²] of wind speeds in the Baltic Sea based on numerical simulated data from coastDat. Usable power density implies the wind power available based on the wind speed distribution

3 Status and Near Future Plans for Energy Production and Transmission in the BSR

This chapter describes resources for wind energy conversion, the current available wind farms and transmission lines, different techniques and future development of parks and electrical infrastructure.

The status and the near future development of offshore wind power and offshore power grids in the Baltic Sea is presented according to the permit application, planned projects and development projects of an earlier nature. A wide range of sources have been consulted to complement the information provided by the project participants. Focus is on offshore wind and electric grid. Oil, gas and minerals are mentioned in brief and information on ocean energy can be found in the separate report "*2030 and 2050 Baltic Sea Energy Scenarios – Ocean Energy*".

3.1 Offshore wind

Offshore wind as a renewable energy source has several advantages compared to other sources of energy by (Freeman, et al., 2016):

1. Making use of benefits from a higher, more consistent wind resource than onshore wind. It has fewer physical constraints than onshore wind generation in populated areas, such as turbine size, operating noise and visual amenity.
2. Avoiding constraints in new onshore wind capacity, weaknesses in transmission infrastructure
3. Producing utility-scale low-carbon electricity using very low levels of water compared to electricity generation from fossil fuels, nuclear and biomass.
4. providing electricity generation capacity close to densely populated coastal areas.
5. Facilitating relatively quickly installation at gigawatt (GW) scale and allowing the decarbonisation of electricity production.
6. Making use of the technologies developed over decades by the onshore wind industry.

3.1.1 Bottom fixed wind – status

After decades of learning, the offshore wind industry has an established supply chain and knowledge how to handle risks in the harsh offshore environment, resulting in a lower risk level and easy access to financing. Nearly all offshore wind development has taken place in Europe and especially the North Sea, with deployment starting in Asia in recent years. The offshore wind development in the Baltic has had a slower development than the North Sea, starting out earlier, but increasing slower. The installed MW per year from the late 80s up to today are shown in the figure below. The installation and commissioning of single parks is visible in the Figure 6. The development has been driven by Denmark and Germany with the highest capacities operational and under construction. The status of offshore wind projects in the Baltic is shown in the Table 2. It is split into the actual status, where operational indicates parks in service, under construction that construction work is currently ongoing, and approved that the park is consented by the local authorities (which does not imply that a final investment decision is made) and planned covered all from early concept to document handed in for authority approval. The calculations are based on 4 000 h full load/ year for converting rated power (MW) to AEP (TWh), the assumed capacity density is 5.4 MW/km^2, which is representative for the North Sea as well as the Baltic Sea projects. More and more countries shift their system to centralised auctions and licensing system which has an impact on the status categorisation shown in Table 2. There are six parks or single turbines that are already decommissioned, but these had low capacities.

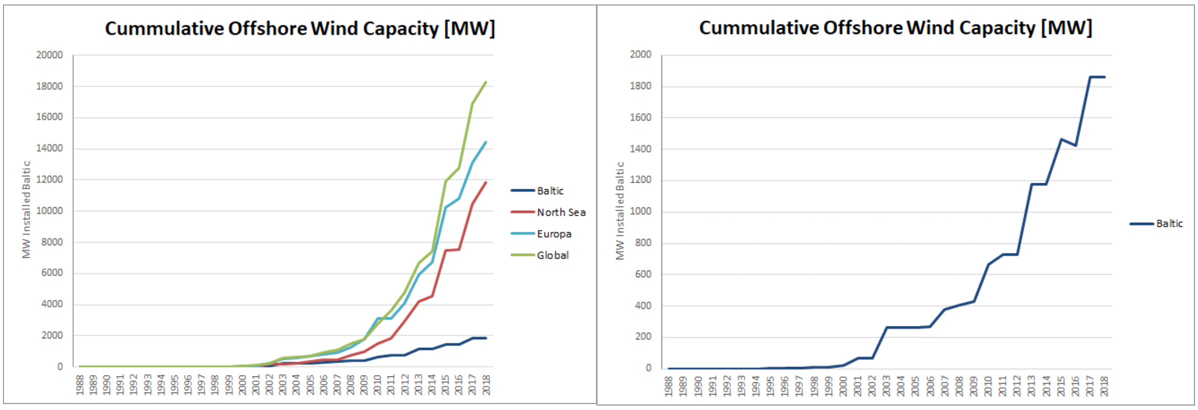


Figure 6: Cumulative installed capacity in the Baltic compared to North Sea, Europe and globally, based on data from 4cOffshore and internal RISE database

The location of the various wind parks is shown in Figure 7 together with their status and size. A list of the existing parks and those under construction or decommissioned is given in Table 3. As shown in the table, the turbine sizes and park sizes have been increasing significantly since the start. Also, the distance to shore and the water depth at site are increasing. Compared to the North Sea, the foundation types in the Baltic are much more varied, as the soil conditions and other environmental factors are more varying, such as ice-cover in the winter time.

Table 2: Installed wind power capacity in the Baltic Sea as of May 2018 along with related calculated energy production and occupied space.

MW *	Planned	Approved	Under Construction	Operational [MW]	Operational [TWh]
Denmark	640	140	598	880	3,7
Germany	271	504	385	689	2,9
Sweden	3 080	2 760	-	200	0,8
Finland	2 070	-	-	90	0,4
Poland	8 610	2 400	-	-	-
Estonia	4 330	-	-	-	-
Lithuania	1 630	-	-	-	-

MW *	Planned	Approved	Under Construction	Operational [MW]	Operational [TWh]
Latvia	-	-	-	-	-
Baltic EU	20 631	5 804	983	1 858	7,8
Norway	1	5	-	-	-
Russia	433	-	-	-	-
Total	21 065	5 809	983	1 858	7,8
GWh	88,5	24,4	4,1	7,8	
Km^2	4 213	1 162	197	372	
% Baltic	1,12%	0,31%	0,05%	0,10%	

*Sources: (4cOffshore, 2018), (WindPower Net, 2018), (Hundleby, o.a., June 2017) (Nghiem, Pineda, & Tardieu, September 2017), (European Environment Agency, 2017), (Fraile, Mbistrova, Pineda, & Tardieu, 2018), Own database

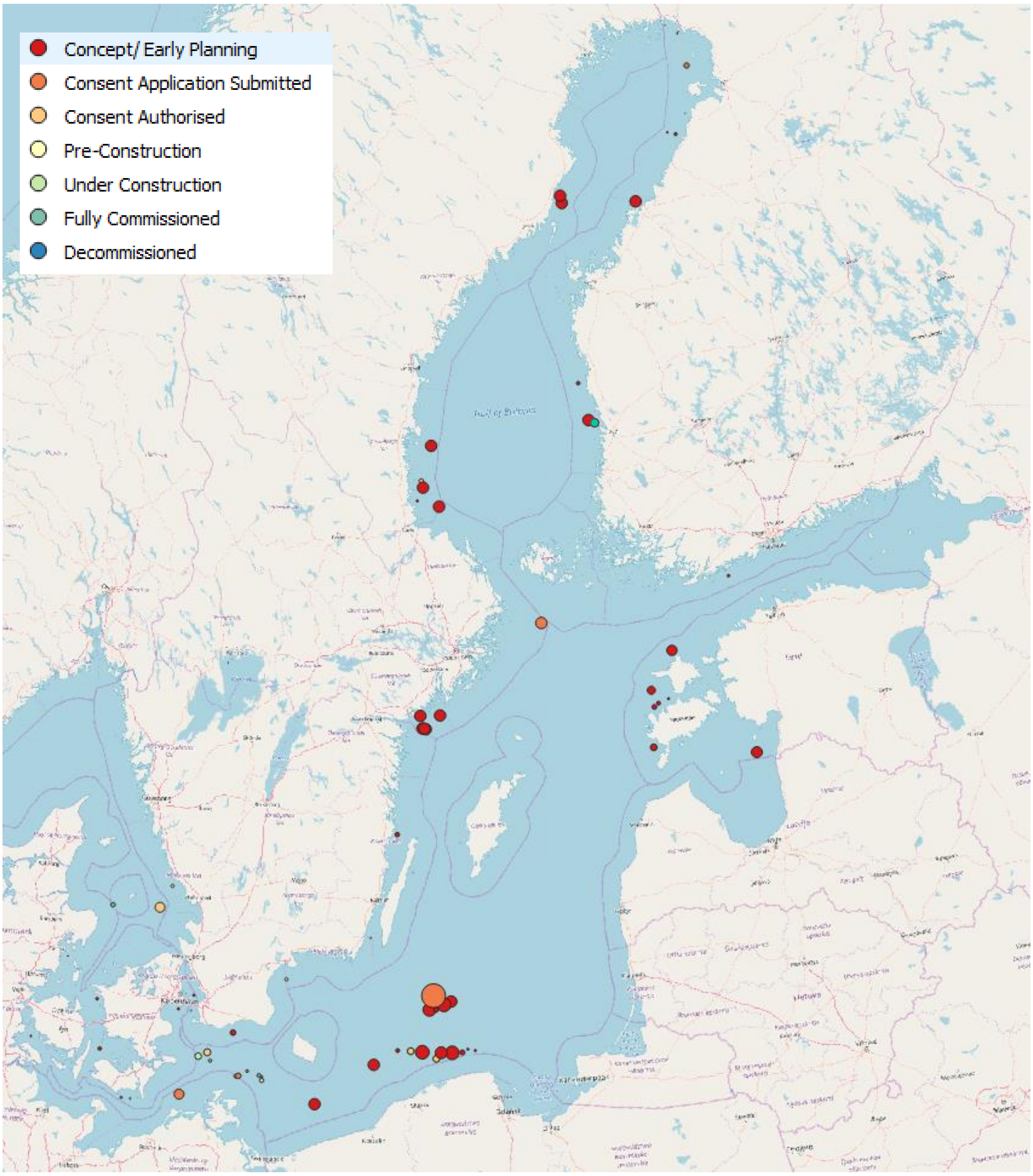


Figure 7: Offshore wind farm development in BSR 2017 based on RISE database. Size of points indicate size of park, colour indicates development status.

When it comes to offshore wind connections, there are only HVAC-based transmissions in the Baltic Sea, even in the German waters, due to the limited distance to the connection points. Only the bigger parks have an offshore substation in the park vicinity. A limited number of wind farm developers act in the Baltic Sea when it comes to significant farm sizes, due to the complexity of such projects. The stated project costs show similar trends as in the North Sea, with decreasing trends for the LCoE (Levelized Cost of Energy).

In a planning perspective, the technique used for electrical transmission is not crucial, as HVDC and HVAC is both based on offshore substations and cables to shore. Basically, HVAC close to shore could be built without substation at all but directly connected to the grid and HVDC might require an additional substation as currently built in the German North Sea.

Table 3: Offshore wind farms in the Baltic Sea, based on internal database

Name	**Country Name**	**Development Status**	**Year**	**Project Capacity**	**Turbine Capacity**	**Number of turb.**	**Sea Name**	**Area [km2]**	**Depth Range [m] min**	**Distance from shore [km]**	**Developer/ Owner**	**MW/ km2**
Nogersund Svante 1	Sweden	Decommissioned	1990	0,22	0,22	1	Baltic Sea	-	3-6	0,8	EON Vind Sverige	-
Yttre Stengrund	Sweden	Decommissioned	2001	10	2	5	Baltic Sea	0	6-8	3,7	Vattenfall	-
Kemin Ajoksen I	Finland	Decommissioned	2008	15	3	5	Gulf of Bothnia	2	0-6	5,1	Innopower	7,5
Kemin Ajoksen II	Finland	Decommissioned	2008	15	3	5	Gulf of Bothnia	1	0-8	6	Innopower	15,0
Kemin Ajoksen Meriperustusha	Finland	Decommissioned	2009	-	-	0	Gulf of Bothnia	-	4	6,6	Suomen Hyötytuuli	-
Sea Twirl P3	Sweden	Decommissioned	2011	0,002	0,002	1	Kattegat	2	7-8	0,6	Sea Twirl	0,0
Tunö Knob	Denmark	Fully Commissioned	1995	5	0,5	10	Kattegat	-	4-7	5,5	Örsted	-
Bockstigen	Sweden	Fully Commissioned	1998	2,75	0,55	5	Baltic Sea	-	6	5,7	OM O2	-

Name	Country Name	Development Status	Year	Project Capacity	Turbine Capacity	Number of turb.	Sea Name	Area [km2]	Depth Range [m] min	Distance from shore [km]	Developer/ Owner	MW/ km2
Utgrunden I	Sweden	Fully Commissioned	2000	10,5	1,5	7	Baltic Sea	0	6-15	7,3	Energy E2/ Vattenfall	-
Middelgrunden	Denmark	Fully Commissioned	2001	40	2	20	The sound	-	3-5	4,6	Örsted	-
Fredrikshavn	Denmark	Fully Commissioned	2003	7,6	2,3	4	Kattegat	0	1-4	3,1	Örsted	-
Nysted/ Rödsand 1	Denmark	Fully Commissioned	2003	165,6	2,3	72	Baltic Sea	26	6-10	10,7	Energi E2/ Örsted	6,4
Samsö	Denmark	Fully Commissioned	2003	23	2,3	10	Kattegat	-	14-20	3,9	Samsö Havvind	-
Breitling	Germany	Fully Commissioned	2006	1	2,5	2,5	Breitling	-	-	0,3	WPD/ Nordex Energy	-
Lillgrund	Sweden	Fully Commissioned	2007	110,4	2,3	48	The sound	6	4-8	9,3	Vattenfall	18,4
Sprogö	Denmark	Fully Commissioned	2009	21	3	7	Kattegat	-	6-16	10,6	Sund&Bält Holding	-
Rödsand 2	Denmark	Fully Commissioned	2010	207	2,3	90	Baltic Sea	34	6-12	9	EON Vind Sverige	6,1
Reposaaren tuulipuisto	Finland	Fully Commissioned	2010	2,3	2,3	1	Gulf of Bothnia	-	9	9,6	Suomen Hyötytuuli	-

Name	Country Name	Development Status	Year	Project Capacity	Turbine Capacity	Number of turb.	Sea Name	Area [km2]	Depth Range [m] min	Distance from shore [km]	Developer/ Owner	MW/ km2
Vindpark Vänern	Sweden	Fully Commissioned	2010	30	3	10	Lake Vänern	3	3-13	10,1	Vindpark Vänern,	10,0
EnBW Baltic 1	Germany	Fully Commissioned	2011	48,3	2,3	21	Baltic Sea	7	16-19	17,1	EnBW	6,9
Avedöre Holme	Denmark	Fully Commissioned	2011	10,8	3,6	3	The sound	-	0-2	0,4	Örsted	-
Göteborg Wind Lab	Sweden	Fully Commissioned	2012	4,1	4,1	1	Baltic Sea	-	0	0,8	Göteborg Energi	-
Anholt	Denmark	Fully Commissioned	2013	399,6	3,6	111	Kattegat	116	15-19	22,6	Nelja Energia	3,4
Kårehamn	Sweden	Fully Commissioned	2013	48	3	16	Baltic Sea	2	8-20	7	EON Vind Sverige	24,0
EnBW Baltic 2	Germany	Fully Commissioned	2015	288	3,6	80	Baltic Sea	30	23-44	35,4	EnBW	9,6
Sea Twirl S1	Sweden	Fully Commissioned	2015	0,03	0,03	1	Gullmarn	-	31		Sea Twirl	-
Wikinger	Germany	Fully Commissioned	2017	350	5	70	Baltic Sea	34	37-43	39,2	Iberdrola Renovables Deutschland	10,3
Ajos	Finland	Fully Commissioned	2017	42,4	3,3	8	Gulf of Bothnia	3	0-8	5,2	Empower	14,1

Name	Country Name	Development Status	Year	Project Capacity	Turbine Capacity	Number of turb.	Sea Name	Area [km2]	Depth Range [m] min	Distance from shore [km]	Developer/ Owner	MW/ km2
Tahkoluoyo Offshore Wind Power	Finland	Fully Commissioned	2017	42	2.3-4	11	Gulf of Bothnia	6	8-15	9,8	Suomen Hyötytuuli	7,0
Arkona	Germany	Under Construction	2019	385	6	60	Baltic Sea	39	23-37	37,5	EON	9,9
Kriegers Flak	Denmark	Under Construction	2019	597,5	8	72	Baltic Sea	183	15-30	25,5	Vattenfall	3,3
Total			1990-2019	2883,6	0,02-8	755		494+	0-37	0.3-39		5.87

3.1.2 Bottom fixed wind – plans

Development in the BSR is ongoing at different pace in different locations and countries. There are several consented. Some will probably never be built as the rapid development of techniques will not make them profitable or where the permit is limiting the deployment of new techniques. Uncertainties in some countries related to subsidies, share of costs the projects must bear when it comes to electrical infrastructure, etc. makes some of the listed farms more uncertain or will shift them to later in the future. A list of parks in different planning stages is attached in annex 3.

3.1.3 Floating wind

Despite some testing in certain areas of the Baltic of scaled prototypes, no floating wind has been installed. There is no information on planned projects in publicly available sources. There are some areas dedicated for testing of pilot devices in the Baltic Sea. One examples is Seatwirl off the west coast of Sweden (https://seatwirl.com/news/successful-testing-and-installation-of-the-prototype-p3/).

3.2 Oil & Gas and Minerals

In the Baltic there is a potential for oil and gas production along the coastlines of Poland, Russia (Kaliningrad), Lithuania and Latvia. Onshore there are activities in all countries, while there are 3 platforms in the Baltic Sea for extraction of oil and gas, 2 in the Polish EEZ and one in the Russian EEZ. Poland has allowed production since 1992. (Lotos, 2018). New exploration is ongoing in Russia and Poland that could affect the energy production and marine spatial planning in the Baltic Sea.

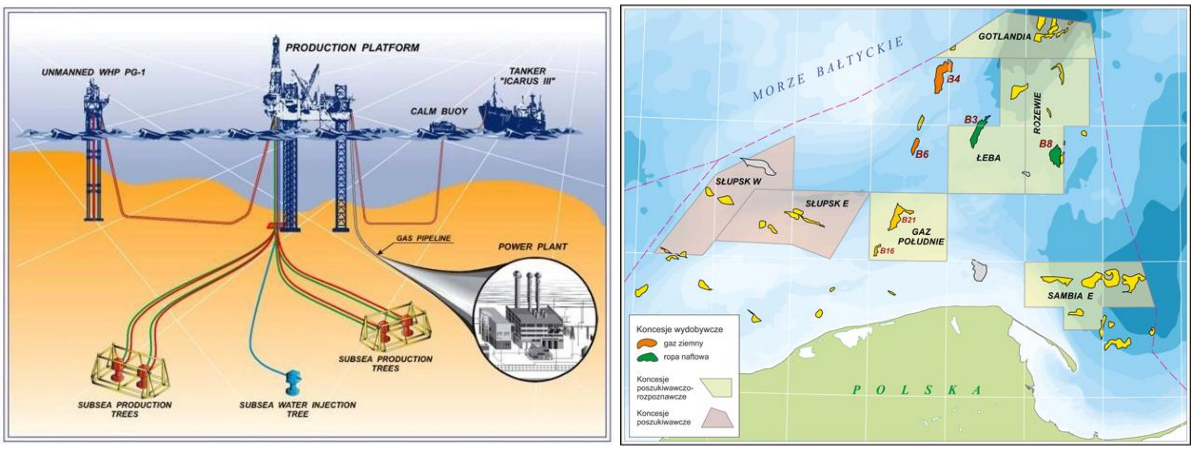


Figure 8: Oil production facilities in Poland and licensed areas, source: http://www.lotos.pl/en/

The Kravtsovskoye oilfield is in the coastal waters of the Baltic Sea, about 22 kilometres west of Russia's Kaliningrad Oblast. The deposit was opened in 1983 and extraction began in 2004. (Offshore technology, 2018). The Nordstream 1 and the Nordstream 2 (currently under construction) pipelines provide central Europe with gas from Russia. There are even licensed areas consented in various countries for minerals.

In Norway as the forerunner, but even in other countries producing oil and gas, power from shore solutions are established to power oil and gas platforms with clean energy from land. This might occur in the long run even in the Baltic, which implies that the platforms will be connected by subsea power cables. The development of oil, gas and minerals in the Baltic is not further covered in this report.

3.3 Electrical transmissions and infrastructure

For marine spatial planning it is important to consider the routing of the existing and planned subsea interconnectors and offshore wind connections in the BSR. This information will be crucial in the maritime spatial planning process elements referring to the energy infrastructure as it can cover more area than the wind park itself, involves crossing of country borders, passing of environmental sensitive areas and interfaces towards other occupancies. Different types of techniques are used, low and medium voltage AC transmissions for short distances, HVAC (High Voltage Alternate Currents) for medium distances and HVDC (High Voltage Direct Currents) for longer distances. The longer the distance, the higher the voltage level of the transmission will be to minimize losses. The HELCOM layer on cables includes 5361 cables of which 213 can clearly be connected to electrical transmission.

3.3.1 Transmission assets for offshore wind

Each offshore wind farm is connected via transmission assets to shore. The transmission assets typically consist of array cables to an offshore substation. Here the voltage level of the electricity is stepped up by transformers and brought to shore via an export cable. In the land station, the electricity is transformed to the required voltage level and connected to the grid. When smaller parks close to land are built, the transformation to high voltage on a substation can be avoided, cables are then either bundled from the turbines or connected to the grid via separate cable tracks. The offshore substation consists mainly of transformers, switches, shunts, filters, breakers and secondary systems. It is typically placed on a separate substructure, so not sharing with one of the turbines. In the German North Sea, converter stations have been built, converting AC from several parks to DC and exporting to shore over longer distances. These converter stations include in addition to the equipment mentioned above even valves. The export cables consist of a subsea cable and of underground cables or in rare occasions overhead line transmission onshore. The export cables for AC and DC transmission deviate in the design from each other.

3.3.2 Interconnectors (national and international)

Electricity interconnectors provide the physical links which allow the transfer of electricity across borders and to islands or platforms. Interconnectors derive their revenues from congestion or from the need to transmit power to/from remote locations.

If price differences exist between markets at either end of the interconnector, congestion revenues are there due to the existence of price differentials. European legislation governs how capacity is allocated and requires all interconnection capacity to be allocated to the market via market-based methods and includes specific conditions on how revenues are used. (OFGEM, 2018). Interconnectors can be both on land, within countries and crossing the sea.

There are a couple of interconnectors existing in the Baltic Sea, some of these already decommissioned. The world first HVDC connector was installed in the 1950:ies between Sweden mainland and the island of Gotland.

The list below provides the existing HVDC stations in the Baltic Sea region that include subsea cables. Despite the one’s listed, various other connections exist to other countries through the North Sea or onshore. The data analysis is based on data from (Wikipedia, 2018)

Table 4: Existing offshore interconnectors in BSR in 2017

Name	Converter station 1	Converter station 2	Status	Total Length (km)	Volt (kV)	Power (MW)	Year	Type
Gotland 1	Sweden - Västervik	Sweden - Yigne	Decomm.	98	200	20	1954	Merc
Konti-Skan 1	Denmark - Vester Hassing	Sweden - Stenkullen	Operational	176	250	250	1965	Merc
Gotland 2	Sweden - Västervik	Sweden - Yigne	Operational	99,5	150	130	1983	Thyr
Gotland 3	Sweden - Västervik	Sweden - Yigne	Operational	98	150	130	1987	Thyr
Konti-Skan 2	Denmark - Vester, Hassing	Sweden - Lindome	Operational	147	285	300	1988	Thyr
Fenno-Skan	Finland - Rauma	Sweden - Dannebo	Operational	233	400	500	1989	Thyr
Skagerrak 3	Denmark - Tjele	Norway - Kristiansand	Operational	230	350	440	1993	Thyr
Baltic Cable	Germany - Lübeck-Herrenwyk	Sweden - Kruseberg	Operational	262	450	600	1994	Thyr

Name	Converter station 1	Converter station 2	Status	Total Length (km)	Volt (kV)	Power (MW)	Year	Type
Kontek	Denmark - Bjæverskov	Germany - Bentwisch	Operational	170	400	600	1996	Thyr
SwePol	Poland - Wierzbięcin	Sweden - Stärnö	Operational	245	450	600	2000	Thyr
Estlink	Finland - Espoo	Estonia - Harku	Operational	105	150	350	2006	IGBT
StoreBælt	Denmark - Fraugde	Denmark - Herslev	Operational	56	400	600	2010	Thyr
Fenno-Skan 2	Finland - Rauma	Sweden - Finnbole	Operational	303	500	800	2011	Thyr
Fenno-Skan 1 Upgrade	Finland - Rauma	Sweden - Finnböle	Operational	233	400	500	2013	Thyr
Estlink 2	Finland - Anttila	Estonia - Püssi	Operational	171	450	650	2014	Thyr
ÅL-link	Finland - Naantali (sv:Nådendal)	Åland - Ytterby	Operational	158	80	100	2015	IGBT
LitPol Link HVDC is B2B	Lithuania - Alytus	Poland - Elk	Operational	160	70	500	2015	Thyr, onsh.
NordBalt	Sweden - Nybro	Lithuania - Klaipėda	Operational	450	300	700	2015	IGBT
Skagerrak 4	Denmark - Tjele	Norway - Kristiansand	Operational	244	500	700	2015	IGBT

Other significant cables, that are based on alternating current are the connections between Sweden and Bornholm, Sweden and Åland, Denmark and Sweden, the currently built Kriegers Flak connection between Denmark and Germany, between the Danish main islands, as well as connections within Estonia, Finland and Sweden. (4cOffshore, 2018).

