Baltic LINes

Coherent Linear Infrastructures in Baltic Maritime Spatial Plans

2030 and 2050 Baltic Sea Energy Scenarios

22 March 2019

Interreg Baltic Sea Region

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2030 and 2050 Baltic Sea Energy Scenarios

22 March 2019

Swedish Agency for Marine and Water Management

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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 describes energy scenarios for 2030 and 2050, covering offshore wind power and grid infrastructure in the Baltic Sea (including Skagerrak and Kattegat). These scenarios are described as central, low and high, as this method provides the MSP process in the Baltic the possibility to consider a range of possible developments.

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.

Offshore wind power is on the rise and so are efforts to create one integrated European energy market. Wind energy (both onshore and offshore markets) already meets 11.6% (336 TWh) 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 and wind power alone accounted for 55% of the installed capacity.

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. The offshore wind development in

the Baltic has had a slower development than the North Sea, starting out earlier, but increasing slower. Development in the BSR is ongoing at different pace in different locations and countries. There are several projects consented. So far, all development is with bottom fixed designs. 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. Technology development is however ongoing and it is expected that floating wind power will be commercialized by 2030.

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 as well as operational costs due to new vessel types used and learnings between projects. All of this contributes to decrease the cost of energy improving the competitiveness of offshore wind power to traditional energy sources.

So far there are only HVAC-based offshore wind power transmissions in the Baltic Sea, even in the German waters, due to the limited distance to the connection points. 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. In 2018, the European Network of Transmission System Operators for Electricity (ENTSO-E) agreed and delivered the newest Ten-Year Network Development Plan (TYNDP). It includes several investments that focus on the construction of new offshore transmission networks in the Baltic Sea.

Based on the analysis presented in the report, it can be concluded that most of the countries in the BSR will meet the near-time targets (2020) set for renewable energy in the energy mix, greenhouse emissions and interconnectivity. The targets for 2030 are not as clear for all countries, but the trajectories for the targets set are reached by most countries. The ever-increasing ambition of EU along with decreasing cost of electricity for renewable energy sources, including offshore wind power, push countries in the BSR, Europe and globally to strive towards a fossil free, renewable energy supply. Thus, a build out of offshore wind assets and interconnections is foreseen in the Baltic Sea.

As mentioned above three levels of scenarios are developed for 2030 and 2050. The central scenario is the most likely scenario from analysing available data and information. The low scenario represents a stagnation or recession in economic development and/or geopolitical instability, shifting priorities away from sustainability and renewable energy thus decreasing the ambitions. The high scenario is a progressive and challenging scenario to highlight what it would take to reach the 2-degree target as stated in the goal of the Paris Agreement.

2030 scenarios are based on Baltic Integrid and WindEurope scenarios for offshore wind power development and the ENTSO-E ten-year plan of 2018 for grid expansion. Offshore wind is a maturing industry in the south-west corner of the BSR. Locations for wind farms in countries such as Poland and Estonia have become available for offshore wind farm developers. The Baltic States, Poland and Russia have invested in their first parks.

The capacities of the low, central and high 2030 scenarios are 7.4, 9.1 and 14 GW respectively. All covering less than 1 % of the Baltic Sea. Interconnectivity is enforced between Sweden-Finland, Poland-Lithuania and Denmark internally Sjaelland-Jylland in the low scenario. An additional combined interconnector and offshore wind transmission between Germany-Sweden is added in the central scenario.

2050 scenarios are based on 2030 predicted levels, Baltic Integrid and Stanford WWS scenarios as well as the logic behind the ECOFYS scenario. To reach the 2050 High scenario, a growth rate of installed new capacity per year of around 16 % is required, which is less than the growth rate of around 25 % so far reached in the Baltic between 1991 and 2017. The growth rate in the North Sea since 2010 has been around 30% as well. Due to the stronger demand in countries like Germany and Poland with at the same time relatively limited economic zones, a higher degree of collaboration is required to reach the 2050 goals and an increased exchange of energy – referred to as green-streaming – is needed. This is achieved by interconnecting power links in-between Sweden, Denmark and the Baltic states towards Poland and Germany. After 2030 wind farms will start to reach their end of life. It is assumed that they are repowered to the same capacity, probably with fewer larger turbines. Also, floating wind opens up the range of water depth available for deployment from 2030 to 2050.

The capacities of the low, central and high 2050 scenarios are 31, 58 and 150 GW respectively, covering 1.5 %, 2.9 % and 7.4 % of the Baltic Sea. Interconnectors will be combined with offshore wind power connections to a large extent.

The 2030 scenarios are largely derived from information about projects already in development and other data that are known or can be predicted with relatively high certainty. Thus, the uncertainties are relatively small which is manifested in the relatively small spread between the central, low and high scenarios. For the 2050 scenario the spread is larger. The reason is larger uncertainties looking much further into the future.

In the 2030 scenarios the amount of offshore wind power in the Baltic is moderate, and the challenges for MSP are limited. They are more focused on local conflicts of interest than global planning of use of the Baltic sea. There is some concentration of projects in the south areas between Denmark, Germany and Sweden where the planning will be more complex and challenging.

In 2050 the exploited sea area is significantly higher, still with concentration in the southern parts. The German capacity quota corresponds to 37 % of the German Baltic sea area and for Poland the number exceeds 20 %. This implies that generating capacity of one country may be placed in the national waters of another. Considering also the increase in interconnectivity and combination of interconnectors with wind farm export cabling the need for coordinated MSP in the BSR, especially in the south, will be considerably higher than in 2030. Dealing with authorities of multiple countries will be more of common practice than an exception.

The 2050 high scenario is optimistic for the year 2050. But is it still optimistic for 2060, 2070 or 2080? The drive for clean renewable energy will likely persist. Rather than talking about low, central and high scenarios, one can reason that something similar to the 2050 high scenario will be the reality at some point in time. It is a good idea to prepare for it to pave the way for the transition to clean and renewable energy.

Table of Contents

1 Introduction

Efficient and sustainable use of the Baltic Sea requires cross border coordination of marine transportation, offshore energy exploitation, coastal tourism, fishing, marine environment preservation and any other activity 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. Framework conditions for use of maritime space are developed, increasing investors' security and laying the foundation for Blue Growth activities (e.g. maritime transportation, offshore energy exploitation, coastal tourism, fishing etc.).

1.1 Background to the study

The Swedish Agency for Marine and Water Management (SwAM) is partner in Baltic LINes, an Interreg project for the Baltic Sea region. Baltic LINes aims to establish more coherent national Maritime Spatial Plans (MSP) in the Baltic Sea Region and thereby to 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. The 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.

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. SwAM (Swedish Agency for Marine and Water Management) has contracted RISE, Research Institutes of Sweden, to provide energy scenarios to the project.