In December 2016, the European Network of Transmission System Operators for Electricity (ENTSO-E) agreed and delivered the newest Ten-Year Network Development Plan (TYNDP). This document contains a list and timetable for the implementation of key European-based investments in new construction and maintenance of existing transmission networks located also in the Baltic Sea area. TYNDP 2016 included several investments that focus on the construction of new offshore transmission networks in the Baltic Sea. Some of them due to the required workload and funds put into use will be commissioned even after 2030. Such a long-time perspective, due to the specificity of the planning process, is presented in three stages, as mid-term projects (commissioning till 2022), long-term projects (commissioning till 2030) and future projects (commissioning beyond 2030).

It is too uncertain to make judgments on how probable these different links will be implemented. The planning process of such projects is long, but in general, the closer in time these projects are, the more certain it is that they will be built. Details on the project are given below the table.

3.3.3 Future offshore grid development plans within the Baltic Sea Region

Besides the projects listed below, all offshore wind farms planned for, will require own or combined transmission links.

Table 5: List of planned offshore cable projects included in TYNDP 2016 (ENTSO-E)

	Name	Country 1, connection point	Country 2, connection point	Total length	Technology	Capacity	Commissioning year
MID-TERM PROJECTS							
1	Kriegers Flak CGS	Denmark, Bjæverskov	Germany, Bentwisch	N/A	HVAC offshore HVDC onshore	600 MW	2018/ 2019
2	Offshore Wind Baltic Sea (I)	Germany, Lubmin	Germany, OWF Cluster Baltic Sea East	N/A	HVAC	N/A	2018
LONG-TERM PROJECTS							

	Name	Country 1, connection point	Country 2, connection point	Total length	Technology	Capacity	Commissioning year
3	Hansa Powerbridge 1	Sweden, Hurva	Germany, Gustrow	100 km	HVDC	700 MW	2025
4	Offshore Wind Baltic Sea (II)	Germany	Germany	N/A	3 x HVAC	N/A	2026
FUTURE PROJECTS							
5	Kontek 2	Denmark	Germany	N/A	HVDC	600 MW	2030
6	Kontek 3	Denmark	Germany	N/A	HVDC	N/A	2030
7	Great Belt II	Denmark, Malling	Denmark, Kyndby	N/A	HVDC	N/A	2030
8	Hansa Powerbridge 2	Sweden	Germany	N/A	HVDC	700 MW	2030
9	Denmark Poland	Denmark, Avedore	Poland, Dunowo	N/A	HVDC	N/A	>2030
10	Kontiskan 2 - Renewal	Sweden, Lindome	Denmark, Vester Hassing	149 km	HVDC	350 MW	2030
11	Fenno-Skan 1 - Renewal	Finland	Sweden	N/A	HVDC	500-800 MW	2030+

Mid-term projects

The **Kriegers Flak CGS** is the world's first combined offshore transmission system of offshore wind connection and interconnection of countries in one integrated system. The connection will connect the Danish region of Zealand with the German state of Mecklenburg-Western Pomerania through the operational German offshore wind farms of Baltic 1 (48 MW) and Baltic 2 (288 MW) and the planned Danish offshore wind farm Kriegers Flak (600 MW). Project is developed by the Danish TSO Energinet.dk and German TSO 50Hertz. The planned transfer capacity is 400 MW. The project increases thus security of supply for offshore wind power plants and provides new transmission capacity for trading electricity in an integrated infrastructure as well.

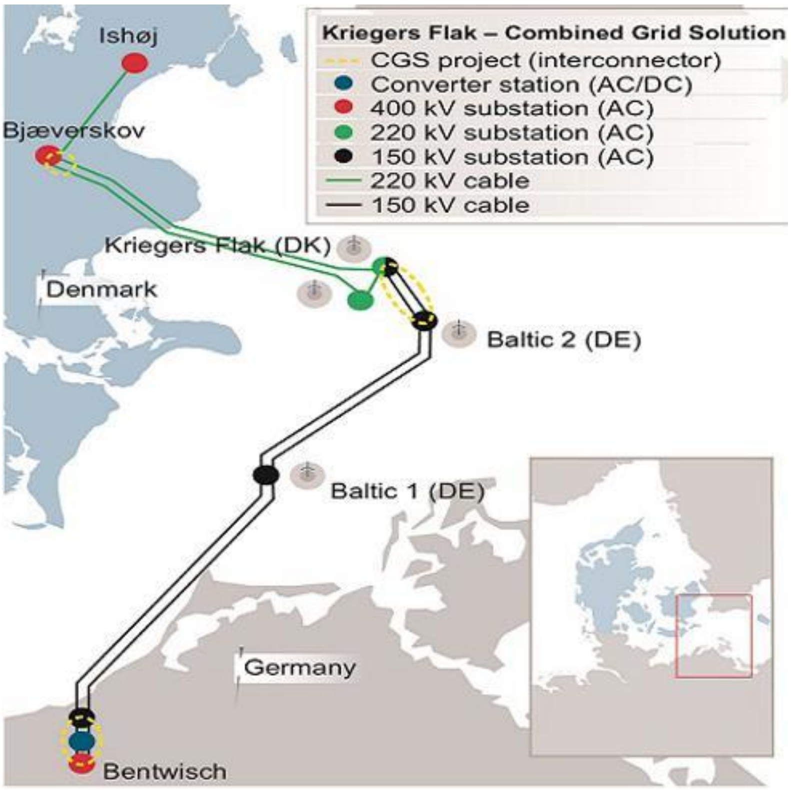


Figure 9: Kriegers Flak CGS between Germany and Denmark, Source: Energinet.dk (http://www.energinet.dk)

The offshore interconnection is based on AC technology, but as frequencies of the Danish and German transmission systems use a slightly different phase, the back-to-back converter system will be installed onshore in Bentwisch near Rostock. Due to the different voltage levels of the Danish and German offshore wind farms (150 to 220 kV), also a transformer will be installed on the Danish offshore platform. The Kriegers Flak Combined Grid Solution has been categorised by the European Commission as a Project of Common Interest (PCI). Such grid development projects are of importance as they close gaps in the European interconnected grid and contribute to the development of a single European energy market. Additionally, the project is subsidised by the European Energy Programme for Recovery (EEPR). The project is currently under construction. It will be commissioned in 2018/ 2019. Operators responsible for the project are 50hertz from German side and Energinet.dk from Denmark. It is highly ambitious project, but it is too early to judge on the outcome of the project. There have even been plans on connecting

The **Offshore Wind Baltic Sea (I)** project is split into different stages with different commissioning dates (starting in 2017) depending on the predicted installed capacity of offshore wind. It will be fully commissioned in 2018. This is internal, German project made by 50Hertz Transmission Operator. The development of the offshore wind farms in the North-East of Germany induces needs for undersea connections to these projects as well as reinforcements of the grid capacity from North to South. According to German law, these grid connections must be constructed and operated by the TSO.

Long-term projects

The main driver of **Hansa PowerBridge1** realization is market integration of the Nordic hydro/nuclear/RES dominated system with the German thermal/RES based system. The increase of renewable power in Sweden and Germany will lead to an increased need for trade in situations with high surplus due to high wind power production. Flows are expected to be balanced on an annual level with southbound flow during peak hours and when the hydro inflow in Sweden are high and northbound in periods of high RES generation in Germany and during nights. System adequacy is enhanced in Germany which will increase the import potential in period of low wind and solar generation. Also, the system adequacy in southern Sweden is enhanced since it given more import capacity in a future with less available nuclear generation capacity.

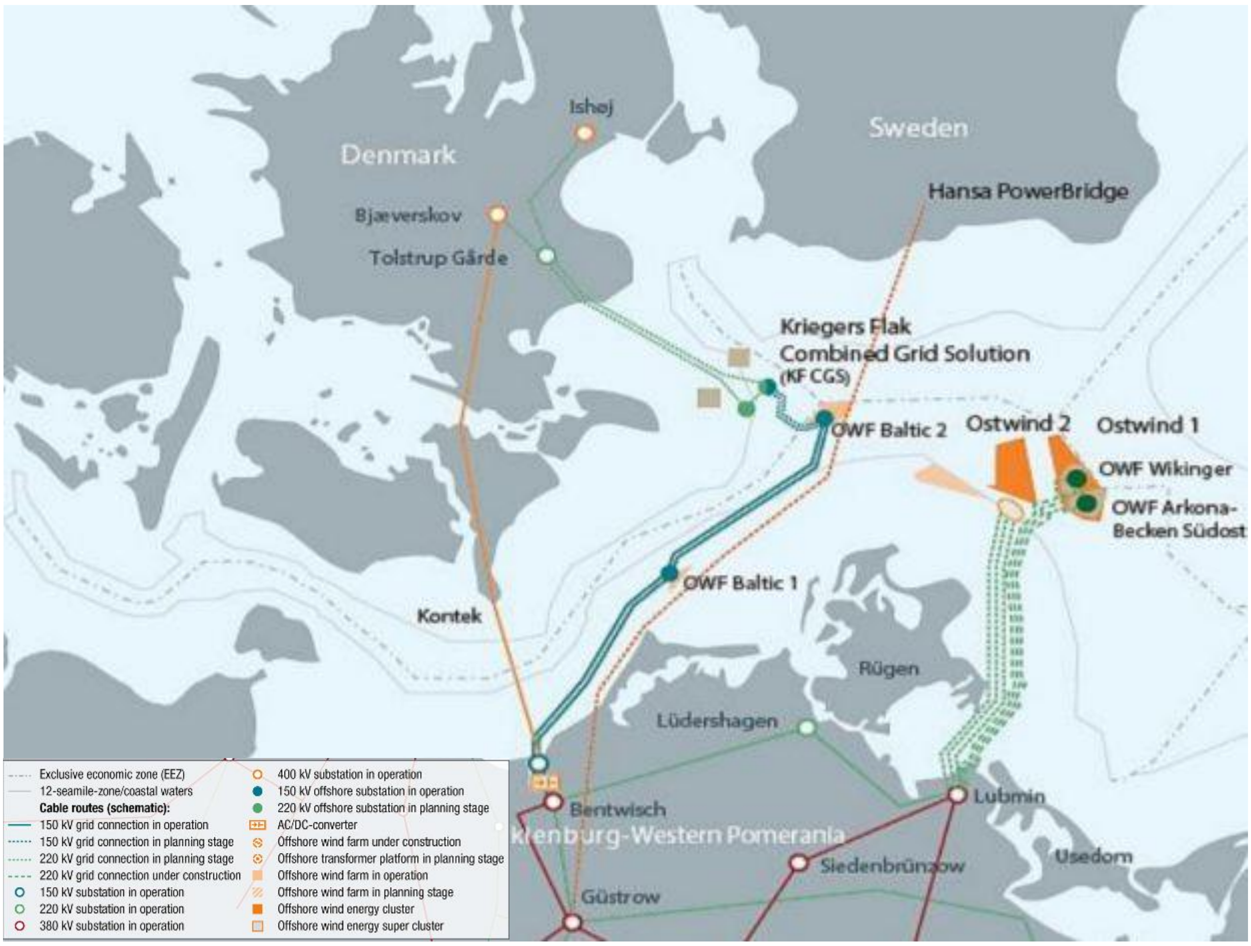


Figure 10: Future grid projects in the south-western Baltic Sea, Image source: 50Hertz

The project contributes with 700 MW at the boundary between the Nordic and the Continental synchronous areas. After this project is completed the capacity between Sweden and Germany would reach 1315 MW in both directions. The project should be commissioned in 2025. Now it is under planning procedure. Responsible TSOs are 50Hertz and Svenska Kraftnät. (ENTSO-E, 2018)

Offshore Wind Farm Baltic Sea (II) project is a further development of its first stage realized in a mid-term perspective. It will deliver an AC grid connection connecting Offshore Wind Farms in Cluster 1, 2 or 4 of the Baltic Sea (see German Offshore Grid Development Plan). Clusters are located north east of Rügen mainly in the German Exclusive Economic Zone. The project will also be realized by 50Hertz. It is planned to be commissioned in 2026. (4cOffshore, 2018) (ENTSO-E, 2018)

*F*uture projects

Kontek 3 project will serve as connection between the Nordic and central European power systems either transporting hydro power from the Nordic area to continental Europe or transporting wind and thermal power from the continent to the Nordics in times of low hydro levels.

The project candidate will serve as a part of the capacity that could be counted as a part of the capacity identified in the capacity analysis as having significant marginal benefit. On the boundary there are significant benefits to be gained by increasing capacity in the 4 visions. The marginal benefit on the boundary evens out somewhere between 15 and 20GW depending on the vision and not accounting for the investment cost.

It will be the third HVDC connection between Germany and Denmark realized by 50Hertz and Energinet.dk. This interconnector is to be commissioned in 2030.

Hansa PowerBridge 2 will be a possible second HVDC cable interconnector between southern Sweden (Bidding area SE4) and Germany (50Hertz). This project candidate is driven by market-based target capacities found in the Common Planning Studies by Regional Group Baltic Sea.

The drivers (social economic welfare, renewables integration and system adequacy) are similar to project 176 Hansa PowerBridge I. However, the need for Hansa PowerBridge 2 is highly dependent on the development of the power system beyond 2025. Hansa PowerBridge 2 is therefore considered by Svenska Kraftnät and 50Hertz as a possible future project which must be further evaluated.

The project candidate contributes with an additional 700 MW at the boundary between the Nordic and the Continental synchronous areas. That would bring the capacity between Sweden and Germany to 2015 MW in both directions. The project might be ready in 2030.

Denmark-Poland is a project candidate mentioned in the Regional Group Baltic Sea regional investment plan 2018 as a conceptual project. It is now under a joint PSE-Energinet.dk screening with the aim of assessing the feasibility, challenges and benefits of a possible interconnector.

The interconnector is mainly based on market integration, where the different makeup of the Danish wind dominated power system with close links to the Nordic hydro power can supplement the mainly coal and lignite based Polish power system.

The project could be a part of the projects that could make up the capacity with some benefit on the boundary between the Baltic/Nordic areas and Poland. Poland will either be a significant surplus or deficit area in terms of energy depending on the CO2 price, hence there is in all 4 visions reasonable benefit in 1000 -2500MW of capacity. The project is now under consideration. It might be realized after 2030. (ENTSO-E, 2018)

Konti-Skan 2 is the older of the two HVDC-connections between western Denmark and Sweden and is due for reinvestment over the coming 10-15 years. Konti-Skan 2 will be renewed with the same capacity as today.

The reinvestment will help ensure that the transmission capacity between the Nordic synchronous area and the continental is maintained. This project maintains 350 MW capacity at the boundary. (ENTSO-E, 2018)

Figure 11: Existing and planned offshore cable connections in the Baltic Sea Region

Chapter 3 Summary

- Time perspective of the grid development planning by the European National System Operators ENTSO-E in TYNDP is reaching 2030, the category of future projects is also presented but not going much beyond 2030 when it comes to real projects and needs partially to 2040.

- According to TYNDP 2016 development of the offshore wind farms and interconnectors will generally run separately in BSR till 2030.

- Kriegers Flak CGS (Combined Grid Solution) is the first combined connection of wind parks to two different countries that will be commissioned under 2019/ 2020. The system is based on HVAC technique but has an HVDC component with a converter station onshore (back-to-back system).

- Bilateral HVDC cable lines will remain the main way to interconnect different national power systems. Combinations as planned in the North Sea are possible as well combining grid and O&M base harbours.

- The impact of choice of transmission type is minor for the marine spatial planning while interconnection combination with offshore wind can have a bigger impact.

- Operational and currently planned offshore wind farm connections are based on the HVAC technology, not following the German trend from the North Sea to concentrate connection infrastructure in HVDC hubs and export cables.

4 EU and BSR Energy Policies and Energy Mix

This chapter describes the relevant EU and national energy policies, the energy mix and trading in the region and transnational energy cooperation and interconnectors in the BSR.

For providing the scenarios, one important cornerstone is the political framework that steers societal challenges such as energy supply and the development of large infrastructure such as the electrical grid. The ongoing energy transition is supported not only financially by the EU and its member states. The high-level policies and targets agreed on EU level are broken down to country-specific targets, that can be more strict or ambitious. Targets of relevance for the energy scenarios are for renewable energy, energy efficiency, greenhouse emissions, and interconnectivity of countries. The EU and the BSR countries have a wide range of targets for the years around 2030. Very little has been decided on or planned for 2050. The EU targets and their effects on the Baltic Sea countries is described below, separated into targets for renewables, interconnectivity, emissions and offshore wind. The creation of plans and implementation of required actions to reach the targets are followed up on a regular basis.

4.1 EU Targets

The European Union's energy policies are driven by three main objectives (European Commission, 2014):

- secure energy supply to ensure reliable provision of energy
- ensure that energy providers operate in a competitive environment that ensures affordable prices
- energy consumption is sustainable, through the decrease of greenhouse gas emissions, pollution, and fossil fuel dependence

To pursue these objectives within a coherent long-term strategy, the EU has formulated targets for 2020, 2030, and 2050. Especially the last two are subject to changes the latest 2023.

The 2020 Energy Strategy defines the EU's energy priorities between 2010 and 2020 (EC, 2017a) aiming to:

- reduce greenhouse gases by at least 20%
- increase the share of renewable energy in the EU's energy mix to at least 20% of consumption
- improve energy efficiency by at least 20%

The European Commission’s Renewable Energy Scenarios for 2030 imply the following targets (European Commission, 2014):

- a 40 % cut in greenhouse gas emissions compared to 1990 levels
- at least a 27 % share of renewable energy consumption
- at least 27 % energy savings compared with the business-as-usual scenario.

The European Parliament has voted for a renewable target of 35 % by 2030 and 35 % for energy efficiency as well. (European Parliament, 2018), but this has not been decided on by the commission and the council.

The corresponding levels named in the roadmap for 2050 (European Union, 2012) are:

- 80-95 % cut in greenhouse gas emissions compared to 1990 levels
- about 2/3 share of renewable energy consumption
- at least 41 % energy savings compared to the peaks in 2005-2006.

EU energy targets for all years, 2020, 2030 and 2050, are summarized in Table 6.

Table 6: EU's Energy Targets

TARGET / YEAR	2020	2030	2050
GREENHOUSE GAS EMISSIONS	20%	40%	80-95%
RENEWABLE ENERGY CONSUMPTION	20%	32%	About 66%
ENERGY EFFICIENCY	20%	27%	41%

The EU aims to achieve an 80% to 95% reduction in greenhouse gasses compared to 1990 levels by 2050. Its Energy Roadmap 2050 analyses a series of scenarios on how to meet this target (EUROPEAN COMMISSION, 2011). The Roadmap set out four main routes to a more sustainable, competitive and secure energy system in 2050: energy efficiency, renewable energy, nuclear energy and carbon capture and storage. It combines these routes in different ways to create and analyse seven possible scenarios for 2050. During this project, the EU has decided on new targets on renewable energy share. On 14th June 2018, the commission, the council and the parliament agreed on binding renewable energy targets for the EU of 32% with a clause of upwards revision by 2023. The agreement needs now to be translated into the various language and formally adopted by the European parliament and the Council. (European Commission, 2018).

These goals provide the EU with a stable policy framework on greenhouse gas emissions, renewables and energy efficiency giving investors more certainty and confirming the EU's lead in these fields on a global scale compared to the total population. On 30 November 2016, the Commission released a draft legislative proposal designed to help achieve these targets. The measures include draft proposals on electricity market design, renewables and energy efficiency. (European Commission, 2018) In February 2015, the European Commission adopted "A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy". The publication of this strategy created a new momentum to bring about the transition to a low-carbon, secure and competitive economy and to deliver on one of the 10 priorities of the Juncker Commission: Resilient Energy Union with a Forward-Looking Climate Change Policy (European Commission, 2016).

The European Energy Union strategy has five mutually-reinforcing and closely interrelated dimensions designed to bring greater energy security, sustainability and competitiveness. The strategy builds on the 2030 policy framework for climate change and energy. These strategies' five inter-related tracks act also as development directions for Baltic Sea region (European Parliament, 2016):

1. Energy security, solidarity and trust
2. A fully integrated European energy market
3. Energy efficiency contributing to moderation of demand
4. Decarbonizing the economy
5. Research, innovation and competitiveness

The national targets as such are set individually for each country, ranging for instance from 15% for Poland to 49% for Sweden for the renewable 2020 targets. While the figures for 2020 have been agreed in 2009, no clear targets are found for 2030 and 2050. The most recent reliable sources are presented below and compared to recent figures (2016 official Eurostat statistics and country-wise information for 2017 when available).

Table 7: Country wise figures for 2016 and 2017 and targets for 2020, 2030 and 2050 for the Baltic Sea EU member states (EEA, 2016), Eurostat for 2016. RES-E is the share of electricity produced by Renewable Energy Sources

RENEWABLE ENERGY TARGETS	2016/ 2017 (RES-E)	2020 TOTAL (RES-E)	2030 TOTAL (RES-E)	2050 TOTAL (RES-E)	SOURCE
EU (28 COUNTRIES)	17.0% (29.63%)	20% (42.8%)	32%	66%	
DENMARK	32.2%/ 35.5% (53.7%)	30% (51.9%)			
ESTONIA	28.8% (15.5%)	25% (4.8%)	>50%		(Lindroos, et al., 2018), https://www.mkm.ee/sites/default/files/ndpes_2030_eng.pdf
FINLAND	38.7% (32.9%)	38% (33%)			
GERMANY	14.8% (32.2%)	18% (38.6)	30% (45%-65%)	60%	(CDU/ CSU, SPD, 2018); https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren
LATVIA	37.2% (51.3%)	40% (59.8)	50%		(Lindroos, et al., 2018)
LITHUANIA	25.6% (16.8%)	23% (21%)	45% (55%)	80% (65%)	https://www.pv-magazine.com/2017/12/01/lithuanias-new-

				energy-strategy-bets-on-wind-and-prosumers/
POLAND	11.3% (13.4%)	15% (19.13%)		
SWEDEN	53.8% (64.9%)	49% (62.9%)	(100%)	

Together with the lower costs for establishing new renewable energy, the EU targets have led to an increasing share of renewables in the total new installed power mix. Norway and Russia were not considered in this study.

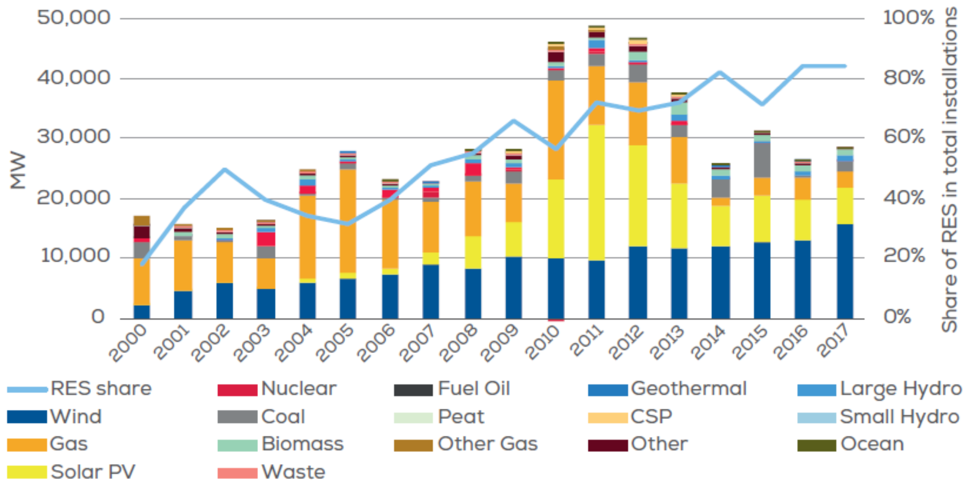


Figure 12: Annual installed capacity and renewable share (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

As stated above, there are no direct targets for offshore wind in most of the countries, but there are estimates made by the EU on how the share of onshore and offshore wind could look like to meet the targets stated above (PREMIS model 2016). These figures are compared to the real figures (in green) from 2017 on the share of wind energy in the mix of each country, as per below. The figures represent total countrywide onshore and offshore wind share production and total for the Baltic EU countries summarised.