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 in the Baltic Sea including Skagerrak and Kattegat. Projections for the years 2030 and 2050 are provided. Three levels of scenarios are developed, low central and high. The central scenario describes a most probable development based on historical development and current ambitions set forth in policies and plans. The low and high scenarios describe deviations from the most likely. The low scenario represents a decrease in ambition while the high scenario shows what it would take to limit global warming to 2 degrees. The result of this work is intended as input to the MSP Challenge computer simulation and workshops.

The work is based on various sources of information. Energy policy frameworks within EU and the countries in the BSR, permitting, planning and development data for offshore wind farms and grid infrastructure at sea in operation or any state of planning/development, energy outlooks and other publicly available publications regarding trends in the offshore wind industry are the main sources of information. From these sources the current status of offshore wind and offshore power grids are presented and future scenarios derived. Marine spatial planning effects that promote or hinder the development of offshore wind power and offshore power grids are identified and evaluated and 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.

This report focuses on offshore wind as the only source of energy. Future trends in marine energy (electricity generation from currents, waves, etc.), and an assessment of whether it 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 in a separate report, see section 1.3 Related Documents.

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 (this report)	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)	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.

1.4 Method Overview

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. Technology readiness levels of the relevant energy converters have been described based on expert knowledge and relevant literature. Some content from the draft Baltic LINes WP 2.1 synthesis report on energy and the NorthSEE Energy report have been adapted in this report.

Based on the energy demand and trajectories needed for each country to reach their targets, scenarios are derived from various authorities, industries and stakeholders. To derive the most relevant scenarios for this report, scenario data and assumptions have been analysed, and prognoses have been established for the different countries as well as the Baltic Sea in total.

The complete outcome of the literature study and all other background information is gathered in "*Offshore Wind and Grid in the Baltic Sea – Status and Outlook until 2050*". Chapters 2 and 3 of this document is a summary to provide a context for understanding and interpreting the scenarios developed in chapter 4.

2 Current Status of Offshore Wind and Grid Infrastructure in the Baltic Sea

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. Further details can be found in the separate report "*Offshore Wind and Grid in the Baltic Sea – Status and Outlook until 2050*" and information on ocean energy can be found in "*2030 and 2050 Baltic Sea Energy Scenarios – Ocean Energy*".

2.1 Offshore Wind Power

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 decarbonization of electricity production.
6. Making use of the technologies developed over decades by the onshore wind industry.

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%.

2.1.1 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 1. The development has been driven by Denmark and Germany with the highest capacities operational and under construction.

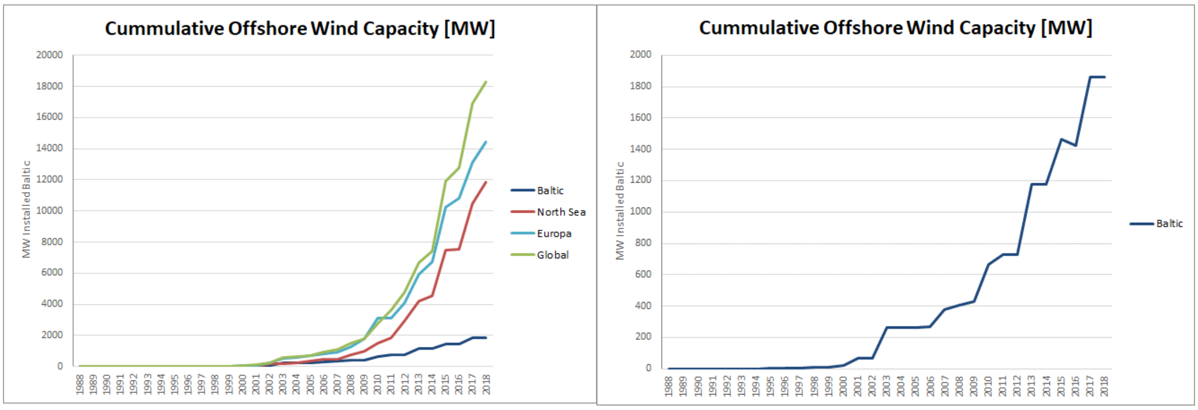


Figure 1: Cumulative installed capacity in the Baltic compared to North Sea, Europe and globally, based on data from 4cOffshore and internal RISE database

The location, status and size of offshore wind projects in the Baltic is shown in Figure 2. 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.