Table 8: Total countrywide onshore and offshore wind for the Baltic Sea region countries: Renewable PRIMES 2016 - total wind power production share compared to real data for 2017

	2015		2017	2020		2030		2050	
Share	Wind	RES-E	Wind	Wind	RES-E	Wind	RES-E	Wind	RES-E
Denmark	43%	58%	44%	50%	80%	56%	81%	56%	80%
Germany	10%	28%	21%	18%	36%	21%	44%	30%	60%

Sweden	8%	63%	13%	9%	64%	13%	65%	14%	63%
Finland	3%	44%	5%	6%	37%	8%	46%	8%	49%
Poland	6%	13%	9%	6%	14%	11%	20%	18%	29%
Estonia	5%	14%	9%	6%	14%	11%	21%	42%	67%
Lithuania	14%	37%	11%	12%	33%	6%	16%	13%	28%
Latvia	2%	62%	2%	10%	67%	9%	61%	19%	70%
Baltic EU	10%	33%	17%	15%	38%	18%	44%	24%	54%

The UN Sustainable Development Goals are adopted by the EU as well and are measured. They support further the importance of the energy transition and indicate a global trend, especially through the Paris agreement established under the umbrella of the UNFCC (United Nations Framework Convention on Climate Change). As these goals/ targets are less specific, the follow up is basically in line with the EU targets. (compare SDG 7 'affordable and clean energy': http://ec.europa.eu/eurostat/statistics-explained/index.php?title=SDG_7_-_Affordable_and_clean_energy)

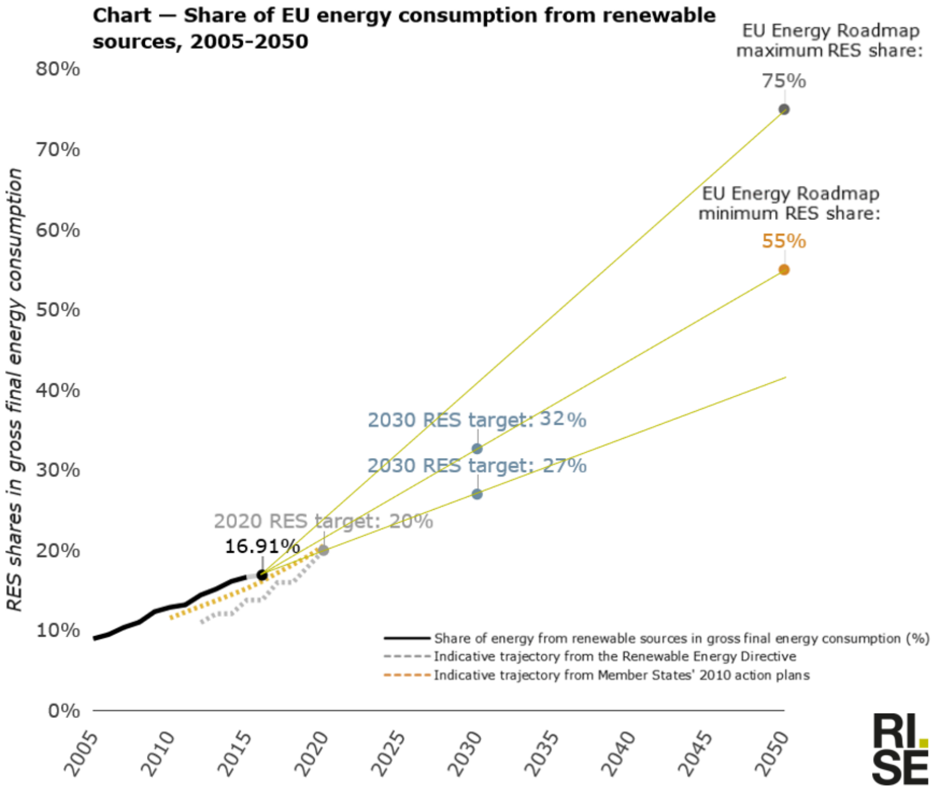


Figure 13: Energy targets of the EU for renewable energy.

4.1.1 Interconnectivity in the Baltic Sea Region

Interconnectivity of countries shall reach 10 % (of their installed electricity production capacity) in 2020 as well as the completion of the internal energy market by reaching an electricity interconnection target of 15% between EU countries by 2030 if cost-benefit analysis is in favour and pushing forward important infrastructure projects. (European Commission, 2017)

This implies that each Member State should have in place electricity connections that allow at least 10% in 2020 and 15% in 2030 of the electricity that is produced by their power plants to be transported across its borders to its neighbouring countries. The EU has established an expert group which have stated that due to the technology developments, the interconnection target should contain a dynamic element allowing it to be adjusted and that the development of cross-border interconnectors needs to be properly coordinated with the corresponding development of national transmission and distribution networks. (Gence-Creux, et al., 2017) The experts recommend further and has been communicated in EUs report (European Commission, 2017): *The interconnection level should be measured based on two new formulas:*

a) the ratio of the nominal transmission capacity to the peak load (demand) >30% and

b) the ratio of the nominal transmission capacity to the installed renewable generation capacity (supply) >30%.

c) minimising differences in their wholesale market prices. Additional interconnections should be prioritised if the price differential exceeds an indicative threshold of 2€/MWh between Member States.

These changes might affect the capacity needed to interconnect countries significantly if a lot of renewable intermittent energy is introduced. The planning and implementation of these targets is followed up by different means. The Baltic Energy Market Interconnection Plan (BEMIP) was established to prioritize and update the planning in the Baltic Sea Region.

Table 9: Interconnectivity levels for electricity in BSR countries in 2017 and expected for 2020 (European Commission, 2017), Estonia, Latvia and Lithuania are not yet fully synchronized with the European grid and are therefore also presented as one entity. They remain asynchronously interconnected through Direct Current (DC) links with the Nordic countries and Poland.

Country	**Interconnection levels in 2017**	**Expected interconnection levels in 2020**
DE	9%	13%
DK	51%	59%
EE	63%	76%
FI	29%	33%
LT	88%	79%

Country	**Interconnection levels in 2017**	**Expected interconnection levels in 2020**
LV	45%	75%
PL	4%	8%
SE	26%	28%
EE, LT, LV	22% (2016)	

Most of the countries in the Baltic Sea Region fulfil the requirements for 2020 already. It is expected that Germany will reach the target as well while Poland needs further efforts to interconnect. The Baltic countries, Poland and Germany do not fulfil all the three new criteria set up above. Efforts have been made to connect the Baltic States by interconnectors such as Estlink 1 and 2 connections between Estonia and Finland, the LitPol Link connection between Lithuania and Poland and the NordBalt connection between Sweden and Lithuania. The LitPol Link and NordBalt were planned within the BEMIP aiming to further integrate the Baltic States' energy market by building more infrastructure.

Under the BEMIP, these projects consist of three sets:

- The Nordic Master Plan which covers those projects linking Nordic countries together such as the Fenno – Skan II connection linking Finland and Sweden, and the Great Belt project in Denmark.
- Projects linking the Baltic area with the Nordic countries, as well as Poland. These include projects such as NordBalt linking Sweden and Lithuania, and LitPol linking Poland and Lithuania. They also include projects to strengthen the electricity grid between the three Baltic States themselves.
- Interconnections between Poland and Germany to help deal with loop flows caused by increased wind generation in Northern Germany. Loop flows occur when the electricity produced in one country is diverted to a different part of its territory through a neighbouring country's' grid.

4.1.2 Emission Reduction

There are also targets for emission reduction for each country, set by the European Commission. These are summarized in the table below. The EU Directive on National Emission Ceilings (2001/81/EC) - NEC directive - sets national emission limits for the five air pollutants sulphur dioxide (SO2), nitrogen oxides (NOx), ammonia (NH3), particulate matter (PM2.5) and volatile organic compounds other than methane (NMVOC), until 2019. The revision of the NEC Directive (now called NERC: National Emission Reduction Commitment) by the year 2030 was formally confirmed by agreement between the European institutions of the Commission, Council and Parliament, at the end of 2016. The new NERC Directive contains percentage reductions compared to the reference year 2005.

Table 10: EU reduction targets for SO2, NOx and volatile organic compounds (NMVOC)

Country	SO2 2020/2029	SO2 from 2030	NOx 2020/2029	NOx from 2030	NMVOC 2020/2029	NMVOC from 2030
Denmark	35%	59%	56%	68%	35%	37%
Germany	21%	58%	39%	65%	13%	28%
Estonia	32%	68%	18%	30%	10%	28%
Finland	30%	34%	35%	47%	35%	48%
Latvia	8%	46%	32%	34%	27%	38%
Lithuania	55%	60%	48%	51%	32%	47%
Poland	59%	72%	30%	39%	25%	26%
Sweden	22%	22%	36%	66%	25%	36%
EU-28 total	59%	78%	42%	62%	28%	40%

4.2 National targets

The national targets of the relevant countries are described here. The information is based on project internal information and publicly available sources.

Denmark: Denmark has, according to its EU commitments, a 20 % greenhouse gas emission target for 2020 (compared to 1990). No further targets have been set in relation to 2030. The Government has a long-term vision for the energy system to be independent of fossil fuels in 2050. Danish parliament unanimously voted in favour of a new energy agreement for the country, which includes building three new offshore wind farms by 2030 with a total capacity of at least 2.4GW.

Estonia: The new plan will include energy and climate policies and objectives for the period up to 2030, with an outlook to 2050. In the current draft it is proposed to set an indicator of 45 % of renewables in final energy consumption by 2030.

Finland: Finland's medium-term climate and energy objectives are outlined in the 2013 updated National Energy and Climate Strategy. Wind power permitting will be facilitated to increase its electricity generation to 6 TWh by 2020 and to 9 TWh by 2025.

Germany: In 2010 Germany has adopted the Energy Concept (Government Decision), a comprehensive strategy covering both medium (2030) and long (2050) term strategies. The Renewable Energy Act (EEG) commits to 700 MW of offshore wind power per year from 2023-2025 and 840 MW per year from 2026-2030. No split between Baltic and North Sea is made here. In the last round, the Baltic Sea was allocated a certain volume, but no split can be made now, but a bigger share is expected in the North Sea as the allocated areas are bigger in total.

Latvia: The Latvian Energy Long-term Strategy 2030 ("Strategy 2030") which includes energy-related targets and planned policy measures contains the targets for Latvia. The Ministry of Economics plans to transpose the goals and principles set by the Strategy into subsequent laws, regulations and planning documents, which is ongoing.

Lithuania: In 2012, Lithuania adopted a National Energy Independence Strategy, which contains strategic initiatives until 2020, and lays down guidelines for the development of the energy sector until 2030 and 2050. By 2050, Lithuania aims to be independent from fossil fuel and to produce its energy from nuclear and renewable energy sources only. According to the terms of the National Energy Strategy, Lithuania will aim for 45% of renewables in its electricity mix by 2030 and 100% by 2050. Renewables are expected to grow to 7 TWh by 2030, and to 18 TWh by 2050 with wind energy covering between 50 and 55 percent of this. In the medium to longer term perspective, Lithuania is set to develop offshore wind in the Baltic Sea. In 2019 there will be an auction for 250 MW wind capacity. If the Lithuanian auctions go smoothly, the amount of wind in the energy mix will grow exponentially: by 2022, the estimate would be around 750 MW installed and around 2.0 TWh produced; by 2025, this would grow to 1,000 MW installed and 2.5 TWh produced; and by 2030 this would grow to around 1,300 MW installed and 3.8 TWh produced.

Poland: No post-2020 climate-specific strategy has been established yet. Poland is currently preparing a National Programme for Development of Low Emission Economy covering, amongst other topics, the development of low-carbon energy sources and improvement of energy efficiency. In comparison to its National Renewable Action Plan (NREAP) for 2020, Poland is in line with its indicative trajectory for renewable heating and cooling sector. However, shares of renewable electricity and transport are below values envisaged by NREAP.

Sweden: Several steps have been taken by Sweden or are underway to prepare a low-carbon development strategy for 2050, such as the appointment by the Government of a Committee to develop a strategy for implementing the vision of zero net emissions in 2050 and 100 % renewable energy by 2040/2045, expected offshore wind capacity (no fixed target): 50 TWh ~ 12 GW

Taking into account the Paris agreement, the targets are nevertheless probably too low, and some analyses show that the full decarbonization must be effective from 2045 increasing the demands. There are no firm targets on how much energy shall be produced by offshore wind, but there are various scenarios on how the electricity needed will be produced [(Nghiem, Pineda, & Tardieu, September 2017), (Müller, Haesen, Ramaekers, & Verkaik, 2017), (Fried, Shukla, Sawyer, & Teske, 2017), (Hundleby, o.a., June 2017), EU PRIMES model (Capros & A. De Vita, 2016), IEA). Even other policies steer the outcome in the energy transition. These are exemplified in the figure below.

NATIONAL POLICY	REGULATORY INSTRUMENTS	FISCAL INCENTIVES	GRID ACCESS	ACCESS TO FINANCE	SOCIO-ECONOMIC BENEFITS
• Renewable energy target • Renewable energy law/ strategy • Technology-specific law/ programme	• Feed-in tariff • Feed-in premium • Auction • Quota • Certificate system • Net metering • Mandate (e.g., blending mandate) • Registry	• VAT/ fuel tax/ income tax exemption • Import/ export fiscal benefit • National exemption of local taxes • Carbon tax • Accelerated depreciation • Other fiscal benefits	• Transmission discount/ exemption • Priority/ dedicated transmission • Grid access • Preferential dispatch • Other grid benefits	• Currency hedging • Dedicated fund • Eligible fund • Guarantees • Pre-investment support • Direct funding	• Renewable energy in rural access/ cook stove programmes • Local content requirements • Special environmental regulations • Food and water nexus policy • Social requirements

Figure 14: Overview of the types of renewable energy policies and measures adopted (International Energy Agency and International Renewable Energy Agency, 2017)

4.3 Energy Profile in the EU and the Baltic Sea region

The energy mix in the EU has undergone a change. The share of renewable energy has increased, but the dominating share of fossil energy source to meet the demand on energy is not changed as indicated in the figures below.

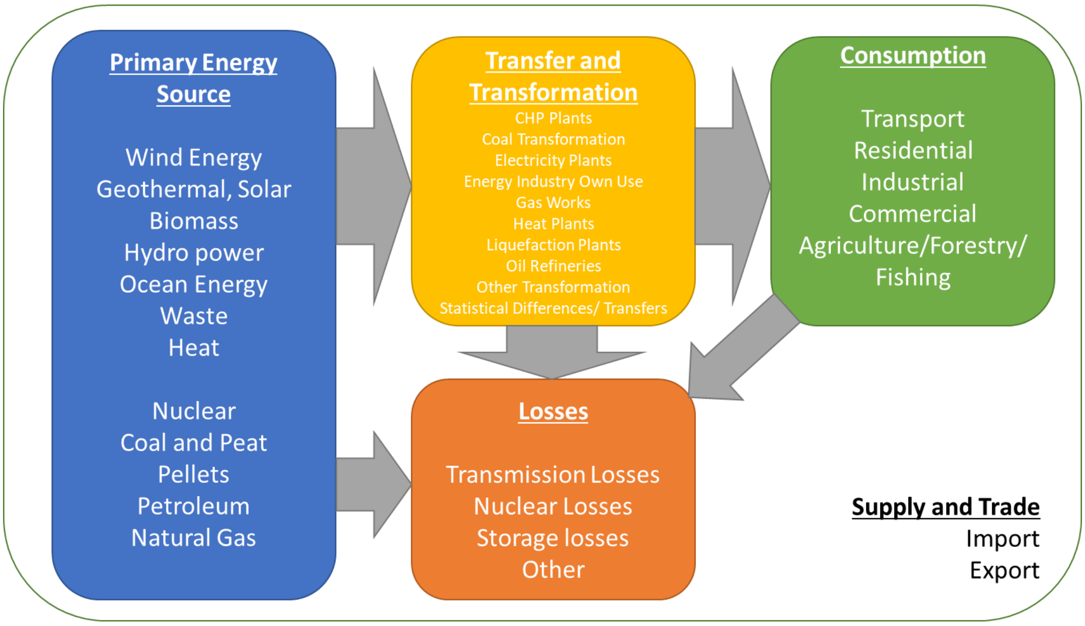


Figure 15: Energy Balance Schematics

Typically, the energy profiles are presented based on Total Primary Energy Supply (TPES) and Total Final Consumption (TFC) as defined by Organisation for Economic Cooperation and Development (OECD).

Each country can be described by its current energy mix, energy produced and consumed, and energy imported and exported in order to meet supply and demand needs. More information about the energy profiles of individual North Sea countries can be found in Annex 1.

TPES is defined by the OECD as energy production plus energy imports, minus energy exports, minus international bunkers and aviation fuels, then plus or minus stock changes. Total Final Consumption (TFC) is defined as the total value of all expenditures on individual and collective consumption goods and services incurred by resident households and general government units. It may also be defined in terms of actual final consumption as the value of all the individual goods and services acquired by resident households plus the value of the collective services provided by general government to the community or large sections of the community. Both TPES and TFC metrics are expressed in million tonnes of oil equivalent (Mtoe).

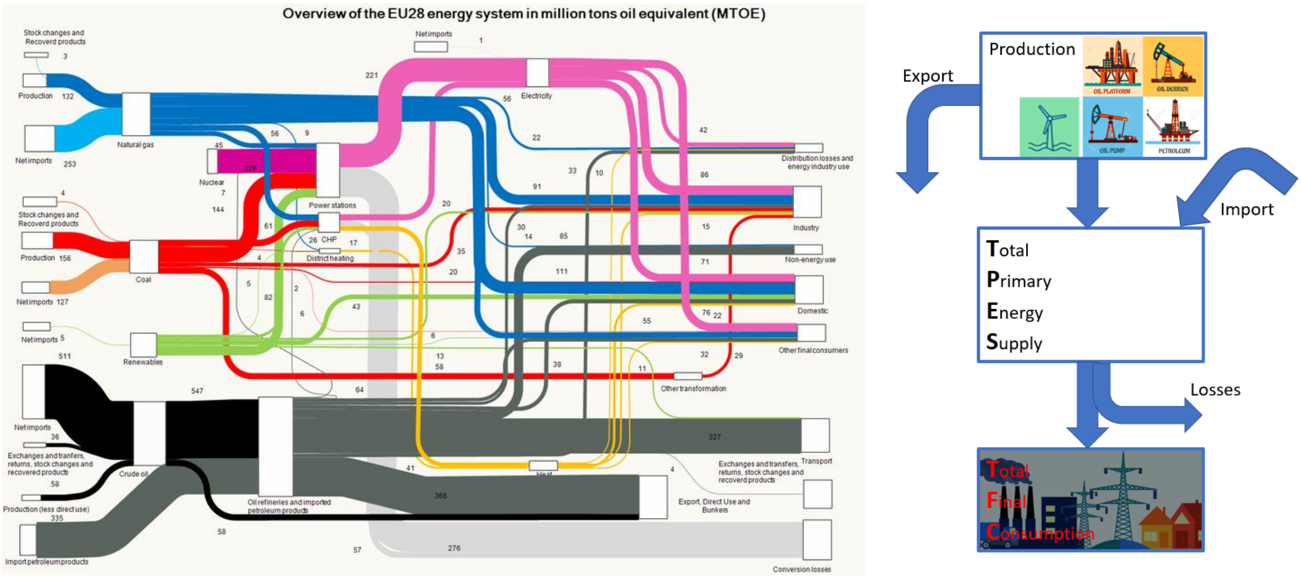


Figure 16: Energy Flows in the EU28 countries, energy flows (Energy export and import patterns in the Baltic Sea region (2010-2012 average, in ktoe)) and definition of TPES and TFC (Source left: (Schiffer, 2016),

The import and export in the region are presented based on Eurostat data below. It indicates a strong dependence in between the various Baltic Sea Region countries when it comes to energy, but also the flow of Russian oil and gas to the main industry nations. A change to renewable energy will have an impact on the security of supply and dependence of many countries on the Russian supply. Percentage wise, the electricity transferred in-between countries is limited while import and export of fossil fuels dominate. Building an energy system based on more renewable energy sources producing electricity, might require quite a few more links to interconnect.

The TPES in the various countries spreads significantly in magnitude and resources used. While Germany has the biggest total energy consumption, the northern countries have a much bigger energy consumption per capita than others, e.g. the Baltic States. Considering Norway with its oil and gas resources, has the highest production of energy, while Germany has the highest consumption. Most of the energy production is based on fossil fuels in almost all countries.

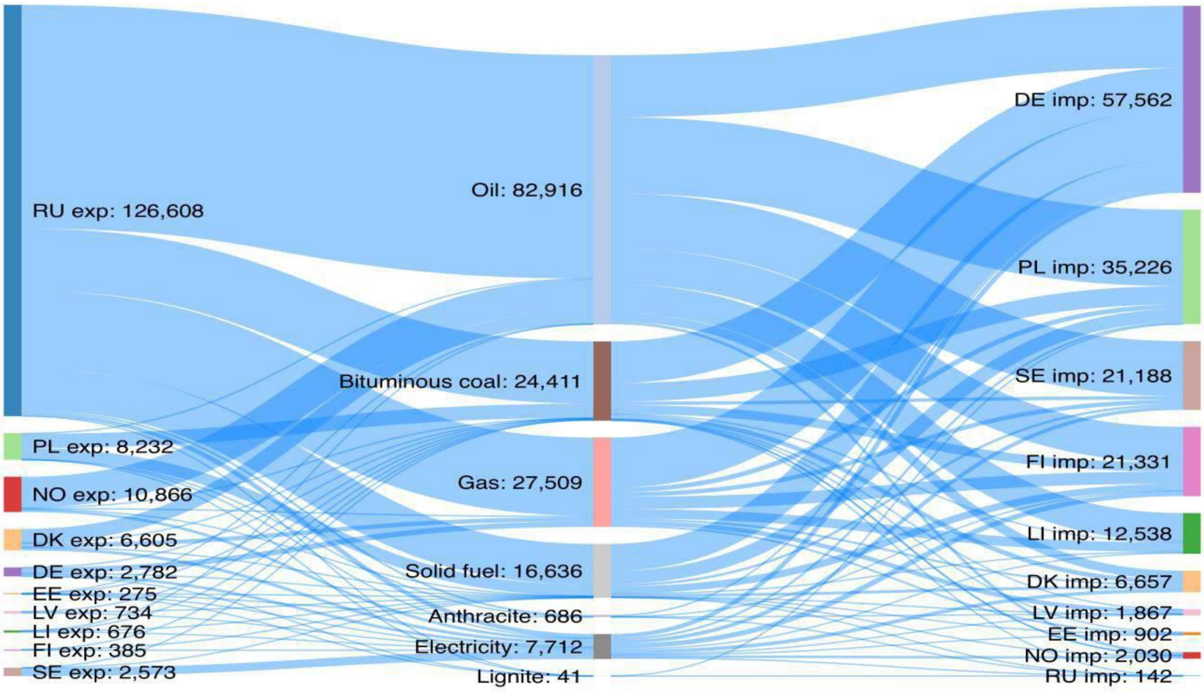


Figure 17 Energy Flows in the EU28 countries, energy flows (Energy export and import patterns in the Baltic Sea region (2010-2012 average, in ktoe)). (Shadurskiy, Westphal, Daborowski, & Liuhto, 2015)).