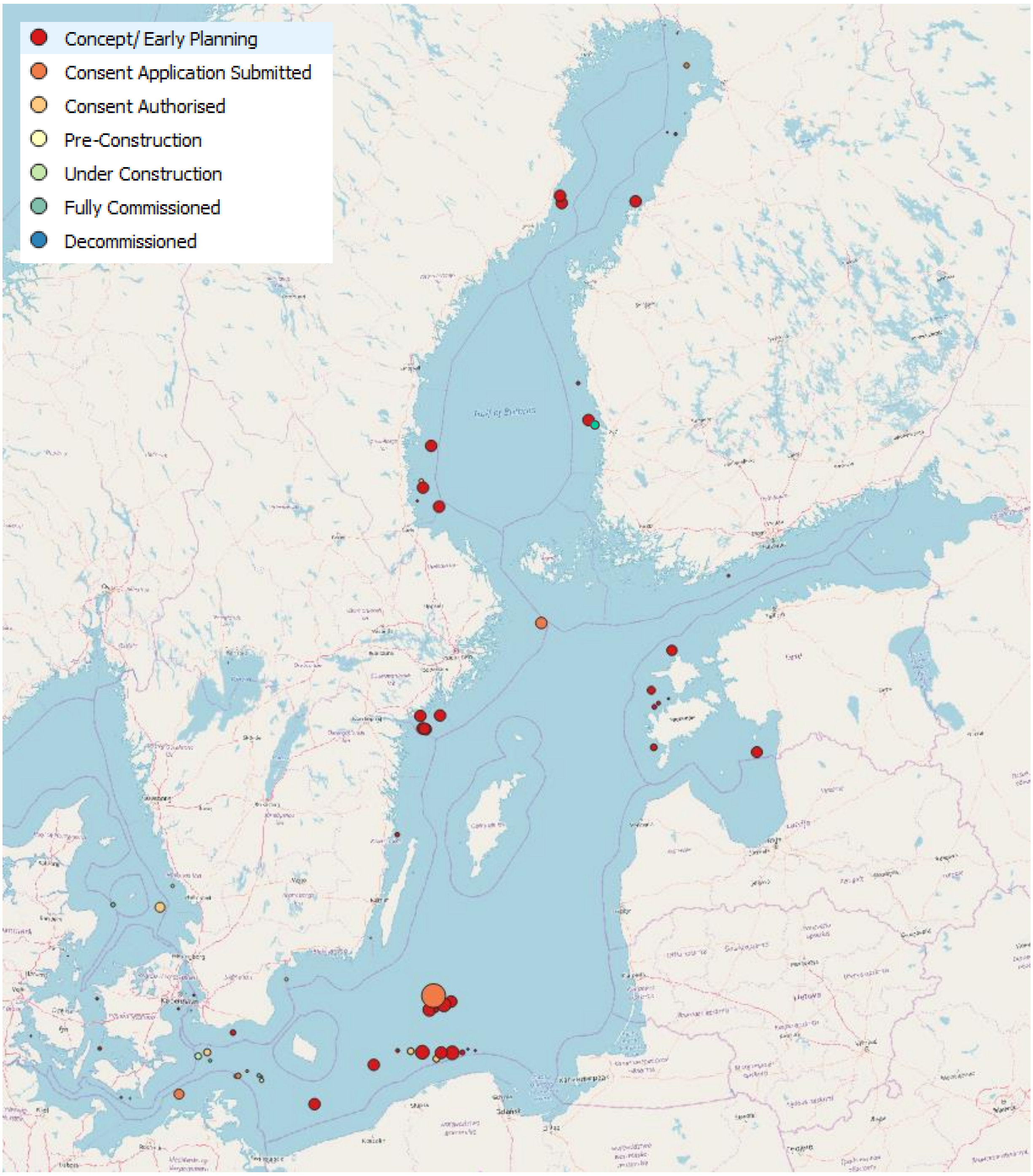


Figure 2: Offshore wind farm development in BSR 2017 based on RISE database. Size of points indicate size of park, colour indicates development status.

2.1.2 Bottom fixed wind – plans

Development in the BSR is ongoing at different pace in different locations and countries. There are several projects consented, as indicated above. 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.

2.1.3 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/).

2.2 Electrical Grid 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.

2.2.1 Transmission assets for offshore wind farms

Each offshore wind farm is connected via transmission assets to shore. For large parks 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 onshore substation, 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.

There are only HVAC-based transmissions in the Baltic Sea, even in the German waters, due to the limited distance to the connection points. In the German North Sea, converter stations have been built, converting AC from several parks to DC and exporting to shore over longer distances. The export cables for AC and DC transmission deviate in the design from each other. In a planning perspective though, the technique used for electrical transmission is not crucial, as HVDC and HVAC is both based on offshore substations and cables to shore.

2.2.2 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 either 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.

In 2018, 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. The TYNDP includes 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.

Existing and planned (until 2030) offshore interconnectors are shown in Figure 3.

Figure 3: Existing and planned offshore cable connections in the Baltic Sea Region.

3 Policies and Trends

This chapter describes the relevant EU and national energy policies along with development and trends in market and technology.

3.1 EU Policies and Targets

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. High-level policies and targets agreed on EU level are broken down to country-specific targets and adapted to national circumstances. 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 creation of plans and implementation of required actions to reach the targets are followed up on a regular basis.

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.

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).

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 2.

Table 2: 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%

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. The 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

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, see Figure 4. Norway and Russia were not considered in this study.

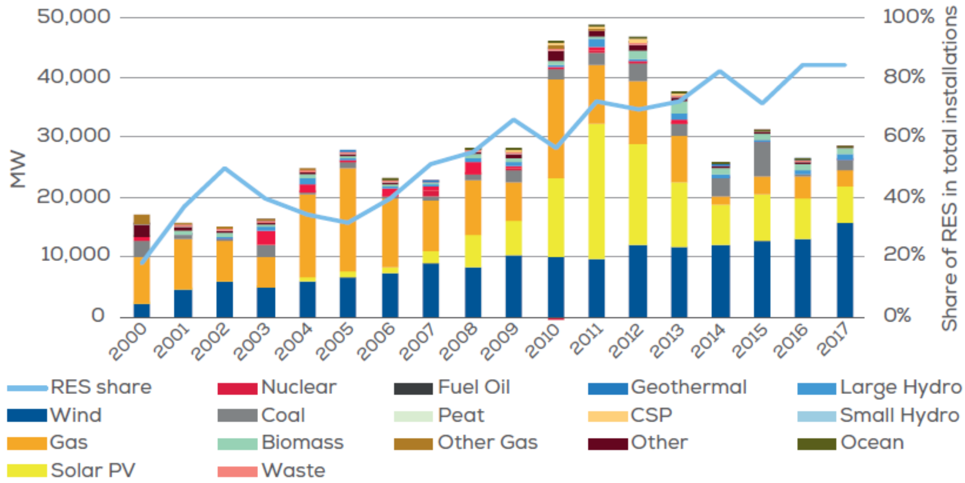


Figure 4: Annual installed capacity and renewable share (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

3.2 National Policies and Targets

3.2.1 Wind Power

The national targets for share of renewable energy 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 3: 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%)			

RENEWABLE ENERGY TARGETS	2016/ 2017 (RES-E)	2020 TOTAL (RES-E)	2030 TOTAL (RES-E)	2050 TOTAL (RES-E)	SOURCE
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%)	

There are no targets specifically for onshore and offshore wind in most of the countries, but there are estimates made by the EU on how the share of wind in total could look like to meet the targets stated above (PREMIS model 2016).

3.2.2 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). In addition an EU expert group recommends (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%.

These additional conditions might significantly impact the interconnection capacity needed for countries where a lot of renewable intermittent energy is introduced.

Table 4: 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%
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 two additional criteria set up above.

3.3 Trends

European offshore wind has seen a strong and steady growth since the early 2000s. Historic annual installations are shown in Figure 5. Turbines and wind farm sizes are ever growing.

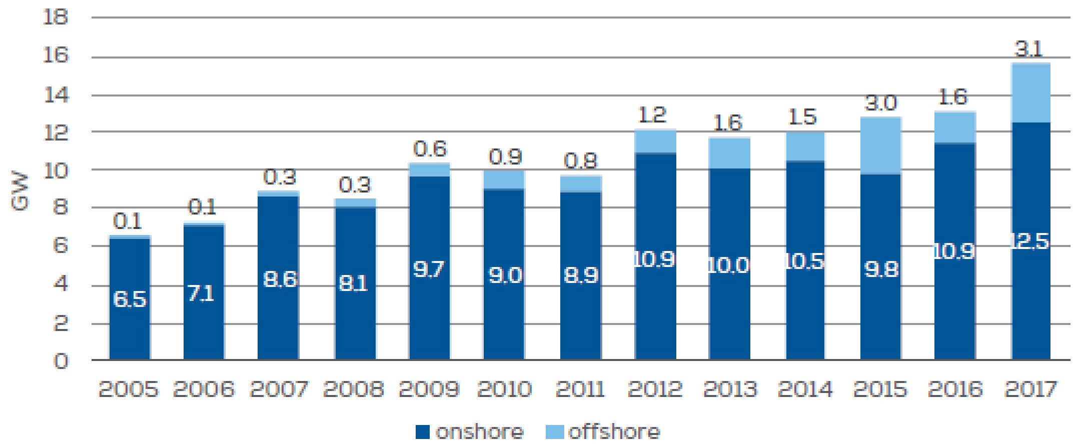


Figure 5: Annual wind installations (both onshore and offshore markets) for the period 2005-2017 in Europe (see left axis). Cumulative wind installations are also shown (light blue line) (Fraile, Mbistrova, Pineda, & Tardieu, 2018)

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 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.

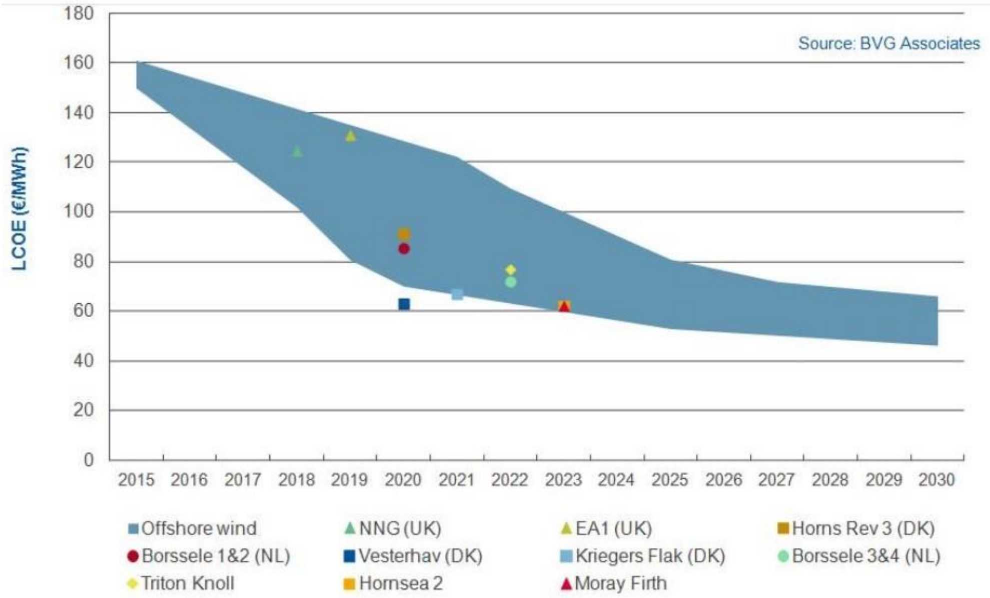


Figure 6: Drop in costs for offshore wind projects based on commissioning date, LCoE (Chamberlain, 2018)

The offshore wind turbines get more reliable and have more up-time producing energy from wind more reliably. With the increased turbine sizes, higher more constant winds at larger altitudes can be approached which together increase the capacity factor (produced energy compared to maximum rating) which has a direct positive impact on LCoE.

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.

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

There is a large number of projects in development. 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)

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. Thus, the cost of electricity generated from offshore wind power will continue to decrease creating more incentives for deployment during the decades to come.

4 Energy Scenarios for 2030 and 2050

This chapter describes the scenarios for 2030 and 2050 with the reasoning and assumptions behind it.

4.1 Method and Assumptions

Experts from RISE have derived scenarios based on the comprehensive data that has been gathered and summarized above. The information has been reviewed and the quality of the content assessed. Supplementary data has been created to fill gaps and necessary assumptions have been made to complete the scenario definitions as presented below.

4.1.1 Scenario Rationale:

Based on the historic development of offshore wind in Northern Europe, plans, policies and future trends on EU and national level in the Baltic Sea region scenarios have been derived for 2030 and 2050. Three levels, of scenarios, central, low and high, have been developed. The central scenario is a best guess of the future, while the low scenario represents a decrease and in ambition and the high scenario an increase. The rationale behind each is described just below. Detailed descriptions, assumptions and calculations are described in subsequent chapters.

Central Scenario

All considered, this is the most likely scenario from analysing available data and information. 2020 EU and national targets will be met. The ambition in goals, plans and commitment on EU and national level continue to evolve, with continuously increasing ambition, through 2030 and 2050 in a way that has been seen over the last decades. Some countries (e.g. Denmark, Germany, Finland and Sweden) are going above and beyond, aiming to become fossil free, others are falling behind and declaring a need for a disruptive change.

Cost reductions have been observed leading up to 2018 and will continue through 2030 and 2050 enabling quicker development of offshore wind. In some countries (e.g. Germany and Denmark) lack of suitable space on land drive further wind development into the sea. In other countries (e.g. Poland) there is large drive for offshore wind from investors. Development in the North Sea is limited by national plans driving developers to seek opportunities elsewhere, in the BSR among other places.

The scenario is based on each country fulfilling their ambition and commitment on renewable energy penetration. However, there is a possibility that the offshore wind development in the BSR is further accelerated to help supply central Europe with clean energy, in which case the build-out will be higher than suggested in the central scenario.

Power grids will be extended to allow higher penetration of intermittent power plants, limit congestion and favour electricity trade. The established plan (ENTSO-E, 2018) until 2030 will be fulfilled thus connecting Sweden bidding area 2 to Finland and increasing capacity in the south of the BSR between Denmark, Germany, Poland and Sweden. Afterwards expansion will continue to meet identified challenges up to 2040. In the near future interconnectors will not be combined with wind farm grid connections. After 2040 a change is anticipated, due to experience from Kriegers Flak and increased transmission demand from clusters of wind farms mainly in the south part of the Baltic. The multilateral grid extensions in the BSR highly depend on EU policy and drive to create one electricity market within EU. In the central scenario it is anticipated that EU will successfully work for grid integration and that effects will be seen in accelerated deployment beyond 2030. However, the extent of grid development and increase in cross border transmission capacities are sensitive to just how efficient the establishment of EU policies and national adaptation of those policies are.

Low Scenario

Stagnation or recession in economic development and/or geopolitical instability could shift priorities away from sustainability and renewable energy. The spirit of trust and free trade is replaced by protectionism. Focus will be more on low cost and securing energy supply and less on environmental concerns compared to the central scenario. Multilateral organizations like EU lose some of their authority resulting in EU and member states failing to commit to or loose ambition with targets beyond 2020. Lack of commitment and unfavourable policies for planning and permitting will slow down deployment of renewable energy compared to the central scenario. Power grids will not be reinforced and extended enough to solve congestion issues.

There will be less incentives for renewable energy than in the central scenario. Subsidies on fossil fuels will not be reduced or removed as quickly as in the central scenario. Therefore, the will to invest in offshore wind will be lower and cost reductions will be not be achieved to the same extent as in the higher scenarios. Electrification of the transport sector, one driver for installation of renewable capacity, will fall behind.

High Scenario

The high scenario is a progressive and challenging scenario to highlight what it would take to reach the 2-degree target as stated in the goal of the Paris Agreement. Compared to the central scenario the bar needs to be raised, the ambitions need to be higher. This scenario assumes that the countries in the BSR will have to embark on a journey that take them to a purely fossil-free, renewable energy mix by 2050 as suggested in the Stanford Study (Jacobson, et al., September 6, 2017). It will require strong efforts to put extensive renewable energy production into operation.