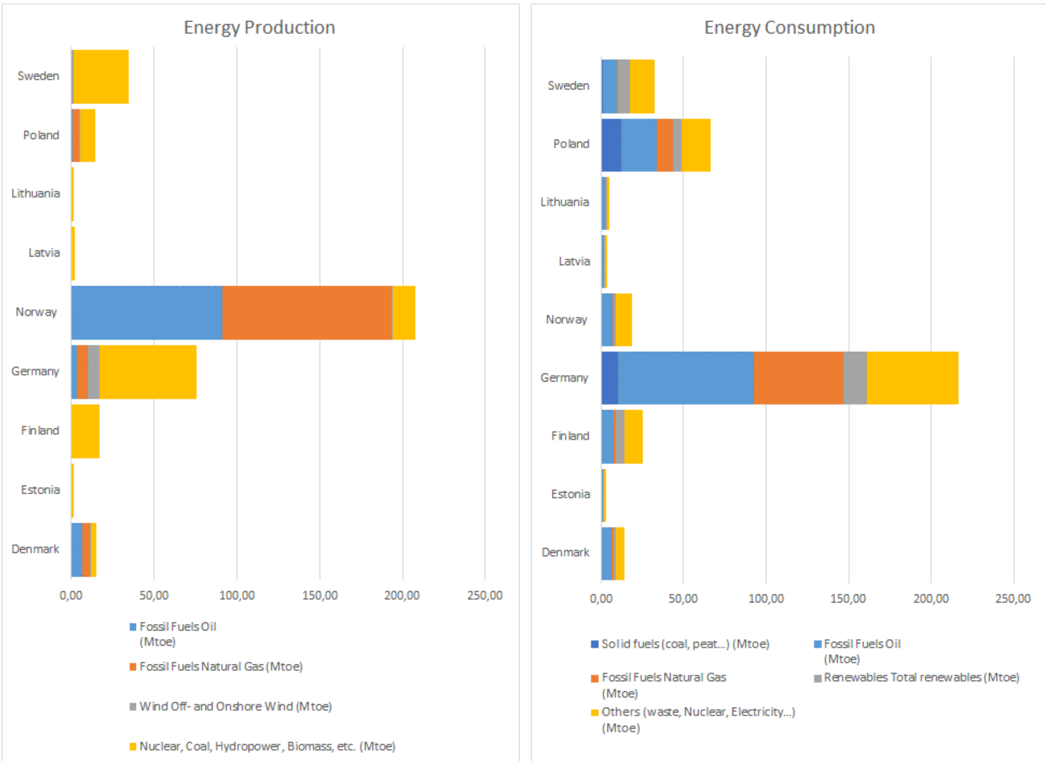


Figure 18: National energy profiles of Baltic Sea Region countries in 2017. Left: Energy production (TPES), Right: Energy consumption (TFC) based on data from Eurostat.

The total figures of the FPES and TFC are shown in the diagrams below compared to the energy mix of fuels in the gross inland energy consumption. While the Scandinavian countries have a high share of renewables in their energy mix, the countries with high populations still rely more on coal, oil and gas. In absolute terms, Germany is the leading country producing wind energy (including both on- and offshore wind) of the North Sea countries. Producing 6.76 Mtoe in 2017, they are by far the largest producer. Sweden, Denmark and Poland follow, producing respectively 1.33 Mtoe, 1.1 Mtoe and 1.08 Mtoe. The other countries all produce less than 0.3 Mtoe. In relative terms, however, the picture is slightly different.

Denmark leads with wind energy representing 7.4 % of its total production. Lithuania follows with 6% as well as Germany with 5.8 % wind energy and Sweden produce around 4 % of their energy using wind. The remaining countries have a share of around 1-1.5%, only Latvia and Norway had the lowest share of wind energy in their total production in 2017 of 0.4% and 0.1%. The resource only represented 0.11 %. Offshore wind has a high share in Denmark and Germany, with 35% and 17% of the total wind production.

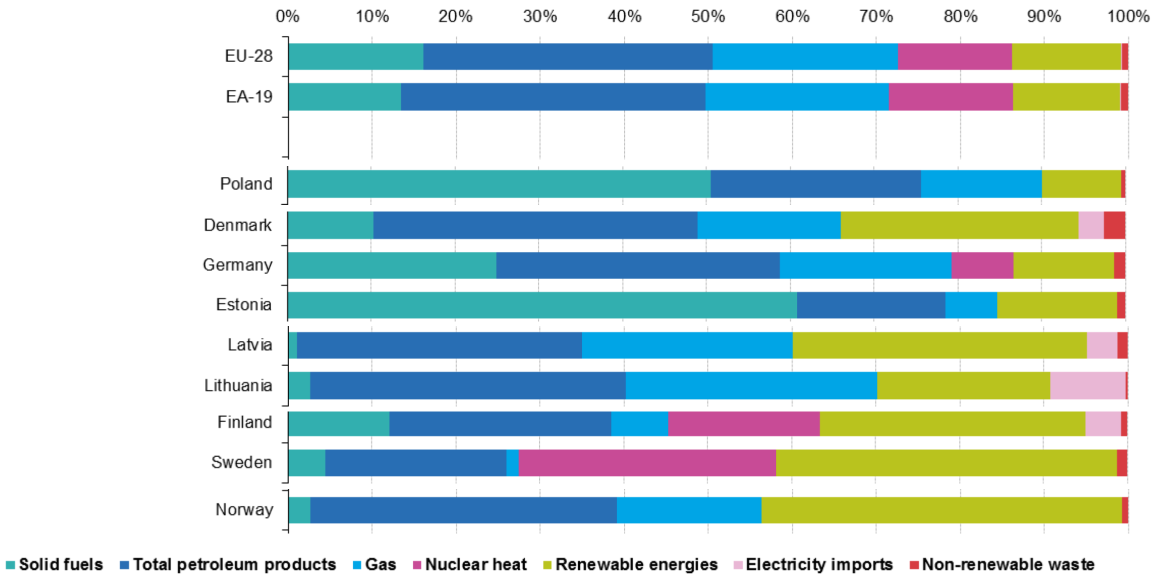


Figure 19: National shares of fuels in gross inland energy consumption, 2015, percentage, Source: Eurostat Energy trends, http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_trends

On a global scale, this resource is steadily growing in importance, although its share is still relatively small. Wind, solar, thermal, solar PV and geothermal together accounted for little more than 1.7 % of the global energy production in 2017 according to the renewable energy report. (Zervos & Adib, 2018). Installed capacities for power production there are Hydropower capacity of 1,114GW, Bio-power capacity 122 GW, Geothermal power capacity 12.8 GW, Solar PV capacity 402 GW, concentrating solar thermal power (CSP) capacity 4.9 GW, Ocean energy capacity 0.5 GW and finally wind power capacity 539GW.

All the Baltic Sea region countries, apart from Norway, have a higher import than export rate. This difference can be explained by the high oil and natural gas production of Norway and the high import rates of fossil fuel. Especially Finland, Germany and Poland have a high import to export ratio while the other countries are mainly more balanced. The development of the renewable energy share is shown in the figures below for the primary energy supply.

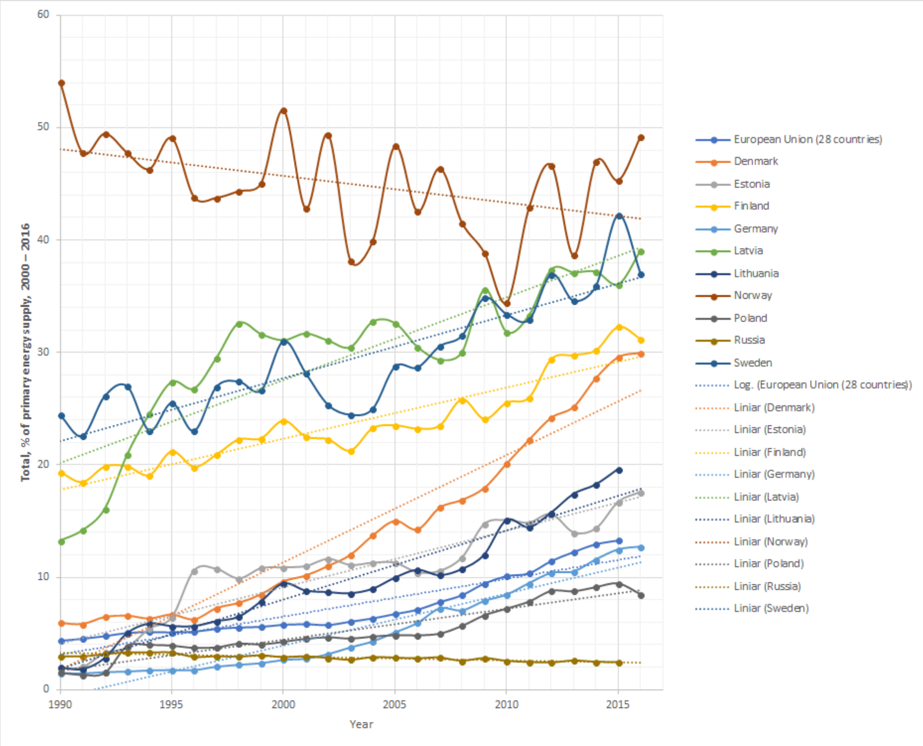


Figure 20: Renewable energy supply, total share in the BSR countries over time [%]

The fluctuations in the figure above are dependent on the economic situation, costs for energy and weather.

4.4 Offshore wind - Drivers and barriers

The main drivers for offshore wind are the better wind conditions offshore, the possibility to build larger turbines, the better energy yield offshore and the possibility to build larger parks.

Barriers of offshore wind include huge investment costs for large farms, the harsh environment, the more difficult access for operation and maintenance, connection challenges and permitting processes as well as uncertain support in countries with offshore wind energy potential.

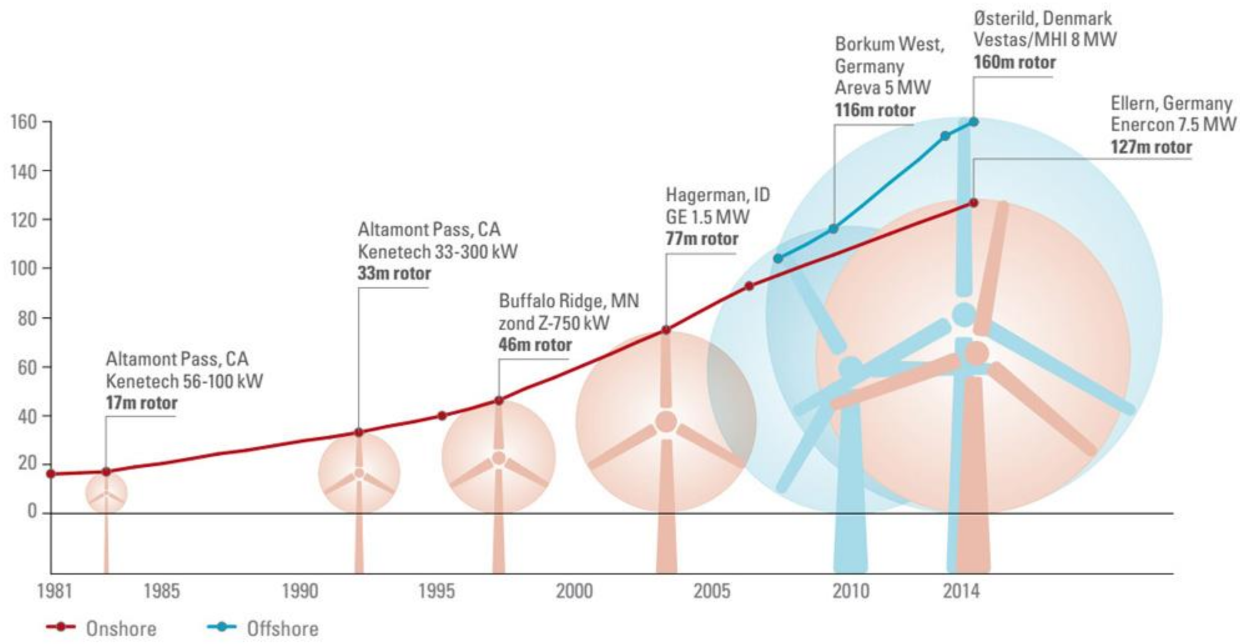


Figure 21: Evolution of bigger wind turbines (http://www.energy-transition-institute.com/Insights/Wind.html)

The typical standard for connecting offshore wind is HVAC (High voltage alternate current). In Germany, where the MSP derived locations for offshore wind that are further offshore to protect the national parks in the North Sea close to shore (Wadden sea), the distance of the wind parks from shore and to the grid connection is so long, that HVDC (high voltage direct current) is feasible with the current technique used. Even parks in the Baltic Sea are feasible to connect by HVDC, but distances in general are much shorter, so HVAC is more competitive.

There are no major technical constraints remaining in the generating system to limit expansion as wind technology has matured. The cost of wind generation has become relatively low compared to other renewable and non-renewable power sources making wind power cost-competitive even without considering subsidies and the negative impact on the environment and health, also neglecting societal costs for distributed generation or intermittency-related considerations (based on various sources).

Like other renewable energy sources, wind power is capital-intensive, especially huge offshore wind projects. Developers are forced to spend large sums at the initial stage of development, mostly before operations begin. Long and unpredictable permitting and authorization periods are a critical barrier in some countries.

Barriers and concerns related to offshore wind are policy and regulation. Also, the environmental issues associated with wind power development are harming, such as concerns about noise, visual impact and impacts on migratory species (such, as mammals, birds and bats) from collisions during operation. Developers try to communicate with stakeholders based on proper environmental impact assessments. The recent development of aerodynamic turbine designs (i.e. efficiency improvement) has reduced operational noise. Proper siting and configuration of wind farms can help reduce concerns about visual impacts and impacts on migratory species. An involvement of local communities, through local ownership, is key for high social acceptance onshore, but is more difficult to achieve for offshore wind farms. To manage the stability of wind power output is another critical, especially for grid-connected systems and farms with high capacity.

4.5 Transnational energy cooperation between Baltic Sea countries

Electricity interconnectors provide the physical links which allow the transfer of electricity across borders and to islands or platforms. Interconnectors derive their revenues from congestion revenues or from needs to supply remote locations with power or vice versa.

4.5.1 Interconnectors – Projects of Common Interest (PCI) and BEMIP

On 28 May 2014 the Commission adopted a Communication on European Energy Security Strategy (EESS) that lists 33 energy infrastructure projects that are critical for Union's energy security (in the short and medium terms). 5 of these projects are electricity projects located in the Baltic Sea Region and are handled by the BEMIP plan [https://ec.europa.eu/energy/en/topics/trans-european-networks-energy/baltic-energy-market-interconnection-plan, (Purvins, et al., 2017), (EUROPEAN COMMISSION, 2017), (EUROPEAN COMMISSION, 2011)].

- Nordbalt 1&2
- LT-PL electricity interconnection
- Electricity internal lines in LV and SE
- EE-LV electricity interconnection
- Synchronization of EE, LV, LT with the Continental European Networks

The needs and PCIs are updated every other year. In the North Sea, the Dutch-German TSO Tennet (TSO - Transmission System Operator) has established a collaboration to build an electrical and maintenance hub close to one of the big development areas far offshore. Similar approaches are studied in the BalticIntegrid project, but these indicate mainly various scenarios, and too little is known about the development until 2050 in this respect. It can be assumed that no such project will be implemented before 2030 due to its complexity (financial, business, legal and technical wise). Other relevant projects include the Hansalink connecting Sweden and Germany.

Generally, a higher level of intermittent renewable energy sources requires increased interconnectivity. This can be visualized based by the energy production in Germany during March 2018:

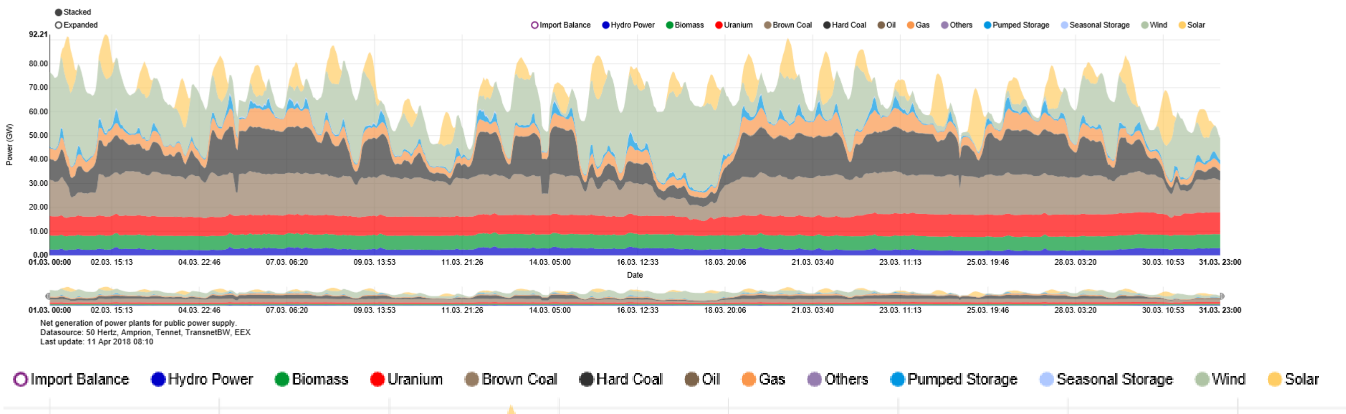


Figure 22: Energy Production in Germany during March 2018 visualizing peaks in production; Source: https://www.energy-charts.de/power.htm?source=all-sources&year=2018&month=3

Interconnectivity of countries shall reach 10% in 2020 and 15% in 2030 if cost-benefit analysis is in favour having regard to EUs resolution of 15 December 2015 on achieving the 10 % electricity interconnection target – Making Europe’s electricity grid fit for 2020.

Chapter 4 Summary

- Renewable energy targets are revised and increasing on a regular basis by the European commission and member states

- Limited number of countries have dedicated targets for offshore wind

- A rapid advances in building and modernising the necessary physical infrastructure remain key conditions for the energy transition to be successful as well as for energy security

- Interconnectivity targets depend strongly on level of renewable energy capacity and might be derived differently in the future.

- Wind parks planned have a time horizon to 2030. There are quite a few parks consented in the region, which have permits that will restrict the building of new parks as technically and economically not feasible

5 Future trends based on EU and national targets

5.1 The role of MSP in offshore wind energy and energy grid infrastructure planning

5.1.1 Key drivers and challenges for spatial planning and development of offshore wind energy

Marine Spatial Planning shall allow for a co-existence of various activities in the marine regime. The main stakeholders are shown in the figure below. While certain stakeholders are established since a long time back and have established claims on marine spaces, such as shipping and fishery, others have either not a clear voice, such as the environment or are new and challenging the other established activities.

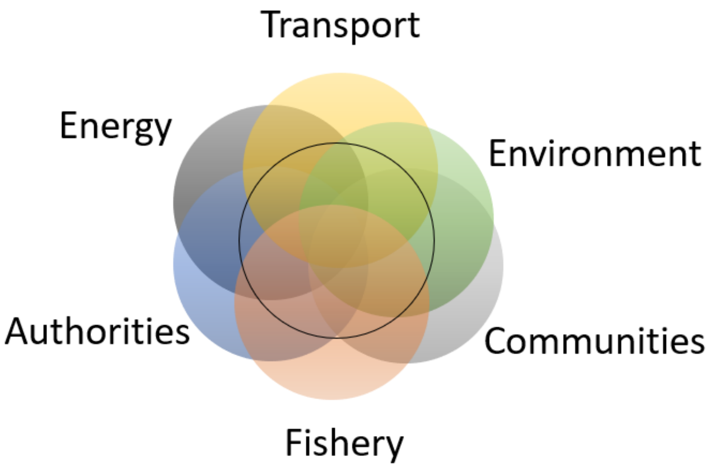


Figure 23: Main stakeholders involved in the MSP processes (Military as a main stakeholder in many countries included in "Authorities"

The space available in countries, the intensity of usage and political/ economical drivers for establishing new or coordinating existing occupations, steers the motivation in countries to perform MSP and make certain priorities. This can be exemplified by the historic processes in Germany and Sweden. While there is little space and dense shipping traffic in the German waters, there is a lot of space with mainly low-density shipping traffic in Sweden. While Sweden has a high degree of renewable energy in its energy mix and a lower population than Germany, the decision for the Energiewende (German for energy transition) closing nuclear power plants forced Germany to invest in new renewable technology, new electrical transmission capacity on land and offshore and a stringent planning of space and resources. This implied a drive towards a detailed marine spatial planning to derive areas for offshore wind conversion and subsequent electrical transmission. The result of the MSP process resulted in a clear decision, legally certain on areas dedicated for wind power plants. This resulted even in wind farms in

Natura 2000 areas, judged to be not a conflict. In Sweden, the need to invest in offshore wind was lower, even though Sweden and Denmark were the first to build offshore wind farms worldwide, as there was enough space to build onshore wind. When starting out with the MSP process, much more considerations was given to the communities and environmental concerns compared to Germany. As there was not the same political drive towards prioritising new and existing occupations, the MSP is not as clear for the energy part and is not that strong legally binding as in Germany. The differences are exemplified in the figure below.

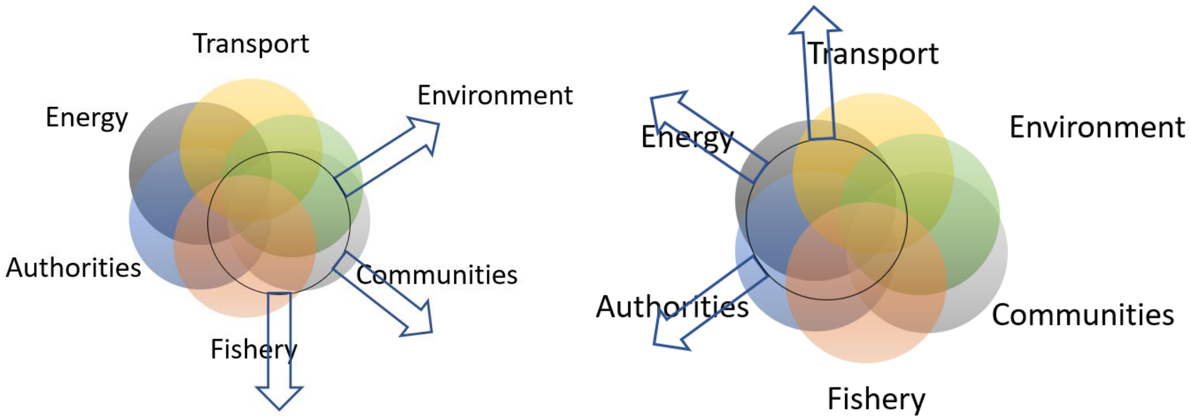


Figure 24: Figure exemplifying different priorities in the MSP process with Sweden on the left and Germany on the right

With reference to the differences in circumstances and drivers, challenges related to MSP and offshore wind is related to

- the rapid technical development with ever increasing turbine sizes and new substructure designs,
- increasing sizes of wind farms to have lower CAPEX and OPEX costs for each project affecting the permits and grid planning for sites,
- the shift of governmental processes and legal requirements, such as the consenting process currently established in Germany
- involvement of many different competent authorities with various competences, standards and regulations
- long lead times for projects with planning and permitting processes of sometimes several decades, while having public and political opinions changing throughout the project.
- Changing financial schemes for the establishment of offshore wind affecting the decision making of the wind farm developers for the nowadays biggest private infrastructure investments in Europe.
- Military is a key stakeholder in many wind energy projects in at least Sweden, Finland and Estonia based on geo-political considerations which are hard to cover in an MSP process.

Taking these points together, the MSP must be sufficiently flexible and fixed at the same time to allow for optimised solutions for offshore wind establishment.