The transition to fossil free and renewable is technologically and economically feasible. Nearly all power generating technologies (solar, wind, hydro and geothermal) needed are commercially available already today. Similarly, electrical options to almost all fossil-fuelled vehicles and equipment already exist. Induction cooking stoves, electric systems for residential heating, electric ground transportation for goods and passengers, etc. are all commercial on a large scale. Fossil free aircraft though is still in development. The challenge is rather a social and political one where authorities, institutions and individuals need to come together to challenge our current habits and make it happen.

4.1.2 Referenced Offshore Wind Scenarios

The offshore wind scenarios for the BSR presented in this work refers to a number of previously published scenarios. This paragraph contains a list of referenced scenarios in the scenario definition simply for the purpose of improving readability of the scenario detailed descriptions.

Table 5. List of referenced offshore wind power scenarios.

Study	Description	Scenarios
ECOFYS (Müller, Haesen, Ramaekers, & Verkaik, 2017)	Scenario for 2045 estimating the capacity of offshore wind power for FR, BE, NL, UK, IE, LU, DE, DK, SE and NO in the North Seas required to meet the Paris agreement. It assumes that the total energy demand is reduced by half from 2010 to 2045 and that fossil energy is completely phased out. Nuclear will remain part of the energy mix thus being CO2 free but not 100 % renewable.	• ECOFYSBaltic2045 (see description below)
Baltic InteGrid	The Baltic InteGrid project promotes a meshed electric grid, with high levels of interconnectivity, for the BSR. To support the planning of such a grid and provide a range of foreseen development needs a low and high scenario for 2030 have been developed for the offshore wind power and grid expansion in the Baltic sea. The low scenario can be considered pessimistic and the high scenario optimistic. The 2030 high scenario is further extrapolated to an upside (optimistic) scenario for 2050.	• BIG2030 low • BIG2030 high • Big2030 average (derived by RISE, average of Baltic InteGrid 2030 low and high) • BIG2050 upside

Study	Description	Scenarios
WindEurope (Nghiem, Pineda, & Tardieu, September 2017)	The "Wind energy in Europe: Scenarios for 2030" report defines scenarios for on- and offshore wind based on different level of fulfilment of the 2030 renewable energy targets set by EU. It presents three scenarios, low, central and high that can be described as pessimistic, probable and optimistic. Latvia, Lithuania and Russia are not mentioned in the offshore figures.	• WindEurope2030 low • WindEurope2030 central • WindEurope2030 high
WindEurope (Hundleby, o.a., June 2017)	The "Unleashing Europe's offshore wind potential" report defines scenarios based on the most economically attractive locations in the North Sea, the Baltic Sea and the Atlantic and suggests policies to support the development. Two scenarios are presented, baseline and upside that can be described as probable and optimistic. Russia is not covered.	• WindEuropeOS2030 baseline • WindEuropeOS2030 upside
Stanford (Jacobson, et al., September 6, 2017)	Stanford university has published an all energy roadmap for 139 countries to achieve a 100 % clean and renewable energy mix based on wind, water and sunlight (WWS) by 2050. It is an optimistic scenario aiming to fulfil the Paris agreement and limit global warming to 1.5 °C. There is also a business as usual (BAU) scenario for reference.	• StanfordWWS2050

The ECOFYS report only covers Denmark, Germany and Sweden of the BSR. The reasoning in the report follows a bit of a different logic than other scenarios, which makes sense to take into consideration. To method described in (Müller, Haesen, Ramaekers, & Verkaik, 2017) has been adopted to all countries in the BSR using the WindEurope 2030 wind power scenarios from 2017 (Nghiem, Pineda, & Tardieu, September 2017) instead of those of 2015 as referenced in the ECOFYS report. The assumed energy demand is low compared to other scenarios but the transition to a carbon free energy mix is somewhat optimistic. For countries with a large share of carbon free electricity generation capacity already today (e.g. Denmark, Finland and Sweden) little or no need for offshore wind power is anticipated, while for countries heavily reliant on fossil fuels (e.g. Germany and Poland) high installed capacity is anticipated. This interpretation of the ECOFYS method for the BSR countries is what is referenced as "ECOFYSBaltic2045". Also, for Denmark, Germany and Sweden the values are recalculated and the actual values from the ECOFYS report are not used. The values are not the same but comparable.

4.1.3 Referenced Grid Scenarios

When it comes to the planned development of energy transmission links, the European network transmission System Operator organisation for Electricity (ENTSO-E) has established a ten-year network development plan (TYNDP) and investigates future scenarios in a high scale perspective which is used as the basis for the study. The current plan, TYNDP 2018 (ENTSO-E, 2018), covers projects until 2027 with scenario outlooks reaching until 2040. The TYNDP states the following main needs for 2040:

- *"Stronger integration Germany-Poland, to increase market-integration and to facilitate thermal decommissioning in Poland,*
- *Further integration Sweden-Finland to increase market-integration,*
- *Further integration Norway-Denmark, due to price-differences and to improve Danish security of supply in high demand and low variable RES (wind and solar) periods,*
- *Further integration between Sweden/Denmark and Germany, due to price-differences and to enable better optimization of the RES-generation (hydro/wind),*
- *Further internal integration in the Baltics, mainly due to Security of Supply.*

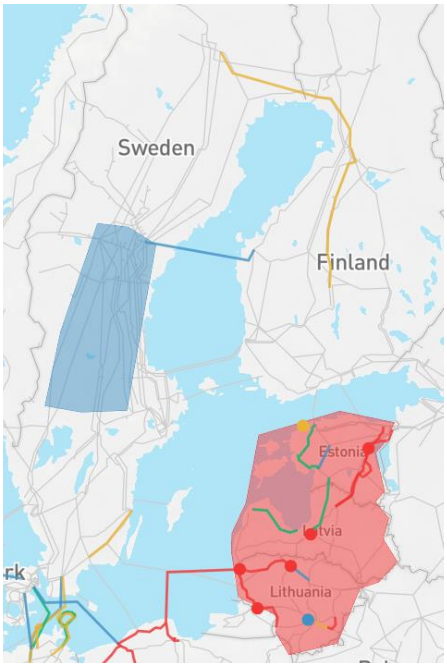
In addition to these main increases, the high wind scenario (Global Climate Action) introduces huge wind growth in the north of Norway (onshore). This scenario will lead to an increased capacity-need in the north-south direction, through Finland, Sweden and Norway." This leads to the potential of green streaming in the Baltic.

A list and map of projects currently under consideration (cost-benefit analysis) is provided below. Looking at the time horizon, these interconnectors will probably be the ones that will be commissioned in the earlier part of the time between 2030 and 2050. It is assumed that there are more projects upcoming later in the time span that are not listed or planned for yet. These have been instead derived based on the congestions and connected (based on the expected wind farms) by the suggested combined grid connections (offshore wind connections & interconnectors).

In addition to the projects under consideration within the Baltic, there are a lot of projects connecting the Baltic Sea-region to neighbouring regions. ENTSO-E states that: "*[…] among the most important projects reported elsewhere are interconnectors from Norway to Germany and Great Britain, interconnectors from western Denmark to the Netherlands, Germany and Great Britain, as well as internal German interconnectors in the North-South-direction of Germany."* (ENTSO-E, 2018)

Table 6: List and map of projects being assessed in TYNDP 2018. The table show projects of the responsibility of the Baltic Sea Region. The map show projects in different stages, green = under construction, orange = in permitting, red = planned not permitted, blue = under consideration. (ENTSO-E, 2018)

PROJ. ID	PROJECT NAME	COUNTRY 1	COUNTRY 2
96	Keminmaa-Pyhänselkä	FI	
111	3rd AC Finland-Sweden north	FI	SE
123	LitPol Link Stage 2	LT	PL
124	NordBalt Phase 2	LT	SE
126	SE North-south Reinforcements	SE	
170	Baltics synchro with CE	LT, LA, EE	PL
175	Great Belt II	DK	
176	Hansa Powerbridge I	SE	DE
179	DKE-DE (Kontek2)	DK	DE
197	N-S Finland P1 Stage 2	FI	
234	DKE-PL-1	DK	PL
239	Fenno-Skan 1 Renewal	SE	FI
267	Hansa Powerbridge II	SE	DE



ENTSO-E has in the TYNDP 2018 considered required interconnection capabilities in-between countries, based on different scenarios. The outlook is for 2040 and does not strictly imply marine interconnections. (ENTSO-E, 2018). The main bottlenecks identified in the region are:

- from Germany to Austria, Czech Republic, Sweden and Poland
- from Sweden to Finland
- from Denmark, Netherlands and Germany to Norway.

Even IRENA (International Renewable Energy Agency) has modelled the interconnector congestion in the EU-28 countries in 2030 (IRENA, February 2018). Some of the most significant congestions are expected in the Baltic by then, as shown below.

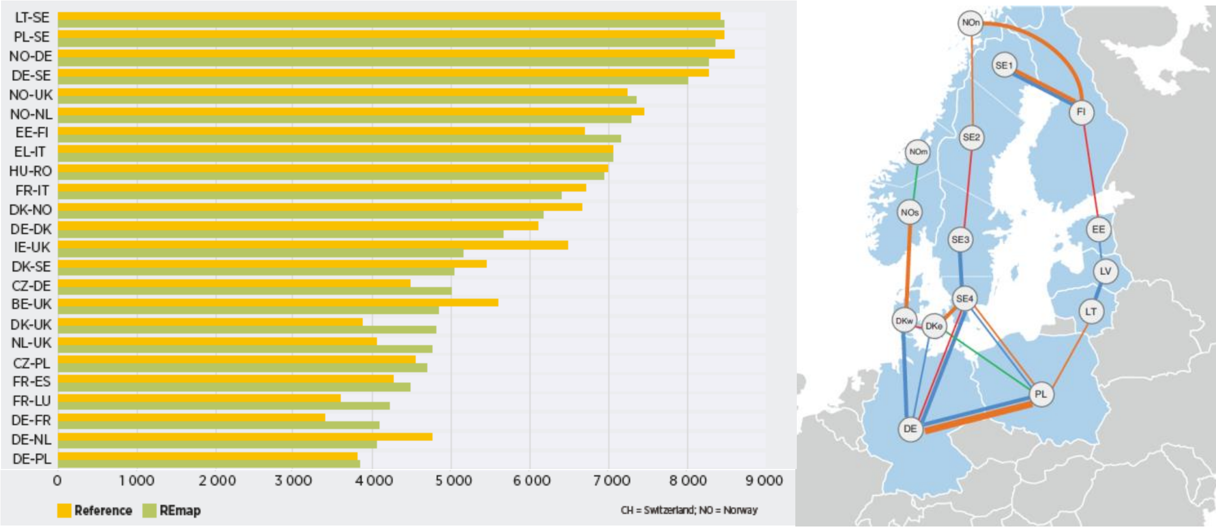


Figure 7: LEFT: Expected future congestions for electricity transmission [MW] (IRENA, February 2018) and RIGHT: Identified capacity increase needs from 2020 to Scenario Grid "Global ClimateAction 2040" (ENTSO-E, 2017)

The considered projects described by ENTSO-E and the congestions derived by IRENA are the basis for the 2030 and 2050 scenarios of this report when it comes to combined coherent electrical infrastructure in the Baltic. The derived transmission links connect Germany with Sweden and Denmark, Denmark towards Poland as well as strengthening the connections between Finland and the Baltic States and Sweden.

4.1.4 Marine Territory Considerations

For countries with their entire EEZ in the Baltic Sea including Skagerrak and Kattegat it is naturally assumed that all offshore wind installations will go in the Baltic and are included in the scenarios. Denmark, Germany and Russia have part of their EEZ in other seas. For these countries it is assumed that the predicted offshore wind installations will be evenly distributed over their EEZ. Hence the part of offshore wind installations located in the Baltic Sea will be in proportion to the ratio of EEZ in the Baltic to total EEZ. For Germany 26 % of offshore wind installations are assumed to be located in the Baltic. The equivalent for Denmark is 40 % and for Russia 5 %.

In general, the windfarm areas are located in the EEZ of each country to reach the quotas. In the 2050 central and high scenarios the exploitation of Polish and German waters is high and therefore some of the capacity is located elsewhere in the Baltic sea.

The capacity density varies quite a lot between wind farms installed in Europe until today (Borrman, Rehfeldt, Wallasch, & Lûers, 2018). The variation is due to nameplate rating, spacing, local regulations, economic incentives etc. Of three studies referenced in (Borrman, Rehfeldt, Wallasch, & Lûers, 2018), r focussing on assessment of offshore wind energy potential in European waters one suggest a capacity density of 5 MW/km^2 and two 5.4 MW/km^2, based on current and assumed future turbine sizes and power ratings. Based on the above mentioned study by (Borrman, Rehfeldt, Wallasch, & Lûers, 2018) the average among wind farms installed so far in the Baltic Sea is 5.5 MW/km^2 (corrected density) and there is no trend observed with the installed wind farms. Thus, there is good agreement between theoretical predicted values and current installations. Based on this, a homogeneous capacity density of 5.4 MW installed capacity per km^2 sea surface area is assumed for the purpose of this report.

However, there are higher densities used in other special cases i.e. when area constraints are a central factor in the offshore development plans. For example, the draft site development plan (FEP), a sectoral plan for the orderly expansion of offshore wind turbines and their grid connections in the German EEZ, addresses the question of capacity densities. Based on a detailed analysis the FEP and the limited access to new areas for energy production determines a corrected capacity density between 9 and 10 MW per km^2 for future offshore wind farms in the German EEZ (Bundesamt für seeschifffahrt und hydrographie, 2018).