Table 11: Drivers, current main and future uses for the Baltic Sea Region countries as shown by the European MSP Platform

Country	MSP Driver:	Current main uses	Future uses
Denmark		Fisheries Submarine cables and pipelines Mineral extraction Military Oil and gas Shipping Tourism Offshore renewable energy production Nature conservation Aquaculture	
Germany	safe and efficient navigation, marine protection, commerce, offshore wind park planning	Offshore renewable energy production Shipping Fisheries Nature conservation Tourism Ports Aquaculture Military Submarine cables and pipelines	Additional offshore wind farms
Finland		Shipping Fisheries Tourism	
Estonia		Shipping Fisheries Tourism Nature conservation	Shipping Fisheries Nature conservation Tourism Offshore renewable energy production Aquaculture
Latvia		Shipping Ports Nature conservation Fisheries Tourism Military Scientific research Mineral extraction Submarine cables and pipelines	Offshore renewable energy production Oil and gas

Country	MSP Driver:	Current main uses	Future uses
Lithuania		Shipping Under water cultural heritage Nature conservation Ports Military Fisheries Oil and gas exploitation	Submarine cables and pipelines Offshore renewable energy production Mineral extraction
Poland	willingness to balance between new and old users with focus on navigation and ports	Shipping Military Tourism Nature conservation Fisheries Under water cultural heritage Mineral extraction Ports Scientific research Oil and gas Submarine cables and pipelines	Offshore renewable energy production Aquaculture
Sweden		Shipping Offshore renewable energy production Military Fisheries Aquaculture Tourism Nature conservation Under water cultural heritage	

5.1.2 Key drivers and challenges for spatial planning and development of transnational energy grid infrastructure

The transnational energy grid planning implies a detailed planning, interaction and coordination between the various competent authorities and TSOs in the different countries as well as a long-term perspective in the planning process. Transnational energy grid infrastructure allows for transferring peaks in intermittent renewable energy to neighbouring countries avoiding investments in the national grid as well as stabilising the grid, allow for import of cheaper and electricity from other sources and possibly make countries politically independent of certain energy exporting countries. These key drivers for the transnational projects are challenged by their characteristics. The interconnectors are typically huge and complex projects with high investment costs and long project execution times, they based on governmental decisions on investments and exposed to permitting processes in various countries. When the MSP processes in the countries involved are synchronized, the process of establishing new transnational energy grid infrastructure is eased. The transnational projects have a long planning period which allows for adjustments of the MSPs.

When it comes to the combination of interconnectors and offshore wind connections, one of the main challenges is the different timing cycle in decision making, the involvement of multiple decision makers and financiers on authority, at the TSO and wind farm developers' level. The first park where this solution has been achieved is the currently built Kriegers Flak link connecting a park to the Danish and the German grid.

Having offshore wind transmission lines as such connected to various countries has not been done yet based on only the financing of the wind farm developers, as the establishment of wind farms as such so far has relied on national subsidies. Financing scheme and incitement system for connecting to different grids might get cost-efficient solution in the future, if the drivers in the various countries are big enough for supporting such solutions. Obstacles remain the different grid code requirements (effect on grid stability onshore), distances to appropriate connection points, lead times for such projects including the planning and permit process. There are as stated earlier, significant differences between countries. In some countries it is mainly the energy sector planning and decision-making that is deciding locations of energy infrastructure also at sea and MSP is simply acknowledging that, while in other countries it is the MSP process that is leading.

5.1.3 Potential impact of MSP solutions in the Baltic Sea Region on development of offshore wind energy and energy grid infrastructure

The different circumstances, drivers and priorities in the various countries result in MSP of different character with respect to legal status, geographical extend, aspects considered, public acceptance and level of detail makes it challenging to synchronize the MSP process in the Baltic Sea region. Different importance and prioritization from one country to another, new businesses impacting existing businesses and marine areas (environmental sensitive areas, shipping, tourism, fishing, oil & gas, pipelines) result in difficulties to synchronize the MSPs. The impact of the MSP can be that it might be to prescriptive for new technical, sustainable and economical viable solutions in certain countries and too weak to allow for establishment of offshore wind farms as the uncertainties and risks remain too high for an investment decision for wind farm developers. Examples are too small sites dedicated for offshore wind, where cost-efficient parks cannot be built due to the limited space for a dedicated park.

When the MSP processes work efficiently, the different occupations are combined in a matter, so that the societal most beneficial and sustainable stakeholders are prioritized and facilitated. Long lead times for project planning are considered and synergies between occupancies allowed for.

Political forces and public opinion are in most cases steering the outcome of the MSP process. If these changes and there is a will to prioritise offshore wind development, the MSP will change and allow for more offshore wind in the Baltic Sea. If certain prioritisation on EU level are done, the cross-border projects would be made possible more easily and synergies possible, such as cross-border grid development.

5.2 Offshore renewable energy developments in the Baltic Sea

The International Renewable Energy Agency (IRENA) has analysed the energy development in Europe and drawn the following conclusions (IRENA, February 2018):

- The EU could double the renewable share in its energy mix, cost effectively, from 17% in 2015 to 34% in 2030.
- All EU countries have cost-effective potential to use more renewables.
- Renewables are vital for long-term decarbonization of the EU energy system.
- The European electricity sector can accommodate large shares of solar PV and wind power generation.
- Heating and cooling solutions account for more than one third of the EU's untapped renewable energy potential.
- All renewable transport options are needed to realize long-term EU decarbonization objectives.
- Biomass will remain a key renewable energy source in 2030 and beyond.

Renewable power generation technologies are quickly becoming cheaper than conventional technologies at a much faster pace than expected just a few years ago. Offshore wind and solar PV are two prominent examples. Over the last two years the costs of offshore wind have shown a steep decline with recent auctions in The Netherlands, Denmark and the UK awarded at record low prices of around 6 Eurocents per kilowatt-hour (kWh). In the case of solar PV, module prices in Europe have declined by about 80% from 2010 to 2016 (IRENA, 2016c).

5.3 Offshore wind energy industry outlook

Wind energy (both onshore and offshore markets) already meets 11.6% (336TWh) of the EU's power demand and is the most competitive source of new power generation. Renewable energy accounted for 85% of all new EU power installations in 2017: 23.9 GW of a total 28.3 GW of new power capacity where wind power accounted for 55% of total power capacity installations. Accounting for 18% (168.7 GW) of EU's total installed power, 153 GW is installed onshore and 15.8GW offshore (Fraile, Mbistrova, Pineda, & Tardieu, 2018; Fraile, Mbistrova, Pineda, & Tardieu, 2018). Denmark is the country with the largest share of wind energy in its electricity demand with 44% followed by Germany with 20%.

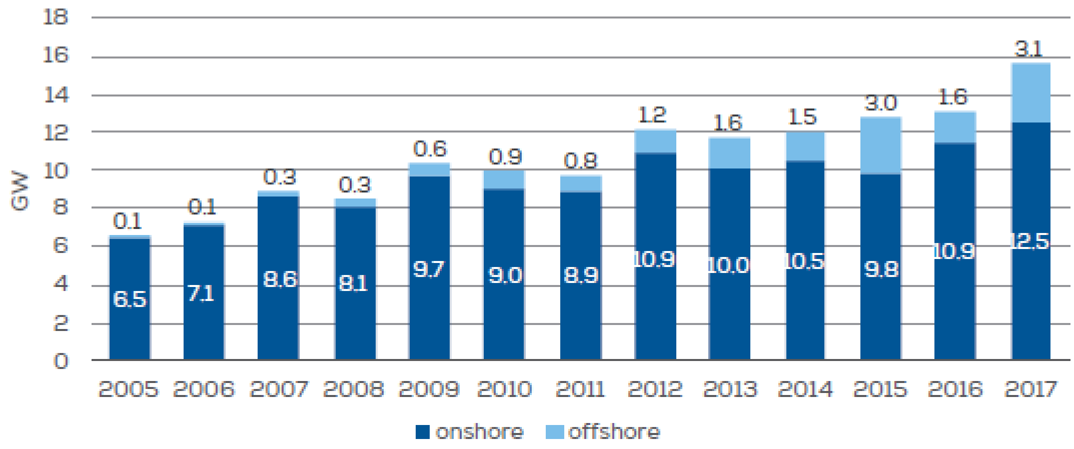


Figure 25: Annual wind installations (both onshore and offshore markets) for the period 2005-2017 in Europe (see left axis). Cumulative wind installations are also shown (light blue line) (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

European offshore wind has seen a strong and steady growth since the early 2000s. By the end of 2017, 92 offshore wind farms with a total of 4,149 offshore turbines have been installed and are grid-connected in 11 European countries, making a cumulative total of 15,780 MW (Fraile, Mbistrova, Pineda, & Tardieu, 2018).

The so called Levelized Cost of Energy (LCoE), a measure for costs of installing new capacities of electricity, has dropped significantly in the last 3 years. Based on the ever-increasing size of turbines and park sizes, there are less resources required per MW for installation and operations, requiring fewer Balance of Plant (BoP) components such as foundations and cables and incurring less maintenance trips per MW. It is also thought that technology costs will decline further provided as well as operational costs due to new vessel types used and learnings between projects. The lowered LCoE as shown in the figure below allows for expansions of offshore wind in the Baltic Sea in a larger scale.

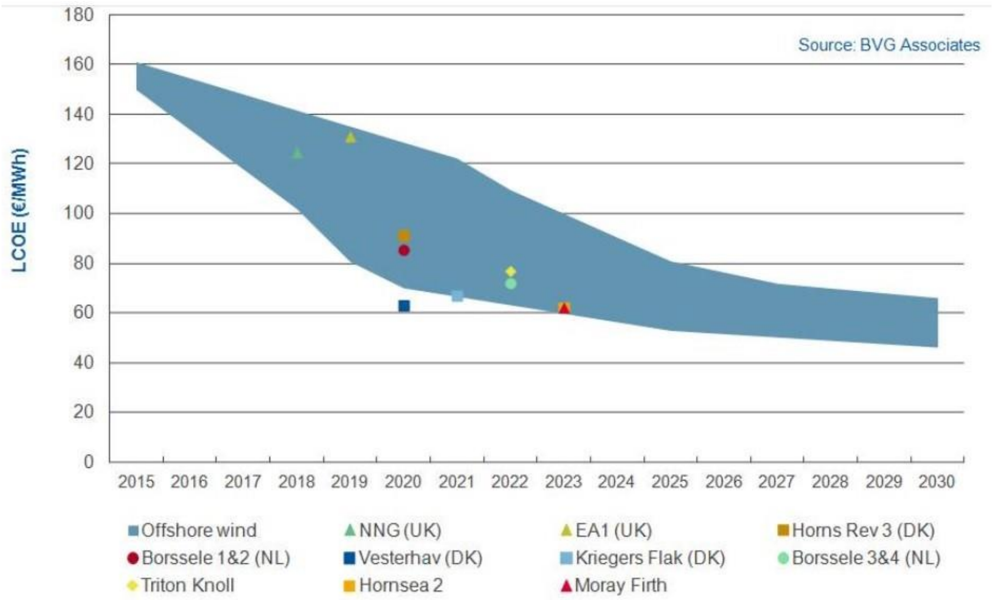


Figure 26: Drop in costs for offshore wind projects based on commissioning date, LCoE (Chamberlain, 2018)

Most of the development in offshore wind has happened in the North Sea, but a significant share is present in the Baltic. Two of the top European countries with the largest amount of installed offshore wind capacity are bordering the Baltic Sea, having installed the bigger share in the North Sea (Denmark and Germany). A map of all offshore wind farms in operation, under construction and consented within the Baltic Sea Region can be found in Figure 7.

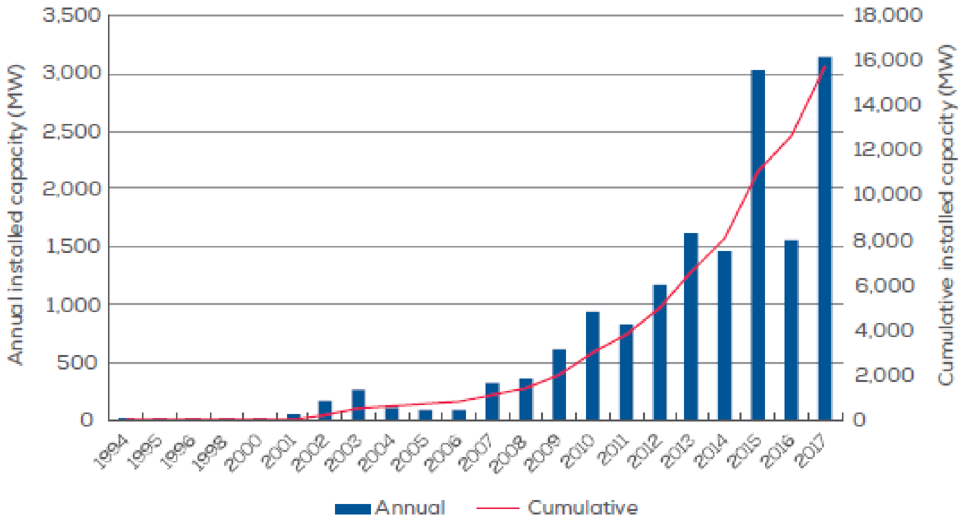


Figure 27: Cumulative (red line) and annual (blue bars) offshore wind installations 2000-2017 in Europe (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

The installation of offshore wind is limited to some major players around the North Sea, of which Denmark and Germany also have the most significant share of the total capacity in the Baltic Sea as shown below.

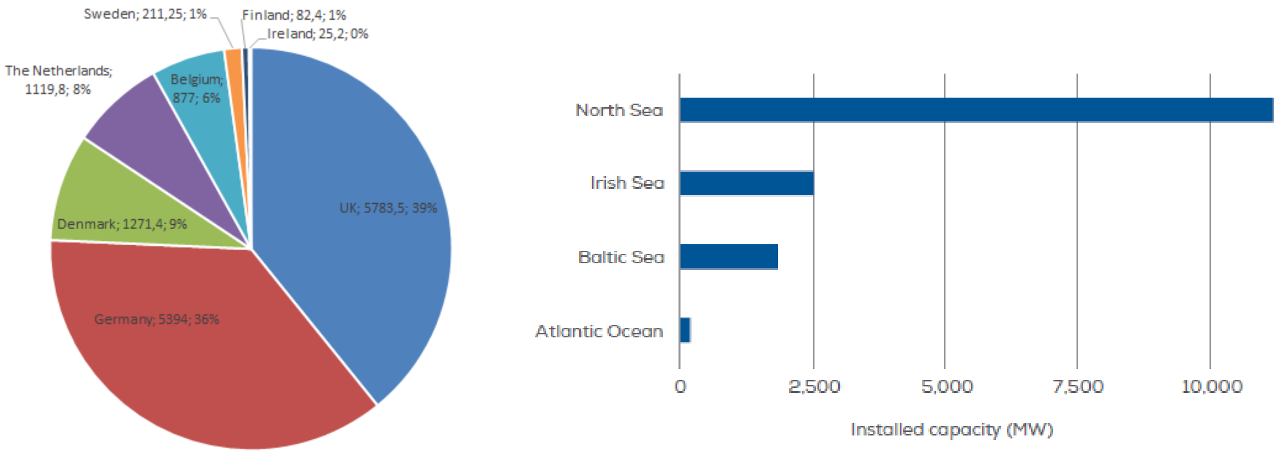


Figure 28: Cumulative installed capacity of offshore wind by country (MW) and percentage share of European total (left). Same metrics broken down by sea basin, Source: RISE internal data and (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

The offshore wind turbines get more reliable and have more up-time producing energy from wind more reliable. With the increased turbine sizes, more constant winds can be approached which together increase the capacity factor (produced energy compared to maximum rating).

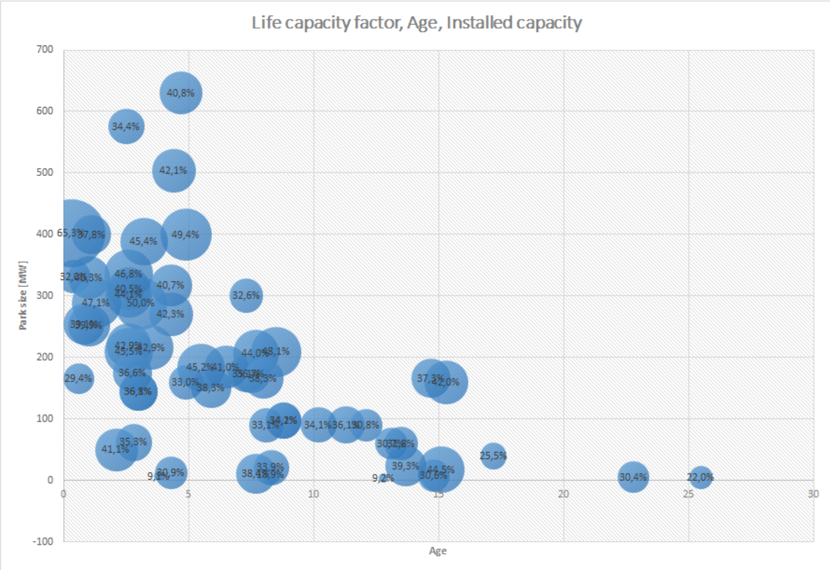


Figure 29: Life capacity factor of wind farms in the UK, Denmark, Belgium and Germany [%], based on data from http://energynumbers.info. Capacity factor compares the name plate rating of a turbine/ park (its maximum power production) with the real production during a certain period of time affected by e.g. lower winds or outages)

5.3.1 Offshore renewable energy project planning

The development of new sites for offshore wind is much longer than for onshore wind projects due to the higher complexity and the typically bigger size. Looking at the time lapse between the tender results / permit and the time that the wind farm starts to operate and is grid connected, typically at least five years have passed. Projects that are in countries with uncertainty in the support mechanisms might never been built despite the permits given, e.g. in Sweden. Even the permit processes might take longer and have an impact on the project execution time.

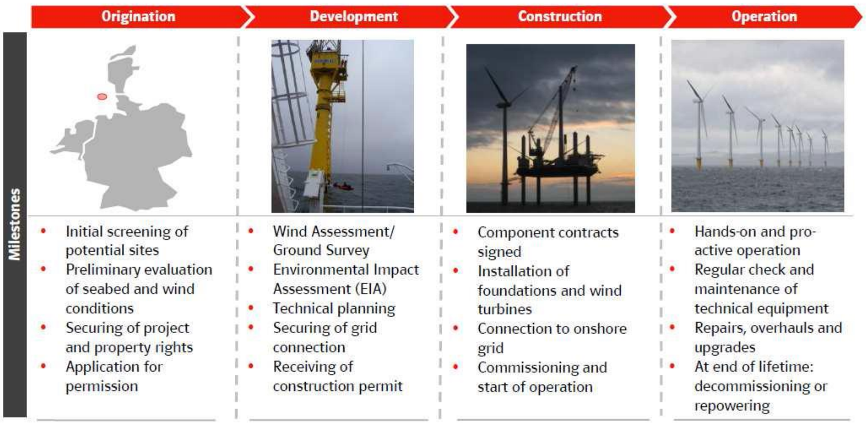


Figure 30: Stages of project development for offshore wind projects (https://formationemr16.sciencesconf.org/file/266745)

The project execution time is even largely affected by the regulatory framework. Therefore, time lapses of offshore wind energy projects are considerable and need to be taken into consideration in marine spatial planning.

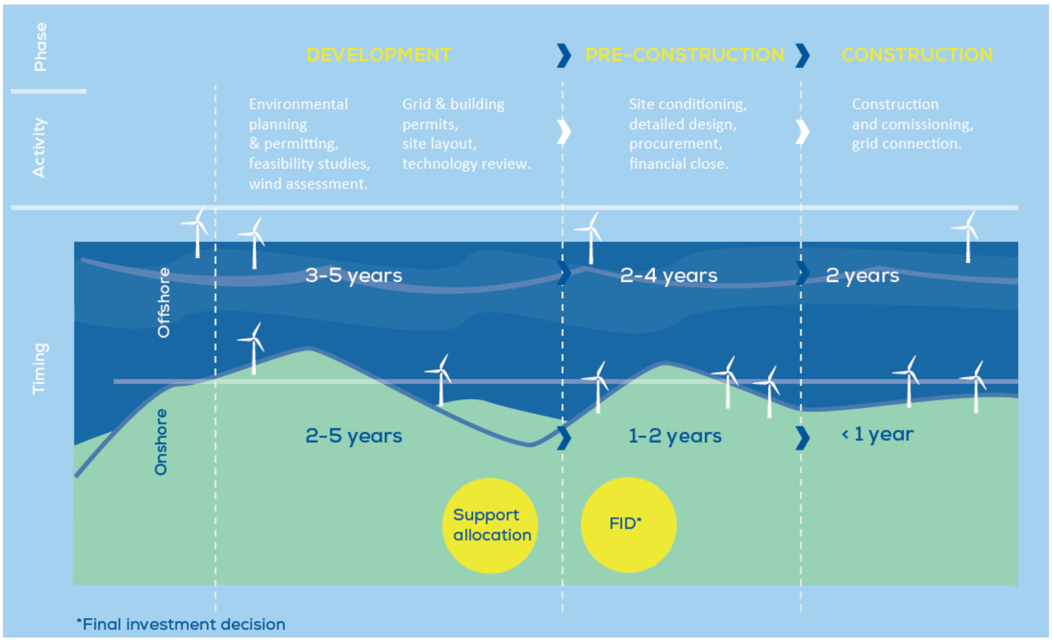


Figure 31: Typical wind energy (on-shore & off-shore) projects' development timeline (Hundleby, o.a., June 2017)

In the last decades the technology development, the economy-of-scale, the legal framework and the experience in offshore wind have contributed to more competitive prices for new farms. There have been significant achievements in the offshore wind industry:

- The rated capacity of offshore wind turbines has grown 102 % over the past decade in Europe, with 8 MW turbines now generating energy at sea, and larger turbines in development. The average rated capacity of newly-installed turbines in 2017 was 5.9 MW, 23% larger than 2016

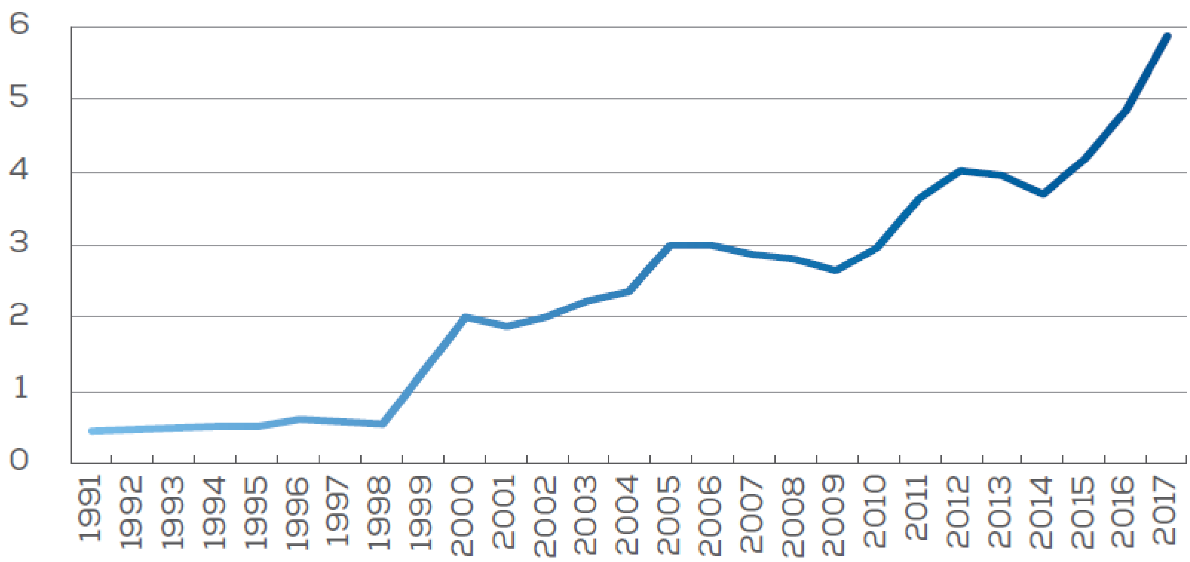


Figure 32: Average capacity of offshore turbines installed per year [MW] KÄLLA? Europe only?

- The average capacity of installed wind farms increased from 46.3 MW in 2006 to 379.5 MW for offshore wind farms under construction in 2016
- The largest wind farm project ever (1.2 GW Hornsea One project) reached financial investment decision in 2016 and is currently built. Even the Hornsea 2 project with an even higher capacity.
- Projects are being constructed in general in deeper waters, with bottom-fixed projects at an average water depth of around 30 m and an average distance to shore of above 40 km during the last years.
- With the Hywind project in Scotland, the first floating wind farm has been installed, that has a significant scale.

For the upcoming wind farm developments, the sum of these effects will drive towards even bigger farms in the Baltic Sea in relatively deeper locations and in the long run even allow for floating wind turbines.

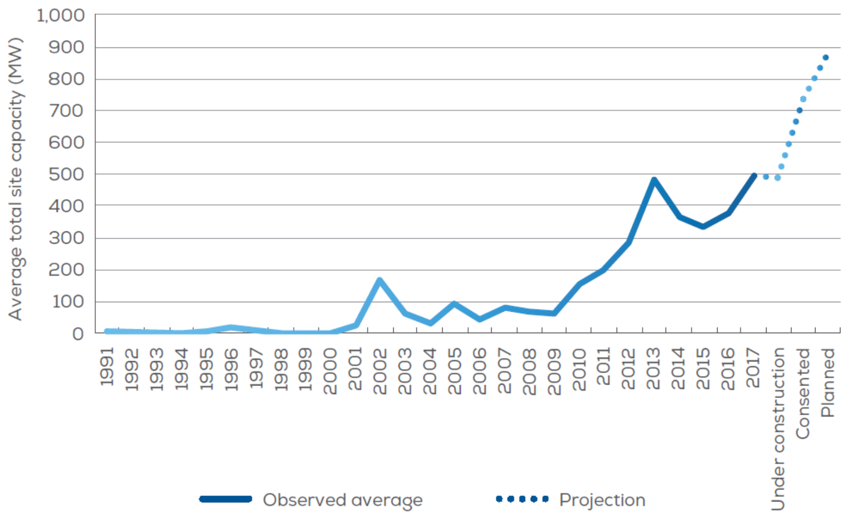


Figure 33: Historic and future park capcities for offshore wind farms KÄLLA?

There are some underlying trends in the offshore wind industry that have spatial implications. These are described in short below.

5.3.2 Turbines

Turbine sizes have increased from the start and are the main underlying factor for the cost-competitiveness of onshore and offshore energy. The past exponential growth of turbine size was driven by several factors. The early small sizes, around 20-60 kW, were very clearly not optimum for system economics due to the high number of components and support systems needed per kW capacity (controls, electrical connection to grid and maintenance are a much higher proportion of the capital value of the system), especially if the prime function is to produce grid quality electricity. This is partly because towers need to be higher in proportion to diameter to clear obstacles to wind flow and escape the worst conditions of turbulence and wind shear near the surface of the earth. Constant technological development and market demand to reduce unit costs in offshore wind energy result in rapid growth of the rated power of the wind turbines. Moving further in time, the development from 2-3MW turbines in the first commercial wind farms has now increased to 8MW and continues in the years to come to 15, sometimes 20MW.

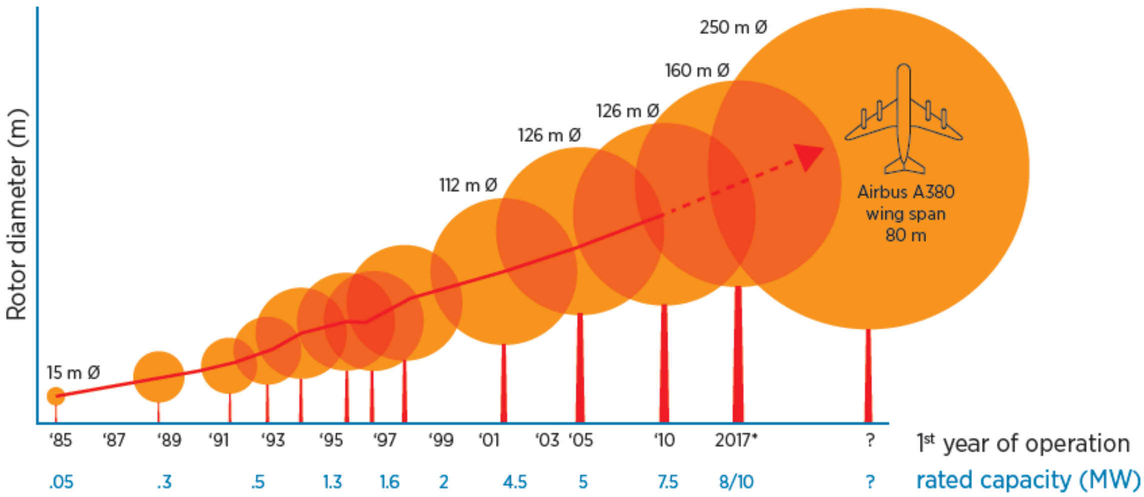


Figure 34: Progression of wind turbine sizes and their rated energy output (MW) up to 2017 and outlook (Lako & Koyama, 2016)

Impact on the MSP process is the reduced number of turbines per area that needs to be installed, reduced number of array cables and even the larger space between turbines required due to changes in the scope of the diameter of the rotor (require wider swept area to convert the energy of wind to the electricity). A typical 8MW turbine has a blade diameter reaching more than 160 meters. Since the rotor diameter is a parameter that determines the area that the wind farm occupies. Distances to be held between single turbines is calculated by multiplying the rotor diameter (e.g. 5x7 diameters). Therefore, the technical development of wind turbine design affects the spatial requirements of the wind turbine, but the trend is positive in terms of decreasing area required for the wind farm with a certain total capacity, although the distance is bigger.

The trend of bigger parks and bigger turbines together with the advancement of building further offshore and even in deeper water depths is critical to be considered in the MSP process.

5.3.3 Economy of scale - Increased farm sizes (no. of turbines)

As the maturity of the technology used has increased, wind parks increase in size. The reduced risks, economy of scale, synergy effects and better understanding of farm layouts have led to increased sizes of the parks. The economy of scale in these huge projects affects the costs of purchasing, installing, operating and maintaining the park.

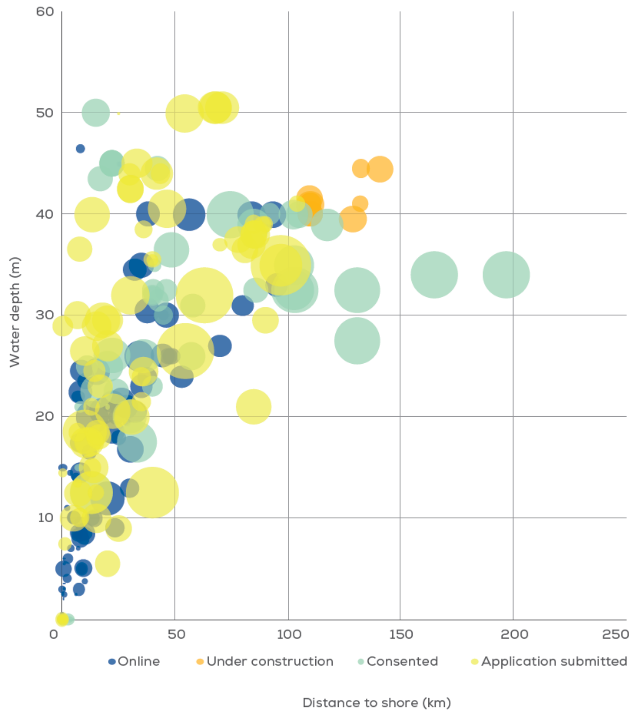


Figure 35: Average water depth, distance to shore of bottom-fixed, offshore wind farms by development status. The size of the bubble indicates the overall capacity of the site (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

The bigger the farm size allowed, the more cost-cuttings can be achieved. This affects the choice of the wind farm developers when choosing appropriate sizes and implies that certain parks in the Baltic that have a permit or are in the permitting process will probably not be built at all or at least not in the near future. The current trend in the North Sea, that is part of the reduced LCoE is economy of scale, i.e. looking for synergies when construction larger parks. In Germany, the dedicated areas are often too small, so developers have started to collaborate to derive bigger farms to develop. The cost reduction potential does not only affect the costs for constructing, ordering components and installing the turbines, but also allow for an optimized operation and maintenance of the park with dedicated resources, such as vessels and hubs. An example is the Hornsea 1 (1 200 MW) and Hornsea 2 (1 400MW) parks which will be the worldwide biggest parks when commissioned. Dedicated vessels are ordered for these projects, the very same components are ordered, substations are standardized, cable redundancy is achieved and will reduce the risk of downtimes.

5.3.4 Substructures

The substructure of an offshore wind turbine is a crucial part and contribute significantly with 10-20% of the overall costs. Different approaches have been used, but historically, monopiles have been the most successful and cost-efficient solution in the sandy bottoms of the North Sea. As the sea bottom conditions vary much more in the Baltic Sea, more Gravity Based Structures (GBS) types have been used in the existing parks. The choice of substructure is based on the most cost-efficient solution depending on different depth, geological structure and oceanographic-meteorological conditions. While the first parks built in mainly shallow waters up to 10-15 meters, gravity-based foundation were used, then gradually substituted by monopiles for the deeper waters up to about 35-40 meters. Jackets and tripods are used for higher water depths allow to enter even 65 meters depths.

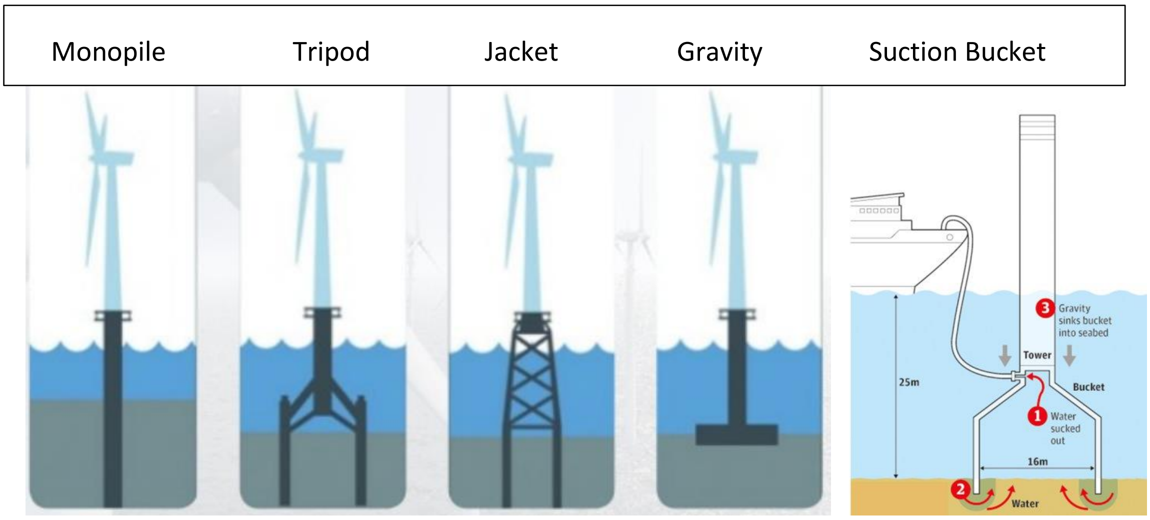


Figure 36: Different substructures used in offshore wind (Arnoudt & Triest, 2013) (4cOffshore, 2018)

Monopiles

Monopiles have had the greatest impact in offshore wind with weight and diameter increasing continuously with increased turbine sizes. Of all wind farms installed about 80% make use of monopiles for foundations of offshore wind turbines. Monopiles used in offshore wind facilities are generally hollow steel piles of diameter larger than 4 m. The piling length and weight depend on the turbine sizes. Recent installations made use of monopiles of 7.8 m of diameter and 1302.5 t (Veja Mate, offshore wind farm located in the German North Sea). (Negro, o.a., 2017). Earlier estimates limited the use of monopiles to 20-25m, but these have been used in water depth larger 40m. There are quite some advantageous with monopiles (Seidel, 2014):

- As the monopile has been used in many projects, it is generally seen as “proven technology” – which is something banks and insurances like.
- Alternative structures for deeper water, mainly jackets, tripods and tripiles are more expensive.
- Fabricators have upgraded their facilities and are now capable to produce monopiles up to 10m diameter and 1500t weight.
- Installation vessels have grown to install the large turbines of >6MW rated power. These vessels are also capable to install large monopiles with lifting capacities of 800-1200t

Due to this change in the market, it can now be anticipated that monopiles will continue to have a large market share also for 6 MW+ turbines in water depths exceeding 30-35m.

Jackets

Jackets are often seen as the best option “beyond monopiles” with wide experience from the oil and gas industry. Their commercial use for offshore wind turbines started in 2006 with the Beatrice project. In total more than 100 offshore turbines on jackets have been erected. The jacket can consist of 3 or 4 legs with corner piles. Advantages are the low wave loads as well as expertise for fabrication, disadvantages are the higher costs for fabrication and maintenance.

Tripods

Tripods have been used in several projects. The tripod is very heavy compared to the jacket and features difficult welding in the central node. There seems to be a wide consensus in the industry now that tripods are not the most economical option and most likely they will disappear from the market.

Gravity Based structure (GBS)

The GBS consists typically of a concrete based structure with or without small steel or concrete skirts. The structures are ballasted by sand, rock or iron ore. The GBS is designed so that it will not allow for pulling/ lifting between the bottom of the structure and the sea bottom by providing enough weight. The structure can be designed to float to the installation site, then filled by water and the ballasting material. The foundations are sensitive to scour. Applications in the Baltic Sea are Vindeby, Rödsand 2 and Kårehamn. Concrete is less volatile and durable in the harsh environment and allows still for mass production. The GBS is applied in non-sandy sea bottoms and with more modest environmental conditions. Sea bed preparations might be required.

Tripiles

Tripiles main idea is having a structure which is easy to install and to mass, but having many disadvantages:

- Due to the three relatively slender piles (4.2m in diameter), it is horizontally soft and experiences a lot of wave excitation, which increases fatigue loads.
- The transition piece is complicated steelwork and quite heavy (more than 400t).
- Total weight including piles and secondary structures is around 50% higher compared to a jacket.
- Secondary structures, esp. boat landings, are difficult to attach to the piles.

It has so far only been used in one park and might not be applied in the future.

Mono-Suction-Bucket

The installation of this concept eliminates driving noise. The system can be self-floating, avoids seabed preparation and can be applied to various site conditions (sand, silt, clay and strata). Apart from the foundation, it is very similar to the monopile and hence close to “proven technology”. The suction bucket may be the innovative concept which will emerge fastest as a real alternative due to its significant advantages especially in the installation phase. The structure can easily be removed by reversing the installation process.

Additionally, to the substructures described above, various kinds of floating foundations are discussed and developed.

It can be concluded that for the spatial planning purposes especially the floating support structures may reshape the areas designated nowadays for the offshore wind farm locations, which however in case of Baltic Sea will not constitute the significant change, thanks to wide areas of favourable water depths below 50 meters.

5.3.5 Floating wind

Floating wind consists of wind turbines fastened on substructures that are floating. These are subsequently moored to the sea floor. There is a huge potential of floating wind power in deeper seas, but potentially even in more shallow waters, where today bottom fasted substructures are used. Offshore oil and gas industry have been using moored and dynamically positioned offshore structures for a long time. Equinor (former Statoil) has financed floating wind applications for decades and is the first mover with installing the first floating large-scale prototype and the first and so far, only commercial floating wind farm in Scotland, Hywind pilot park, 25 km off the coast. It consists of a 30 MW wind farm made up of 5 wind turbines on floating structures at Buchan Deep. The pilot park covers around 4 square kilometres, at a water depth of 95-120 meters and is connected to land by dynamic cables. Another planned large-scale project in the North Sea is the Kincardine Floating Offshore Windfarm, approximately 15 km south east of Aberdeen, Scotland. The wind farm shall consist of 8 floating wind turbines with a maximum generating capacity of 50 MW. The wind farm area will cover around 110 square kilometres, at a water depth of around 60-80 meters. [3]

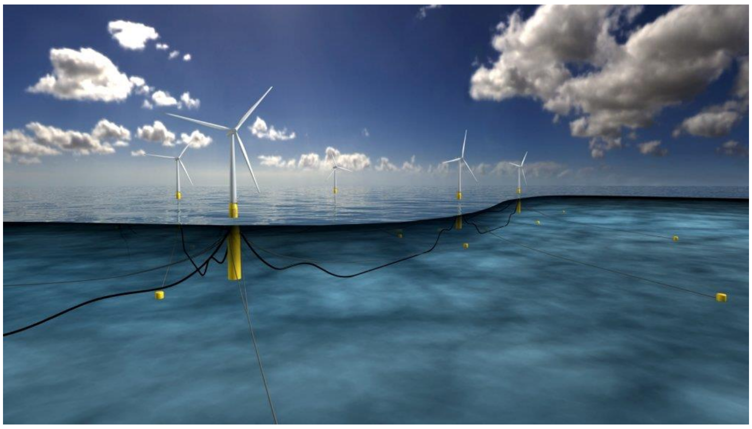


Figure 37: The world's first floating wind farm, Hywind pilot park, 25 km off the coast of Peterhead, Aberdeenshire in Scotland (Source: Equinor/ Statoil[4]).

Still some challenges remain in the design of robust and reliable floating foundations, their installation, and optimized operation and maintenance to make them competitive with bottom-fast and onshore wind on the long run. The turbines can then generate electricity in water depths where bottom-mounted structures are not feasible. This offers the advantage of unlocking deeper water sites and a virtually inexhaustible resource potential. In European waters, 80% of all the offshore wind resource is

[3] https://www.gov.scot/Topics/marine/Licensing/marine/scoping/Kincardine
[4] https://www.statoil.com/en/news/hywindscotland.html

located in waters 60 m and deeper. Having the focus on areas with higher wind capacities than the North Sea, nine projects, with a total capacity of 338 MW are planned to be commissioned by 2021 in France, the UK, Ireland and Portugal. (Kafas, et al., 2018) Challenges in the deeper part of the Baltic remain with respect to ice coverage in the winter which would imply tremendous forces on the mooring arrangement. Another driver for offshore floating wind is the possibility to standardize bigger parts of the substructure in order to save production costs, enabling possibly total costs to fall significantly in the years to come.

Implications for the MSP is that so far unexploited areas might get attention for offshore wind applications, the risk for concurring occupations of certain sites with shipping increases and that space requirements for floating farms differ from bottom-fixed due to mooring and dynamic cables.

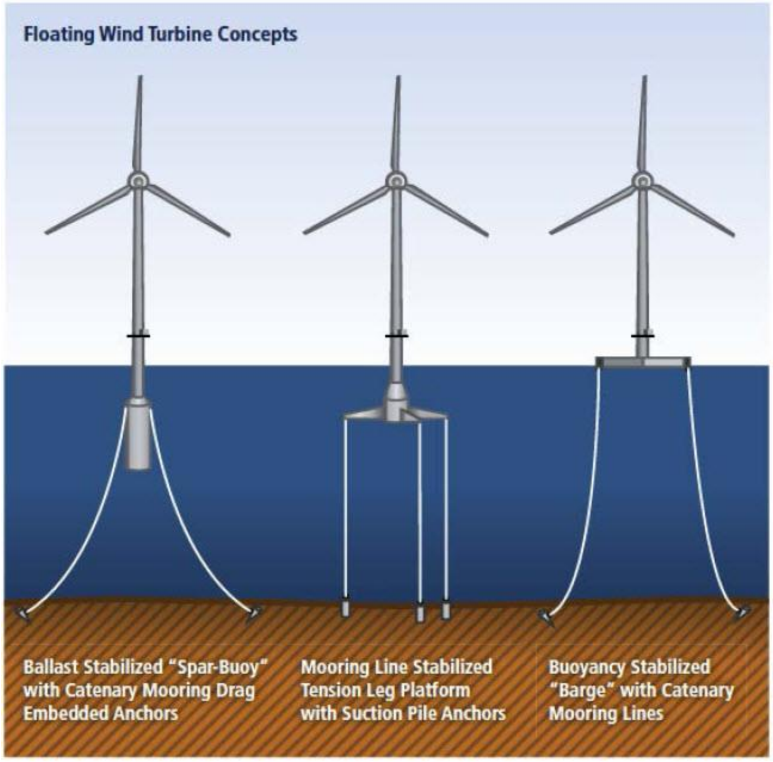


Figure 38: Main technologies for floating offshore wind (Source: Global CCS Institute[5]). Equinors concept builds upon spar buoys concepts that require deep water, while other substructures might work on shallow water as well. Semisubmersible and spar buoy floating substructures are deemed feasible, while the barge and the tension leg platform (TLP) floating substructure concepts are still under development in offshore wind.

The technology is already available, but at least in the norther part of the Baltic Sea ice will pose a serious problem still in the coming decades. Recent reports about the offshore wind energy potential in Northern Europe they saw the floating wind turbines possible/likely in the North Sea, but not in the Baltic Sea, because of the ice conditions. For this study it is nevertheless assumed that the ice conditions

[5] https://hub.globalccsinstitute.com/publications/renewable-electricity-futures-study-volume-2-renewable-electricity-generation-and-storage-technologies/114-technology-cost-and-performance

off the coasts and south of Gotland are not significantly affected by ice coverage and therefore feasible for floating foundations.

5.3.6 Transmission technology

Subsea power transmission cables are existing in the Baltic Sea since a long-time back powering the islands allow connection to the mainland. Based on the distance and the required capacity, different voltage levels are used, that can differ from the onshore grid. Changing the voltage level requires a step-up or step-down transformer that is placed in a substation. When a step-up transformer is required offshore, typically an offshore substation is built. Having shorter distances to transmit electricity, the main choice is HVAC, having longer distances, HVDC is used, as AC solutions would require midpoint compensation to minimize losses. HVDC is requiring for shorter distances higher investment costs and get more cost efficient for bigger transmission capacities. The break-even point depends on criteria related to costs, capacity, distance, reliability, availability and maintainability of the transmission link. So far, only in the German North Sea, HVDC solutions have been employed, while for most interconnectors in the Baltic Sea HVDC is the most common choice. HVDC Back-to-back solutions, such as currently built at Krieger's Flak, are used to configure two independent neighbouring systems with different and incompatible electrical parameters (Frequency / Voltage Level / Short-Circuit Power Level).

So far, all transmission links in the Baltic are built based upon alternate current systems as most of the farms are very close to shore and smaller in size. Typical step changes in transmission capacities are at about 400-500 MW, requiring additional substation set-ups. Based on the redundancy-requirements of the national grid codes, the responsible TSO or the wind farm developer, redundant cables are placed on the sea-floor to transmit offshore wind energy to the onshore grids. Interconnecting various wind farms or parts of these is done to increase reliability and availability of the transmission links. In the Hornsea 1 project in the UK, for the first time a compensation platform is built to make an AC connection feasible for a park above 1200 MW and distance to the grid of ~140km. Even for the bigger farms currently built, AC solutions are utilized with several cables (Wikinger and Arkona, TSO in Germany 50Hz), as distance to shore still are rather short and AC seen as more cost efficient. The Krieger's Flak Combined Grid Solution project is a unique approach as it will connect a Danish and a German offshore wind farms, as well as interconnect the national grid systems onshore, using generally the AC solution offshore, with a back-to-back DC converter station located onshore near Rostock.

In the North Sea, the TSO in Germany, TenneT uses a different approach, having to connect farms further offshore to pass the natural protected areas Wadden Sea. Here the TSO tries to build clusters of farms that are connected with HVDC mother and daughter platforms allowing redundant transmission with converter stations close to each other, collecting electricity from AC substations in the several wind farms of the cluster.

As offshore cables are a cost driver of offshore wind projects and sensitive to failures, alternative solutions are researched and tested such as different circuits and cable-in-a-pipe approaches.[6]

There are no direct implications on the MSP process when it comes to new cable systems. The choice of an appropriate transmission system dependents mainly on the park size, distance to shore and grid code requirements.

The average size of offshore wind farm projects is expected to grow further with average size of currently being built at 500MW and consented projects at 700 MW, and projection of planned projects by WindEurope exceeding 900 MW in average size.

5.3.7 Technical development and research

The technical research and development currently ongoing can affect the marine spatial planning for offshore wind energy. There are a couple of expected areas of development in the figure below, indicating the most promising one's on a timeline. An example is the site layout optimisation, which could be influenced by the MSP, possibly limited in its development. Anotherone are reduced or changed electrical infrastructure, where the array cable layout, the export cable and inteconnections and the substations are affected, by for instance slooping of the substation, interconnection of parks in order to increase redundancy, cable-in-a-pipe. Airbourne wind on the other hand consists of kites circulating at more extrem heights instead of the common wind turbines, having possibly a different need in terms of space.