4.1.5 Assumption Summary

The assumptions described above are summarized in the table below to provide a quick overview.

Table 7. Summary of scenario assumptions.

Scenario:	**Assumptions:**
Central	• Continued increase in EU and national renewable energy commitments. • Continued cost reductions. • Lack of space for onshore wind power build-out drive activity offshore. • No green-streaming beyond the BSR region. • ENTSO-E ten-year grid development plan of 2018 to be fulfilled. • Identified grid-related challenges (ENTSO-E and IRENA) up to 2050 will be solved. • EU will push for integrated European power grid. • Combination of interconnectors and wind farm connections after 2040.
Low	• Decrease/stagnation in EU and national renewable energy commitments. • Cost reductions will not be materialised. • Identified grid related challenges will not be solved. • Subsidies on fossil fuels will persist. • Electrification of the transport sector will fall behind.
High	• Accelerated increase in EU and national renewable energy commitments. • On path to 100 % renewable energy supply by 2050.
All	• The part of offshore wind installations located in the Baltic Sea assumed to be in proportion to the share of EEZ in the Baltic (for Denmark, Germany and Russia). • Scenario quotas primarily fulfilled on national EEZs. • Capacity density used for calculations is 5.4 MW/km^2.

4.1.6 Scenario Maps

The scenario maps differ slightly from the calculated offshore wind capacity for each scenario. It is partly explained by the imperfect match between scenario quotas and project pipeline. Another part of the explanation is that part of the German and Polish quotas are developed outside of their territorial waters and EEZs, as described above. The total geographical allocation for each scenario is within 5 % of the predicted quotas, even though deviation may be higher for individual countries. Considering the uncertainties related to the actual build-out of offshore wind power, capacity density, etc. the impact of the small deviations between national scenario quotas and scenario maps on marine spatial planning is negligible.

4.2 2030 Scenarios

By 2030 offshore wind is a maturing industry in the south-west corner of the BSR. Locations for wind farms in countries such as Poland and Estonia have become available for offshore wind farm developers. The Baltic States, Poland and Russia have invested in their first parks. The scenarios for 2030 is shown in the figure below. Projects to be built until 2025 are already in different phases of planning and therefore known. Considering the time required for permitting and construction 2030 is not that far away. There will be limited time for any change in ambition to have impact, why the scenarios, low, central and high, do not differ that much. Few wind farms will have reached their end of life by 2030 why repowering of offshore wind is yet to become a mature business. It is anyway assumed that all currently installed capacity decommissioned until 2030 will be repowered, most likely with fewer and larger turbines, to the same power rating on wind farm level.

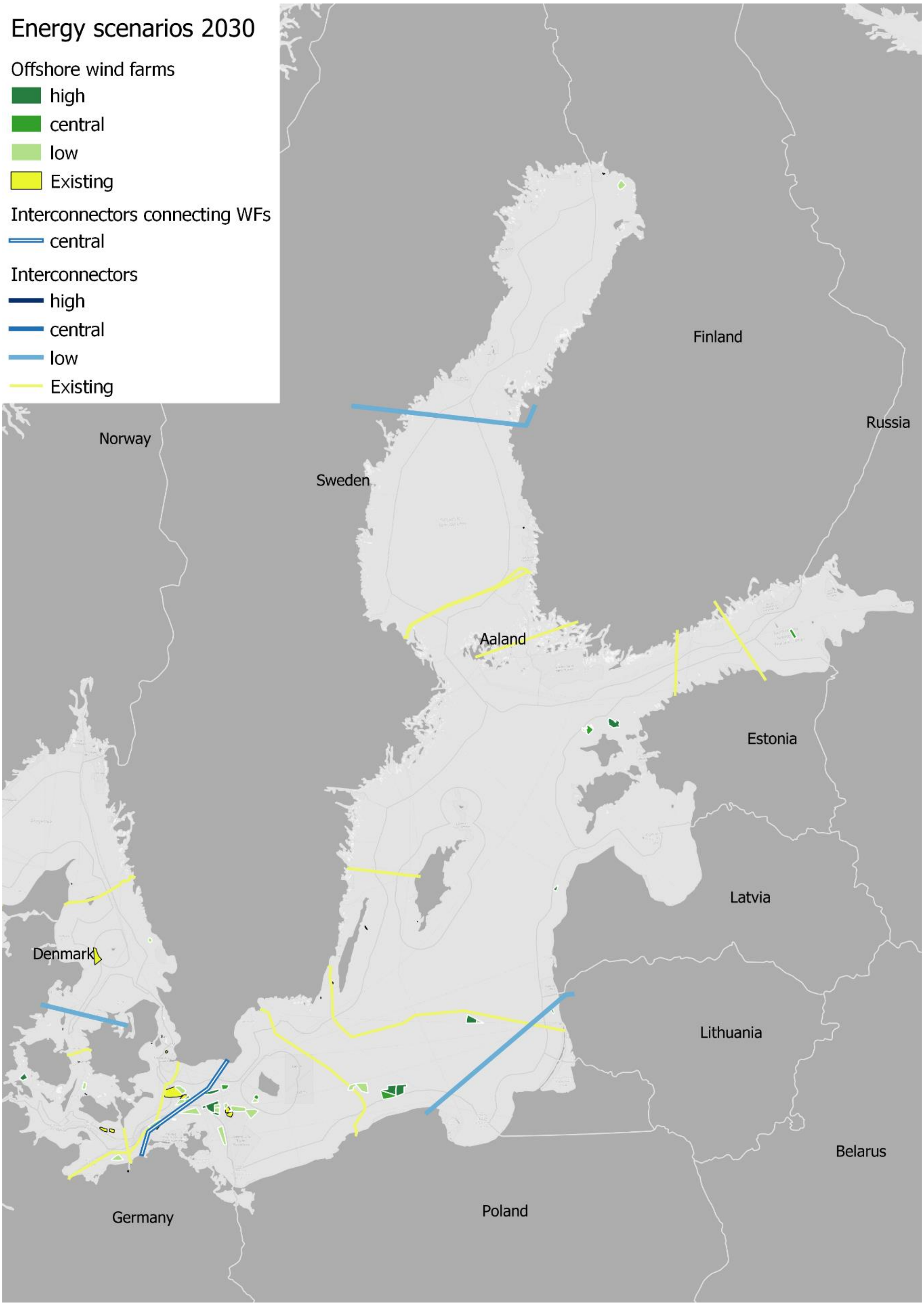


Figure 8. 2030 energy scenarios for the Baltic Sea. High, central and low scenarios for 2030 as well as currently operational installations of offshore wind power and interconnectors.