[6] https://www.offshorewind.biz/2018/06/19/siemens-gamesa-danish-demo-site-proves-cost-effective/?utm_source=emark&utm_medium=email&utm_campaign=daily-update-offshore-wind-2018-06-20&uid=18844

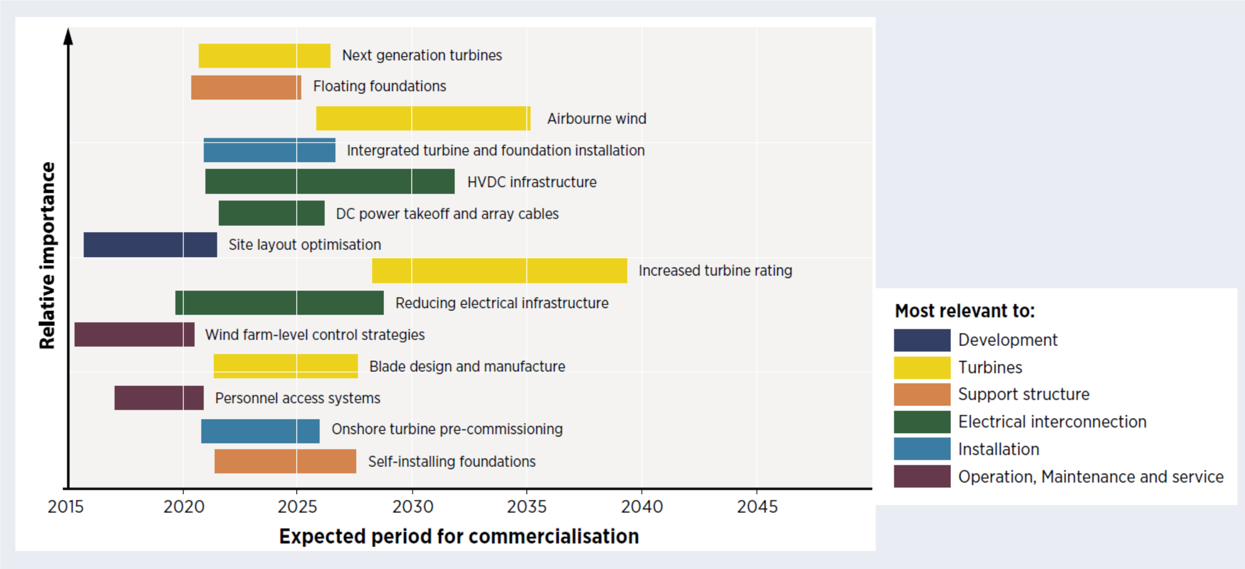


Figure 39: Anticipated timing and importance of innovations in offshore wind technology, 2016-2045, (Freeman, et al., 2016)

The new ETIP (European Technology & Innovation Platform on Wind Energy) Wind Research Agenda suggest the following focus areas for development within offshore wind that could affect MSP (ETIP Wind, 2018):

1. **Bigger turbines** which put a strain on foundations, substructures and supply chain. Research and innovation needs relate to an analysis of which foundations are best suited to support bigger turbines such as sackets, BGS, suction buckets and floating as monopiles are expected to go "out of fashion" by 2030 due to increased "deep water" as well as modular foundations. Based on the local circumstances the crossover point between the viability of bottom fixed versus floating wind systems, including shallow waters will differ.
2. **Optimal offshore grid design** refers a lot to DC connections and cables. Topics such as solutions on DC within the wind farm (i.e. move the sub-station converter) and inter-cable lay-out (DC without substations or AC or low frequencies) and inclusion of the substation in the foundation as well as low frequencies and 50 hertz options and options with the AC and crossover points between HV and AC.
3. **Macro level European grid** with the target to increase cross border compatibility of offshore infrastructure by creating synergies in interconnecting the grid and evaluate DC connections costs in order to avoid a bottle neck of offshore expansion.

These developments are already now affecting the MSP, but the order of magnitude of these effects is difficult to estimate.

Conclusion and effect on MSP

- Trends of offshore wind farms becoming bigger, more powerful and moving further offshore in deeper waters are set to increase
- Floating wind will become more popular in deeper waters, further offshore.
- Maritime spatial planning can help the development of offshore wind farms in deeper waters by defining spatial zones. This will provide stability and clarity for investors and help to reduce project costs.
- Provided there is appropriate siting and careful spatial planning of wind farms in deep water locations, it will reduce spatial conflict within congested inshore waters and avoid higher densities of marine users.
- Trend for increased development area (no. of turbines) is not yet clear
- Fewer, more powerful turbines may be favoured over the more, less powerful turbines due to spatial restrictions.
- For MSP this means that offshore wind farms will require and occupy more sea space and increase competition with other sea users.
- Floating wind unlocks relevant deeper water sites and might in the long run even be competetive in shallower water due to eased installation and scale effects around the Baltic Sea.
- Time lapses of offshore wind energy projects are considerable and should be taken into consideration in marine spatial planning.
- The trend of bigger parks and bigger turbines together with the advancement of building further offshore and even in deeper water depths is critical to be considered in the MSP process.
- Floating wind turbines are – depending on the substructure and mooring - also expected to be able to support larger wind turbines, for example 12-15 MW, which is consistent with the trend of increasing capacities of wind turbines.

5.4 Outlook 2018 to 2030

Wind energy is contributing to the drive towards more extensive use of renewable energy in Europe and contributes towards achieving energy policy commitments in the global to local power sector, allowing countries to reach their targets and continue their energy system transformation. In year 2020 the central milestones set by the European Union will be benchmarked, including the Baltic Sea region countries, where the first specific targets will have to be reached. Even though Europe will represent only a quarter of the new offshore wind power installations until 2020 compared to the global wind market, Europe (primarily North European countries) will be leading the total offshore wind market worldwide until 2020, followed by China. As areas in the North Sea get more limited, the offshore wind developers and supply chain already now search for new opportunities, including the US, Taiwan but also the Baltic and Atlantic coast in Europe. Within new installed renewable energy capacities, the main share of wind power will at least persist or more likely increase, with levels above 50 % until at least 2025 (prognosis 2017-2020: Wind 52 %, Solar PV 37 %, Bioenergy 7 %, Hydro 4 %).

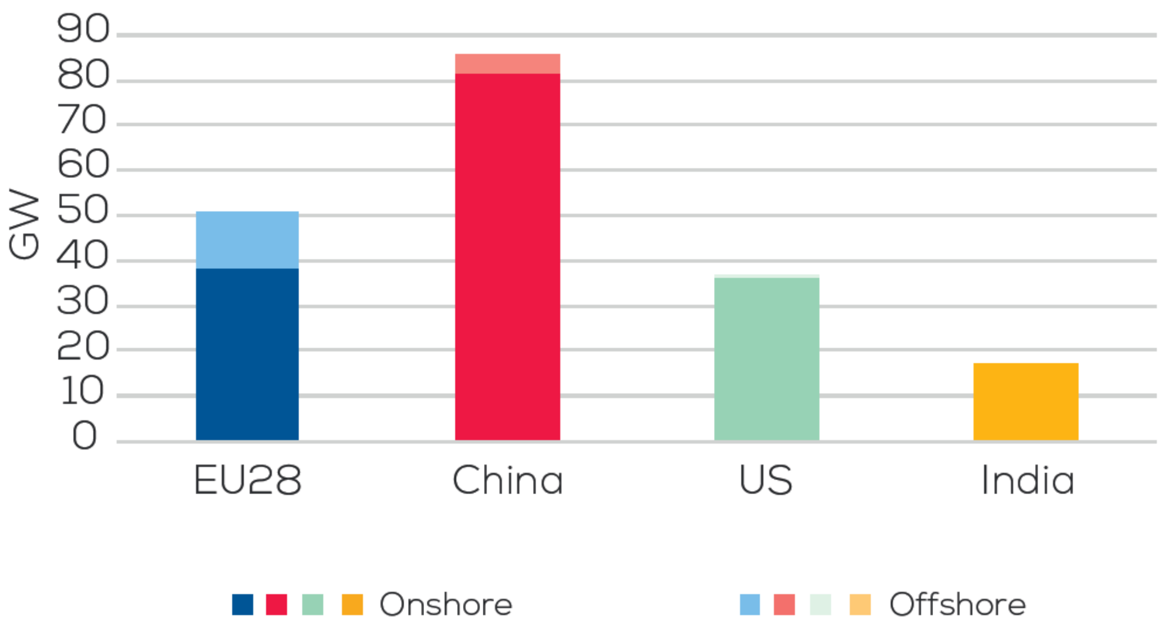


Figure 40: Global wind installations in 2017-2020 (WindEurope, 2017)

The biggest share of wind energy in Europe is so far mainly created by onshore wind farms as the costs for these remain lower on a project basis. However, offshore wind has been growing significantly over the last 10 years and its share of annual installed capacity is expected to grow further. Offshore wind might under certain conditions be cost competitive compared to onshore wind within less than a decade.

The legal aspects in each country needs to be considered. A list of the ongoing development in the BSR countries is shown in the table below.

Table 12: Summary of wind energy policy landscape per Member State (Nghiem, Pineda, & Tardieu, September 2017), RES: Renewable Energy Supply, MVA: Mega Volt Amp; FIT Feed-in tariffs

COUNTRY	UPCOMING DEVELOPMENTS	Policy Outlook	2020 RES targets
Denmark	The scheme for onshore wind expires in February 2018. One year stand still is unavoidable until new scheme introduced	Neutral	Achieved
Estonia	Incentives to remain with a yearly production cap at 600 GWh despite reaching their RES target.	Positive	Achieved
Finland	FIT applications to end once the capacity limit of 2,500 MVA is exceeded	Neutral	Achieved
Germany	Full switch to tender's system both for onshore and offshore with good visibility and long-term certainty	Positive	On track
Latvia		Negative	On track
Lithuania	Government sets a new target of 30% of RES in final energy consumption by 2020 (beyond their original 2020 obligation)	Neutral	Achieved
Poland	Current legislation highly restricts installations. Ongoing Parliament discussion to improve the situation	Negative	Not on track
Sweden	Target of addition 18 TWh RES electricity by 2030 but exponential trajectory with strong growth only at the end of the period	Neutral	Achieved

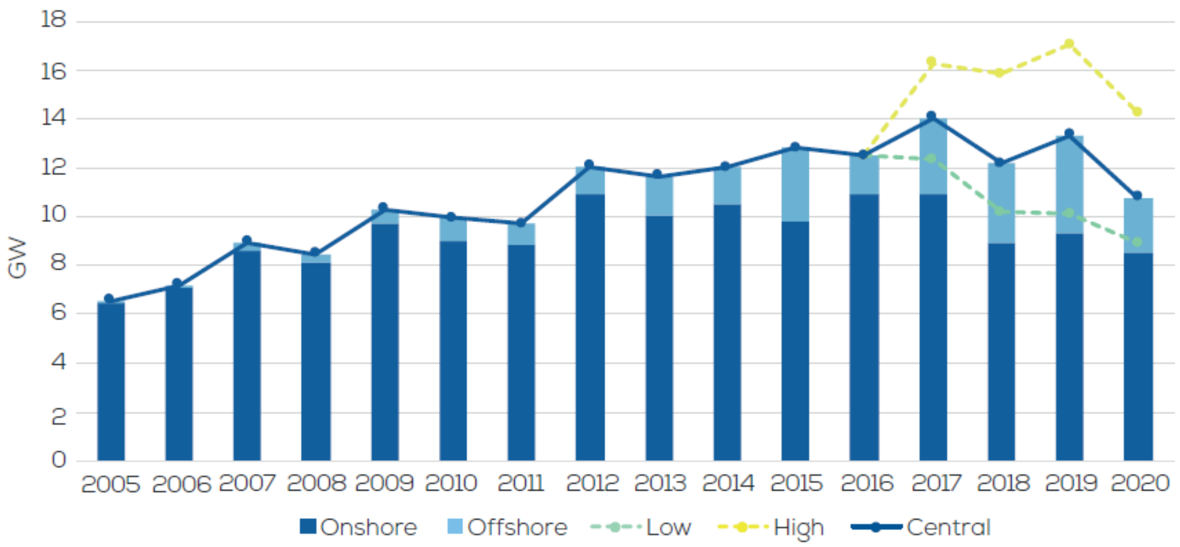


Figure 41: European wind energy (on-shore & off-shore) market outlook up to 2020 (WindEurope, 2017)

There are many different prognoses for the energy development in the world and in Europe, most of them being based on scenarios. Equinor (earlier Statoil) describes in their Energy Outlook several scenarios (Equinor, 2018). The definition of these scenarios can be found in annex 4:

Reform: market forces and technology

Renewal: The Renewal scenario represents a future trajectory for the energy markets that is consistent with limiting global warming at below 2°

Rivalry: a volatile geopolitical environment

Comparing the energy mix in the world based on the possible developments, as shown in the figure below.

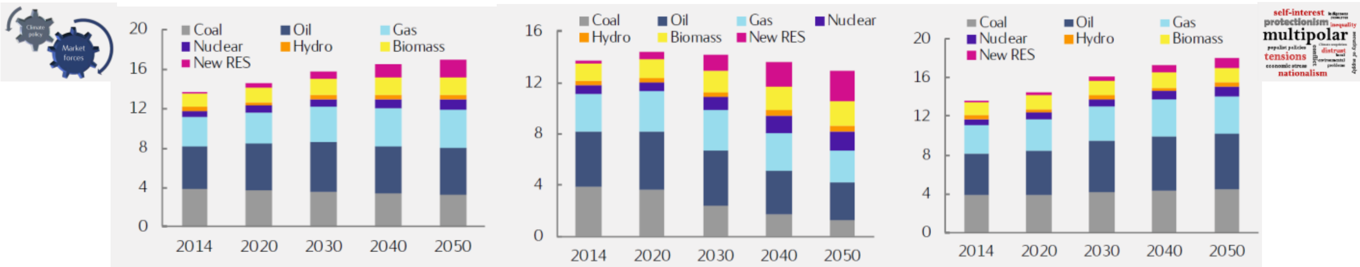


Figure 42: Share of energy sources in the world for three different scenarios in Btoe Billion tons oil equivalent, Left: Reform, middle: Renewal, right: Rivalry Scenario [Statoil, 2017]

WindEurope's Central Scenario provides a best estimate of the installed capacity in Europe in the next 3 years (up to 2020). With an average 3.1 GW/year, offshore wind will represent about one quarter of the total wind energy market by 2020. The offshore market will mainly be concentrated to the UK with 5.2 GW or 42 % of new grid-connected capacity. Another four countries will see offshore installations: Germany (3.5 GW), Belgium (1.5 GW), the Netherlands (1.4 GW) and Denmark (1.0 GW). All projects in this immediate outlook are situated outside the Baltic Sea despite the ongoing project to be finalised in 2018. By 2020, total European offshore wind capacity will be 24.6 GW.

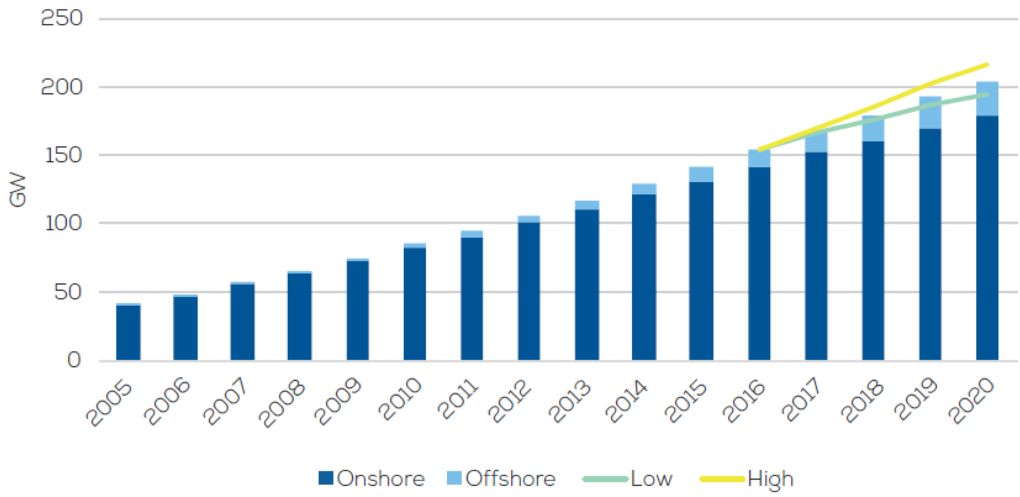


Figure 43: Expected cumulative European installed capacity until 2020 under WindEurope's Central Scenario (adapted from (WindEurope, 2017)

According to WindEurope, a total of 65.6 GW of projects are currently in the planning phase. As a result, it is expected that the offshore market will grow at a higher rate over the coming years and especially North Sea countries are expected to see significant capacity additions. Later, in the period until 2030 there will be significant development of offshore wind projects in the Baltic Sea. (WindEurope, 2017)

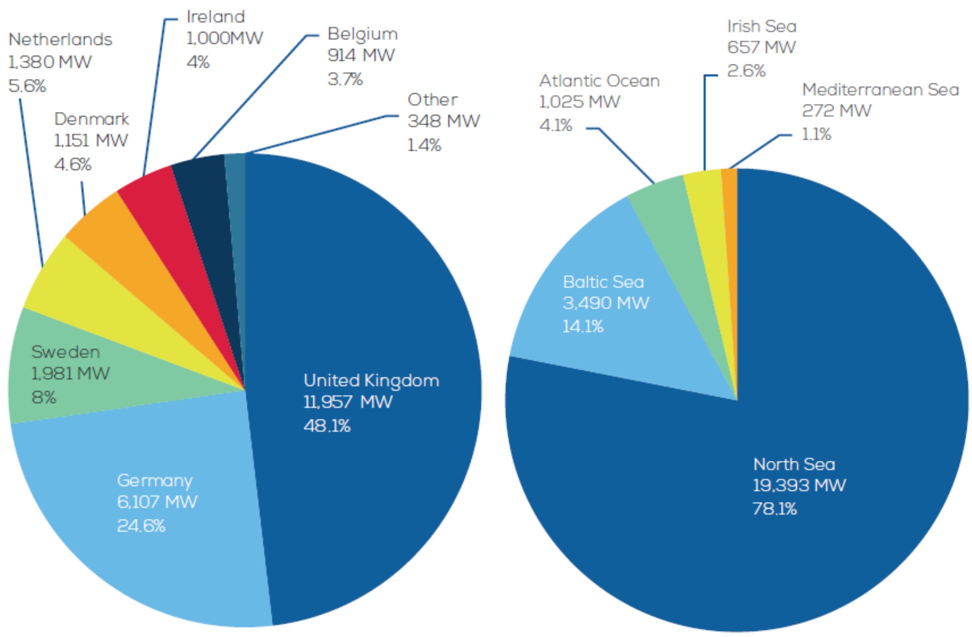


Figure 44: European share of consented offshore wind capacity (MW) by country (left) and by sea basin (right; (WindEurope, 2017)) as of 2017.

Many projects started construction in 2016 and 2017 and grid-connected activity is ongoing. According to WindEurope (Nghiem, Pineda, & Tardieu, September 2017) there are 11.4 GW which have obtained consent to construct, and a further 6.7 GW of projects that are applying for permits. They state further that beyond 2022, there is increased uncertainty regarding EU market volume for offshore wind. While member states have just started drafting their National Climate Action Plans (NCAPs) for the post-2020 period, Germany is the only country with clear volume commitments enshrined in legislation. It is the Renewable Energy Act (EEG) that commits to 700 MW of offshore wind power per year between 2023 and 2025 and 840 MW per year in the period 2026 to 2030.

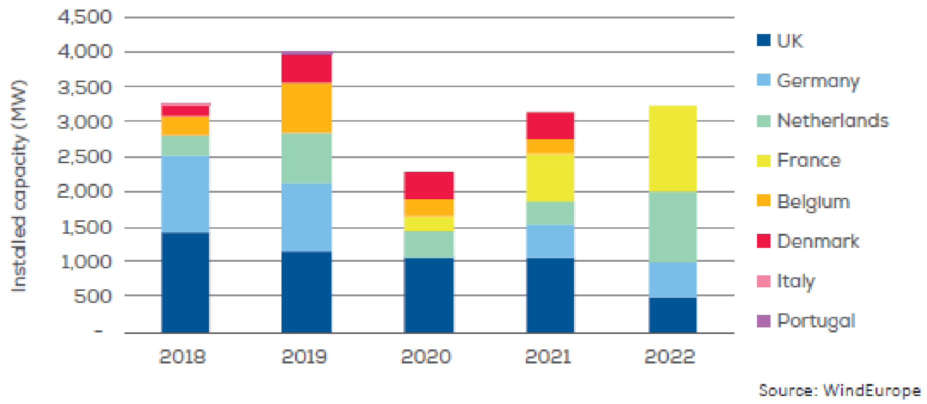


Figure 45: Project pipeline: five-year outlook (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

Little development is expected in the Baltic Sea. The figure below shows the expected cumulative installed capacity of wind (both onshore & offshore) for each BSR country up to 2020.

The BalticIntegrid project used the following scenarios for the time up to 2030 for the Baltic Sea region:

Table 13: BalticInteGrid scenarios used (Source: Project internal information)

Scenarios BalticInteGrid	Status Quo	Scenario 2025 low	Scenario 2030 low	Scenario 2025 high	Scenario 2030 high
Denmark	880	1 480	1 880	1 880	2 096
Germany	689	1 577	2 849	1 577	3 305
Sweden	172	172	472	472	472
Finland	71	71	471	471	616
Poland	0	0	728	728	2 232
Estonia	0	0	450	450	900
Lithuania	0	0	0	0	300

Latvia	0	0	0	0	0
	1 811	3 299	3 299	6 849	6 849

The figures derived in the project were based on assumptions on which wind parks would get consent and subsidies based on the current legal framework in each country.

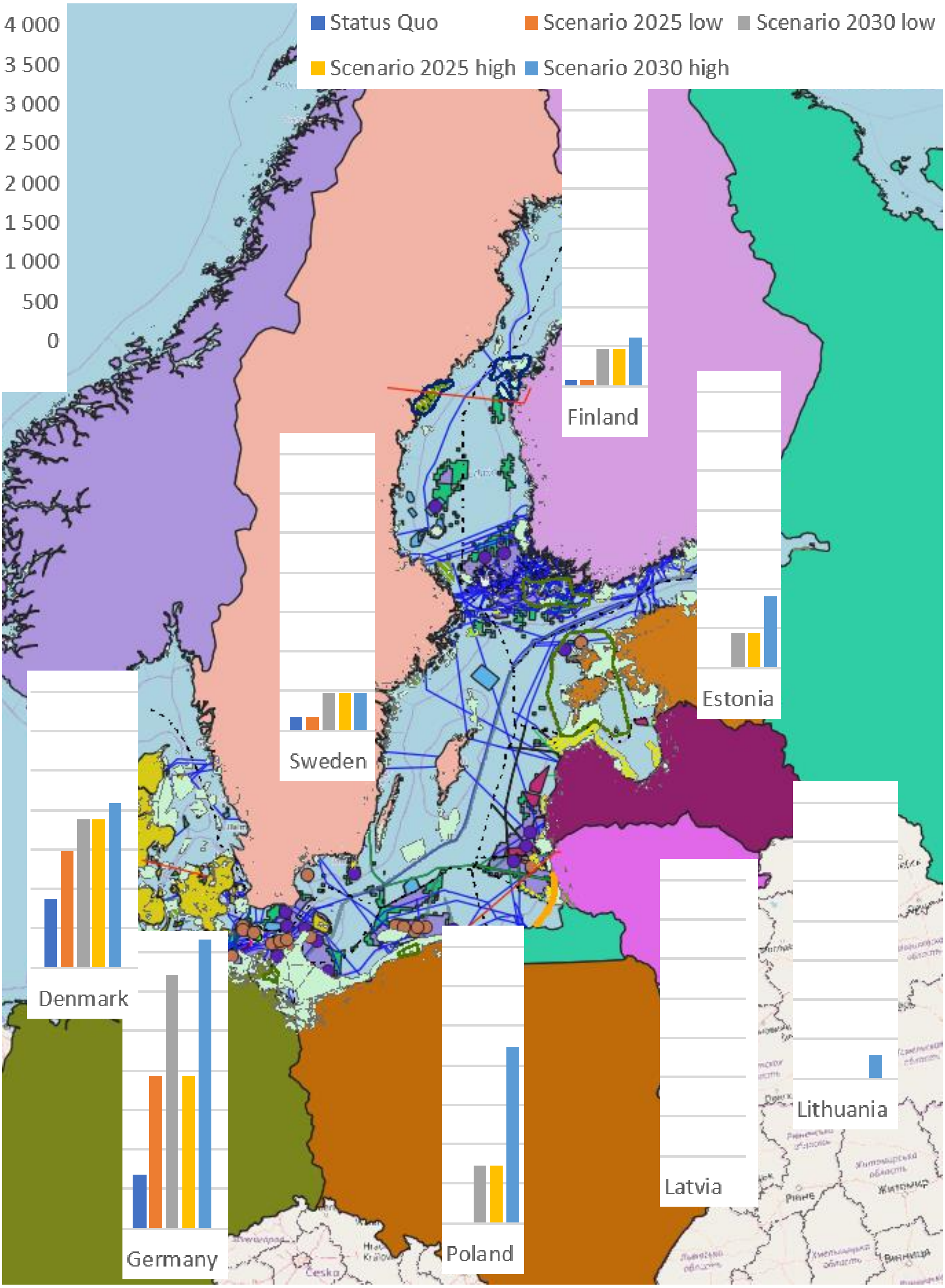


Figure 46: Wind energy (off-shore) installed capacity by BSR country and BalticInteGrid's scenario of added capacity between 2025-2030

According to WindEurope's Central Scenario, from an industry perspective it would be feasible to have 323 GW of cumulative capacity installed by 2030: 70 GW offshore and 253 GW onshore (Hundleby, o.a., June 2017).

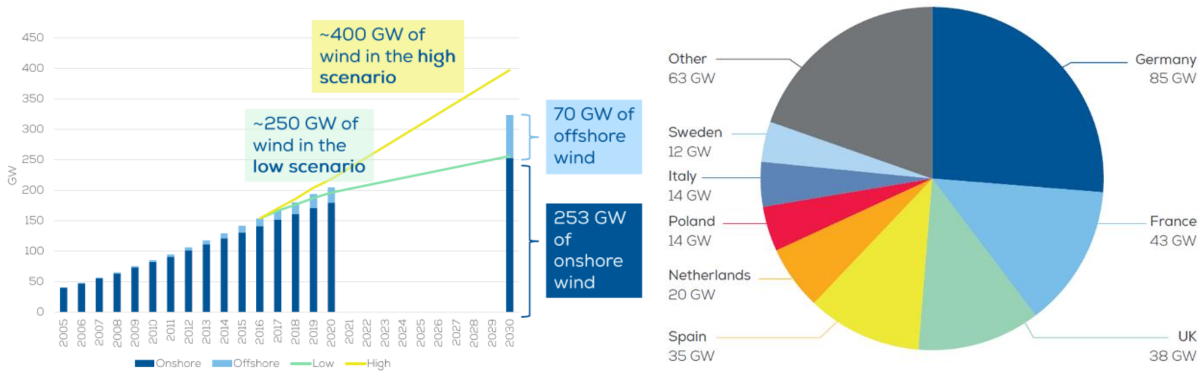


Figure 47: Left: Forecasted cumulative installed capacity until 2030 under WindEurope's low and high scenario and right: Wind energy (on-shore & off-shore) 2030 growth forecasts for EU countries by WindEurope according to Central Scenario (Nghiem, Pineda, & Tardieu, September 2017)

As expected, the branch organization WindEurope shows prognoses that are significantly more progressive than those by the European Commission (+78 GW) or the International Energy Agency (IEA) New Policies (+31 GW) scenarios. IEA has derived scenarios accounting for the national policy and targets of all EU member states, country climate pledges as part of the Paris Agreement, as well as an aspiration of limiting average global temperature increase in 2100 to 2°C above pre-industrial levels. Also, the European TSO organization ENTSO-E predicts lower levels for 2030, in numbers up to 306 GW wind energy capacity in total of which 65 GW offshore. Many of these scenarios did not have the timing to consider the latest reduction in LCoE of wind energy (see also chapter 5.3) that affect prognoses positively towards further increase of share of offshore wind energy. The European Commission Reference 2016 scenario results in 255.4 GW of cumulative wind energy capacity installed by 2030 assuming

1) that the EU's legally binding greenhouse gas emissions and renewables targets to 2020 are met.
2) a constant decrease in CO_2 emissions
3) strong reduction in final energy demand due to successful energy efficiency policies

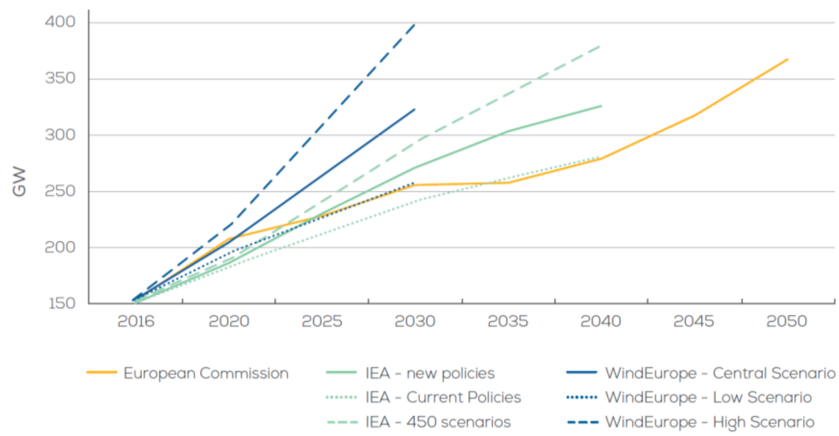
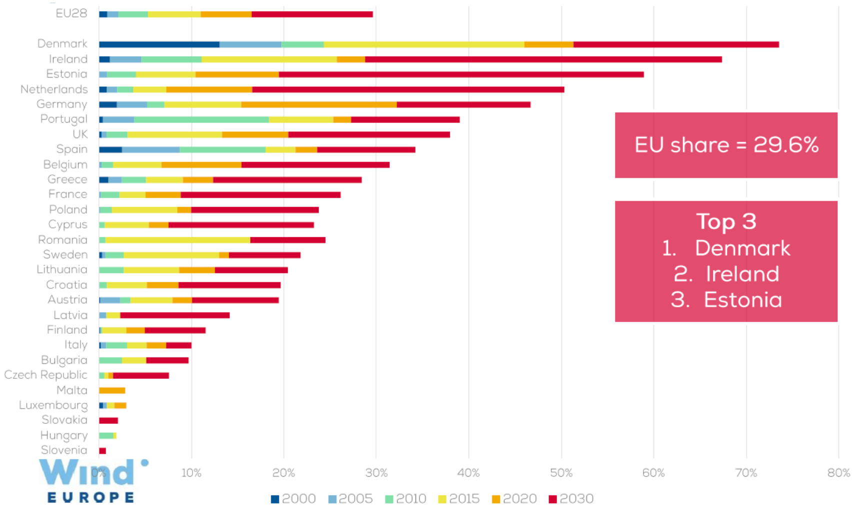


Figure 48: Wind energy (on-shore & off-shore) growth forecasts. WindEurope scenarios in comparison to Commissions and IEA's forecasts (Nghiem, Pineda, & Tardieu, September 2017)



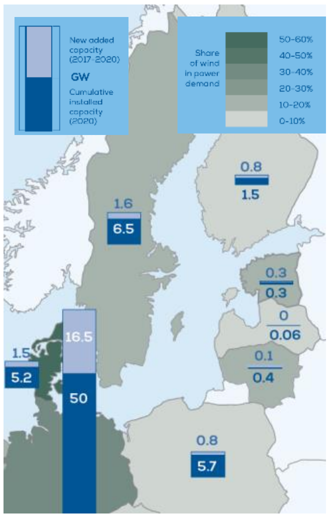


Figure 49: Share of wind in the EU's power demand according to WindEurope's scenario for 2030 (Nghiem, Pineda, & Tardieu, September 2017)

The expected resulting energy increase provided by wind is indicated above.

5.5 Outlook 2030 and beyond

The offshore energy technology as well as the production and installation processes of the industry have matured over the last decade. Rules and standards have evolved, and the financial and technical risk levels of such projects have improved resulting in drastically reduced LCoE. The technology development will continue, and even bigger and more powerful turbines will be introduced, and bigger parks will be planned and built. Floating wind is already in full scale demonstration and can probably be industrialized latest after 2030. Airborne wind might be introduced mainly at sea. and multi-use for energy production feasible. Based on the political circumstances, the current increase in will continue, but even more growth is possible to reach set energy targets in order to tackle energy demand, security of supply, minimizing CO_2 emissions and stopping climate change.

For the 2040 scenarios, ENTSO-E made prognoses where the offshore wind industry in the Baltic Sea region is growing much faster and reaching shares higher than in other regions in Europe. The BSR countries might operate around 36 to 50GW offshore wind (even North Sea included for Denmark and Germany).

5.6 Multi-use of sites

A combination of different occupations for one site might be feasible. To allow for such a development, clear rues need to be made in the permit, possibly even in the MSB, to ensure smooth synergies between acting companies.

5.7 Offshore Energy Renewable Developments Decommissioning

Many of the offshore wind farms in the North Sea and Baltic Sea have a design life and marine license for 25 years. After this end-of-life, the licenses require decommissioning with a bit different requirement from country to country. With the experience from the oil and gas industry, it is crucial to include this phase in the licensing process and even insure financial viability of the wind farm owner to ensure removal of all components as already done in various countries in the Baltic Sea region. Re-powering of wind farms (replacing turbines, etc.) will not be cost-efficient for the smaller turbines installed prior to today but might be feasible for the newest parks developed. The permit often details how the developer intends to remove the installation when it comes to the end of its useful life and how the costs of doing so needs to be funded. This gives the project financial security and protects against developers failing to pay the decommissioning costs and not being liable for the removal of the infrastructure, resulting in it being left on the seabed.

Conclusion and effect on MSP

- A fully-costed decommissioning programme agreed prior to license award will benefit MSP as it will ensure that any offshore energy development infrastructure will be decommissioned and removed from the seabed after 25 years when the marine licence expires. This will free up marine space and reduce conflicts with other marine users.
- Re-powering might be feasible later on in time, but is not financially worthwhile for at least two decades from now

6 Conclusions

Based on the analysis presented in the report, it can be concluded that:

- Most of the countries in the region will meet the near-time targets (2020) set for renewable energy in the energy mix, greenhouse emissions and interconnectivity. Breaking down these targets by trajectories and targets for the different consumers, the transport sector is lagging in most of the countries. Efforts are made in many countries to lower the environmental impact and intend further electrification that will impact the need for electricity.
- The targets for 2030 are not as clear for all countries, but the trajectories for the targets set are reached by most countries. The newly made decision on renewable energy share will force further efforts by many countries as there is a good chance that the targets will be increased by 2021. The increase of targets will facilitate that there is a realistic chance to meet the 2050 targets set by the European Union. Based on decisions made on investments in source of new power plants, further interconnection is needed in the BSR.
- Renewable energy is becoming the cheapest option for new electricity generation and European electricity systems will undergo a transformation to very high renewable shares in the coming decades
- Drive towards fossil-free, renewable and low-carbon energy assumed to persist.

The prediction of offshore wind power development is challenging due to rapid evolution in a number of areas:

- Rapid technology and sector development in offshore wind
- Technology development of other renewable energy sources and their subsidy systems.
- Concurring activities at lucrative sites hinder to make use of the most cost-efficient sites
- Differences on drivers and barriers for developing offshore wind in the Baltic Sea Region
- Long term impact of auction system on prices
-

How the offshore wind industry will develop depends not only on how the technology and costs of offshore wind develops, the political framework and subsidies, but also on the cost development of other renewable technologies, increased need for electricity due to e.g. electrified mobility and concurring use of marine spaces. So, the impact on which technique will be most cost competitive, have the public opinion on their side and fulfil the requirements of the various countries is essential for the mid and long-term scenarios, as shown in the figure below.

Contracts have been established in the EU to provide clean energy to other countries to improve the share of renewable energy in the receiving country. This kind of green-streaming has a direct impact on the where deployment of renewable energy generation capacity will be installed and would imply more wind farms and interconnectors.

Figure 50: Global levelized cost of electricity from utility-scale renewable power generation technologies, 2010-2017, Source: IRENA and prognosis on net growth in renewable capacity in 2017-2020 (WindEurope, 2017)

The different renewables techniques that could be utilized have quite a spread in costs as described above. While the development in general indicates lower costs for all techniques, the specific costs for projects in the Baltic might impact the choice of suitable source of energy in a future scenario.

New energy sources in the marine space are evolving, such as data-centres cooled by the ocean water currently tested at Orkney, floating solar parks in Asia and even the electrification of the shipping industry could have an impact on the MSP processes, as these require possibly floating charging stations.

Figure 51: Other energy related activities in the oceans that could affect the MSP processes, left: tanker at single point mooring loading station, floating solar farm, and submerged datacentre prototype. Picture sources: https://www.marineinsight.com/offshore/how-single-point-mooring-spm-offshore-operation-works/, https://www.youtube.com/watch?v=qKpYH5SYUeo, https://news.microsoft.com/features/under-the-sea-microsoft-tests-a-datacenter-thats-quick-to-deploy-could-provide-internet-connectivity-for-years/

Another important field related to energy is carbon capture and carbon storage. The society trends are referring currently not only to sustainability, i.e. limiting the impact of human activities on the environment, but even actively recovering the nature. This could imply that bio-fuels that are used make transportation fossil-free, but with an added carbon storage and capture, a negative balance could be achieved. Carbon storage under the sea bottom has been performed in Norway for many years (https://www.technologyreview.com/s/406222/storing-carbon-dioxide-under-the-ocean/).

Altogether, the uncertainties of the prognoses made increase the further in the future they aim to predict as indicated below. Also, the number of gaps, indicated by dots will have a higher impact.

To be more certain on prognoses and their outcome, various reports on the same topic should be studied to get a wider picture. As stated by ENTSO-E, even reading the updates of the same report will allow the decision makers to make good decisions (ENTSO-E, 2018):

"The dependency of the needs to the respective scenario assumptions needs to be taken into account. Only by considering a variety of studies (e.g. several TYNDPs) can a robust statement of the needs be made."

No analysis has been made on areas that are dedicated for offshore wind now but will not be cost efficient to be used after decommissioning of the parks.

Repowering of parks will probably occur first after 2030 and will have an impact on MSP. Cable routes with replaced cables or cables laid close to existing cables will widen the cable corridors. Increased park sizes at existing sites will affect the MSP process. No analysis of these effects has been performed.

Combination that currently are on research level of combining heating/ cooling with electricity production more closely is not considered in this study but could eventually influence MSP.

7 Glossary and Abbreviations

BoP Balance of Plant

BSR Baltic Sea Region

CCS Carbon Capture and Storage

CEF Connecting Europe Facility

CGS Combined Grid Solution

CHP combined heat and power plants

EEZ Exclusive Economic Zone

ENTSO-E European Network of Transmission System Operators for Electricity

ETS Emissions Trading System

EU European Union

FIT Feed-In Tariffs

GHG Green House Gases

HELCOM HELCOM Convention (Helsinki Commission Conventions) for the protection of the marine environment in the Baltic Sea

HVAC High Voltage Alternate Current

HVDC High Voltage Direct Current

ICES International Council for the Exploration of the Sea

IRENA International Renewable Energy Agency

LCoE Levelized Costs of Energy

MSP Marine/Maritime Spatial Planning

Mtoe Million tons of oil equivalent

MVA Mega Volt Amp

MW Megawatt

MWh Megawatt hour

NERC National Emission Reduction Commitment

OEC Ocean Energy Converter

PCI Projects of Common Interest

RES Renewable Energy Sources

RES-E Renewable Energy Sources for Electricity

RES-H Renewable Energy Sources for Heat, even RES-H&C including Cooling

RES-T Renewable Energy Sources for Transport

SwAM Swedish Agency for Marine and Water Management

SEA Strategic Environmental Assessment

SEAP Sustainable Energy Action Plan

TEC Tidal Energy Converter

TW Territorial Waters

TFC Total Final Consumption

TPES Total Primary Energy Supply

TYNDP 10-year network development plan

WEC Wave Energy Converter

WP Work Package

8 References

4cOffshore. (2018, 04). *4coffshore*. Retrieved from Offshore Wind Farms: https://www.4coffshore.com/

Arnoudt, J., & Triest, G.-J. (2013). Early Stage Cost Estimation of offshore wind farm projects using Monte Carlo Simulation. Ghent, Belgium.

Capros, P. P., & A. De Vita, N. T. (2016). *EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050.* Brussels: European Union.

CDU/ CSU, SPD. (2018). *Ergebnisse der Sondierungsgespräche von CDU, CSU und SPD, Finale Fassung 12.01.2018.* Berlin: CDU/ CSU, SPD.

Chamberlain, K. (2018, 07 07). *Offshore wind opex set to fall 40% by 2030 as suppliers dig deep*. Retrieved from http://newenergyupdate.com/wind-energy-update/offshore-wind-opex-set-fall-40-2030-suppliers-dig-deep

EEA. (2016). *Renewable energy in Europe 2016 - Recent growth and knock-on effects.* Luxembourg: European Environment Agency Report No 4/2016.

EEA. (2017). *Trends and projections in Europe 2017 Tracking progress towards Europe's climate and energy targets.* Luxembourg: European Environment Agency.

Encyclopædia Britannica. (2018). ENCYCLOPÆDIA BRITANNICA. Chicago, Illinois, United States: Encyclopædia Britannica, Inc.

ENTSO-E. (2017). *Regional Investment Plan 2017 - Regional Group Baltic Sea.* Brussels: ENTSO-E.

ENTSO-E. (2018). *Ten Years Development Plan 2018.* Brussels: ENTSO-E.

ENTSO-E. (2018). *TYNDP 2018 Regional Insight Report Focus on the Nordic and Baltic Sea.* Brussels: ENTSO-E.

Equinor. (2018). *Energy Perspectives 2018, Energy term macro and market outlook.* Oslo: Equinor.

ETIP Wind. (2018). *Workshop conclusions wind energy R&I priorities to 2030.* Brussels: ETIP Wind.

EUROPEAN COMMISSION. (2011). *Impact Assessment Energy Roadmap 2050.* Brussels: EUROPEAN COMMISSION.

European Commission. (2014, January 22). A policy framework for climate and energy in the period from 2020 to 2030. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*. Brussels, EU, Belgium: European Commission.

EUROPEAN COMMISSION. (2017, 11 23). COMMISSION DELEGATED REGULATION (EU) 2018/540. *Regulations*. Brussels: EUROPEAN COMMISSION.

European Commission. (2017). *Communication on strengthening Europe's energy networks COM(2017) 718 final.* Brussels: European Commission.

European Commission. (2017). Communication on strengthening Europe's energy networks, COM(2017)718. Brussels, Belgium: European Commission.

European Commission. (2017). *Renewable Energy Progress Report.* Brussels: REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS.

European Commission. (2018, 07 09). *Energy*. Retrieved from Renewable Energy: www.ec.europa.eu/energy

European Environment Agency. (2017). *Renewable energy in Europe – 2017 Update, Recent growth and knock-on effects, EEA Report No 23/2017.* Luxembourg: European Environment Agency.

European Parliament. (2016). *European Energy Strategy.* Brussels: European Parliament.

Fraile, D., Mbistrova, A., Pineda, I., & Tardieu, P. (2018). *Wind in power 2017 - Annual combined onshore and offshore wind energy statistics.* Brussels: WindEurope.

Freeman, K., Hundleby, G., Nordstrom, C., Roberts, A., Valpy, B., Willow, C., . . . Boshell, F. (2016). *Innovation Outlook Offshore Wind.* Abu Dhabi: IRENA.

Fried, L., Shukla, S., Sawyer, S., & Teske, S. (2017). *GLOBAL WIND ENERGY OUTLOOK 2016.* Brussels: GWEC Global Wind Energy Council.

Gence-Creux, C., Lepy, S., Minciuna, I., Heidrecheid, C., Blanco, P. B., Štritof, I., . . . Mathiesen, B. V. (2017). *Towards a sustainable and integrated Europe - Report of the Commission Expert Group on electricity interconnection targets.* Brussels: European Commission.

Hundleby, G., Freeman, K., Barlow, M., Blanch, M., Tardieu, P., & Walsh, C. (June 2017). *Unleashing Europe's offshore wind potential.* Brussels: WindEurope & BVG Associates.

International Energy Agency and International Renewable Energy Agency. (2017). *Perspectives for the Energy transition - Investment needs for a low-carbon energy system.* Paris: International Energy Agency and International Renewable Energy Agency.

IRENA. (February 2018). *Renewable Energy Prospects for the European Union.* International Renewable Energy Agency.

Jacobson, M. Z., Delucchi, M. A., Bauer, Z. A., Goodman, S. C., Chapman, W. E., Cameron, M. A., . . . Goldstrom, O. K. (September 6, 2017). 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World. In *Joule 1* (pp. 108–121). Elsevier Inc.

Kafas, A., Ripken, M., Wright, K., Billet, M., Sangiuliano, S., Ooms, E., & Scheffler, U. (2018). *Status quo report on offshore energy planning provisions in the North Sea Region, NorthSEE project.* Hamburg: NorthSEE project, German Federal Maritime and Hydrographic Agency.

Lako, P., & Koyama, M. (2016). *Wind Power Technology Brief.* IRENA.

Lindroos, T. J., Lehtilä, A., Koljonen, T., Kofoed-Wiuff, A., Hethey, J., Dupont, N., & Vītiņa, A. (2018). *Baltic Energy Technology Scenarios 2018.* Copenhagen: Nordic Council of Ministers.

Lotos. (2018, 06 01). *LOTOS LOTOS Group Our companies LOTOS Petrobaltic News*. Retrieved from 25 years ago: first Polish crude oil from the Baltic Sea deposits: http://www.lotos.pl/en/1031/p,717,n,4625/lotos_group/our_companies/lotos_petrobaltic/news/25_years_ago_first_polish_crude_oil_from_the_baltic_sea_deposits

Müller, M., Haesen, E., Ramaekers, L., & Verkaik, N. (2017). *Translate COP21: 2045 outlook and implications for offshore wind in the North Seas.* Utrecht: ECOFYS.

Negro, V., López-Gutiérrez, J.-S., Esteban, M. D., Alberdi, P., Imaz, M., & Serraclara, J.-M. (2017). Monopiles in offshore wind: Preliminary estimate of main dimensions. *Ocean Engineering 133, Elsevier*, 253-261.

Nghiem, A., Pineda, I., & Tardieu, P. (September 2017). *Wind energy in Europe: Scenarios for 2030.* Brussels: WindEurope.

Offshore technology. (2018). *Lukoil's Kravtsovskoye (D-6) Oil Field*. Retrieved from Offshore technology: https://www.offshore-technology.com/projects/kravtsovskoye/

OFGEM. (2018, 06 01). *OFGEM*. Retrieved from Electricity interconnectors: https://www.ofgem.gov.uk/electricity/transmission-networks/electricity-interconnectors

Purvins, A., Huang, T., Zalzar, S., Pi, R. J., Flego, G., Masera, M., . . . L'Abbate, A. (2017). *Integration of the Baltic States into the EU electricity system.* Brussels: European Commission.

Schiffer, H.-W. (2016). *WORLD ENERGY RESOURCES 2016.* WORLD ENERGY COUNCIL.

Seidel, M. (2014). Substructures for offshore wind turbines - Current trends and developments. *Festschrift Peter Schaumann, Hannover 2014, doi:10.2314/GBV:77999762X, ResearchGate*.

Shadurskiy, A., Westphal, K., Daborowski, T., & Liuhto, K. (2015). *Natural gas revolution and the Baltic Sea region.* Centrum Balticum Foundation.

Weisse, R., Feser, F., & Storch, H. v. (2005). Northeast Atlantic and North Sea Storminess as Simulated by a Regional Climate Model during 1958–2001 and Comparison with Observations. *Journal of Climate*, 465-478.

Wikipedia. (2018, 06 01). *Wikipedia*. Retrieved from Interconnector: https://en.wikipedia.org/wiki/Interconnector

WindEurope. (2017). *Wind Energy in Europe: Outlook to 2020.* Brussels: WindEurope.

WindPower Net. (2018, 04). *WindPower Net*. Retrieved from Wind energy database: https://www.thewindpower.net/index.php

Zervos, A., & Adib, R. (2018). *Renewables 2018 Global Status Report.* Paris: REN21.

Data Sources:

Eurostat

Data coastDat:

Weisse, Ralf (2015). coastDat-1 Waves Baltic Sea. World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.1594/WDCC/coastDat-1_Waves_Baltic_Sea

Data derived from GridKit representing an extract from ENTSO-E interactive map: https://zenodo.org/record/55853#.W5iyt3kUmIo

https://tyndp.entsoe.eu/tyndp2018/projects/

National renewable energy action plans

Lead partner

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

EUROPEAN UNION

Partners

HELCOM

corpi

Mecklenburg Vorpommern
Ministry of Energy, Infrastructure and State Development

Liikennevirasto
Finnish Transport Agency

Swedish Agency for Marine and Water Management

NHTV Breda University of Applied Sciences

SYKE

Vides aizsardzības un reģionālās attīstības ministrija

Aalborg University

Maritime Institute in Gdańsk

VASAB
VISION & STRATEGIES AROUND THE BALTIC SEA

Urząd Morski w Gdyni

Tartu Ülikool
Universitas Tartuensis 1632