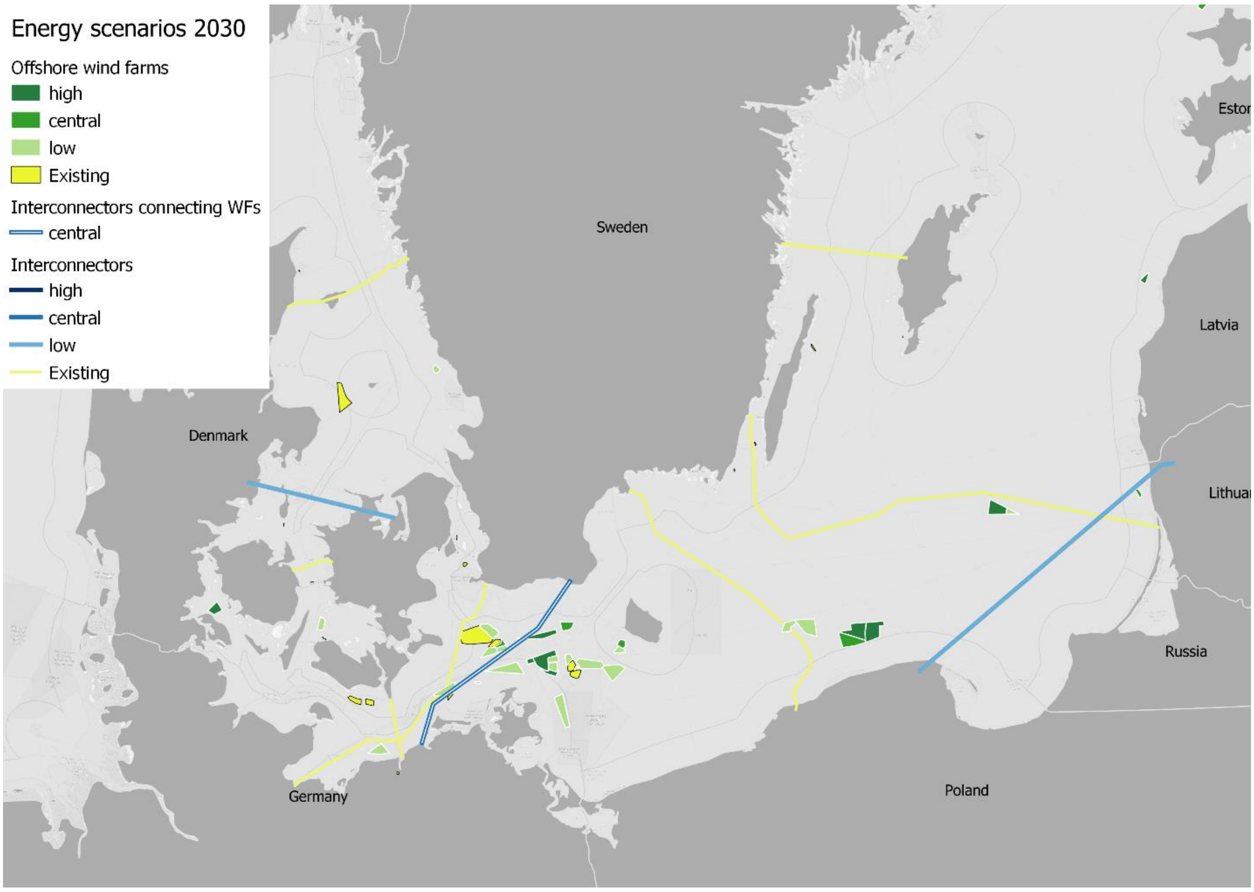


Figure 9. 2030 energy scenarios for the Baltic Sea, zoom in on southern part. High, central and low scenarios for 2030 as well as currently operational installations of offshore wind power and interconnectors.

4.2.1 Scenario Definitions for Offshore Wind

The offshore wind power central scenario for 2030 is defined as the average of BIG2030 average, WindEurope2030 central and WindEuropeOS2030 baseline scenarios. The scenarios all come from credible sources, two of them from the same organization. Even so, there is quite a large spread why it was decided to use the average value of the three. For Russia it is assumed that the two known planned projects (A. Lappo) in the Baltic will be built. The scenario is well aligned with development plans for Germany (Bundesamt für seeschifffahrt und hydrographie, 2018) and Denmark (Danish energy agency, 2018).

The offshore wind power high scenario for 2030 is defined as the average of BIG2030 high, WindEurope2030 high and WindEuropeOS2030 upside scenarios. The scenarios all come from credible sources, two of them from the same organization. Even so, there is quite a large spread why it was decided to use the average value of the three. The referenced scenarios do not cover Russia. It is assumed that the development in Russian waters follow the same trend as for the Baltic states (Estonia, Latvia and Lithuania), hence the 2030 high scenario is taken as 2.4 times the 2030 central scenario.

The offshore wind power low scenario for 2030 is defined as the average of BIG2030 low and WindEurope2030 low scenarios. Both scenarios come from credible sources. Even so, there is quite a large spread why it was decided to use the average value of the two. The referenced scenarios do not cover Russia. It is assumed that the development in Russian waters follow the same trend as for the Baltic states (Estonia, Latvia and Lithuania), hence assuming that the low scenario for build-out in the Russian part of the Baltic sea will be half of the capacity in the 2030 central scenario.

4.2.2 Geographic Allocation of Wind Farms and Interconnectors

For the 2030 scenarios, the dedicated and commercially planned areas for offshore energy development in the Baltic Sea region have been used. Based on the newest estimates and prognoses, the most relevant offshore wind parks have been picked to represent the 2030 scenarios. When it comes to the centrally coordinated markets like Denmark and Germany, the parks that will be built up to 2025 are already known. It is assumed that the other parks will be built late in the window 2018-2030. The most important criteria for choosing sites is related to the wind energy resource. It is assumed that water depth is still a cost driving factor as well as distance to shore. Park sizes are moderate, especially in the countries that install their first parks. Even though the highest court of the country disapproved Estonia's plans of suitable OWE areas north the Hiiumaa Island, these have been used for the 2030 scenario map as the most probable locations, as these are minor sites close to shore, typical first sites for countries' first establishments of offshore wind.

When it comes to the needs to interconnect countries and regions, the base line has been to take the projects currently evaluated in the ENTSO-E ten-year plan of 2018. The grid expansion is assumed the same in all 2030 scenarios, except for a combined interconnector and wind farm connection between Germany and Sweden that is assumed to be built in the central and high scenarios, but not in the low.

4.3 2050 Scenarios

To reach the 2050 High scenario, a growth rate of installed new capacity per year of around 16 % is required, which is less than the growth rate of around 25 % so far reached in the Baltic between 1991 and 2017. (compared to ~55% in the North Sea between 2000 and 2017) The growth rate in the North Sea since 2010 has been around 30% as well. Due to the stronger demand in countries like Germany and Poland with at the same time relatively limited economic zones, a higher degree of collaboration is required to reach the 2050 goals and an increased exchange of energy – referred to as green-streaming – is needed. This is achieved by interconnecting power links in-between Sweden, Denmark, the Baltic states towards Poland and Germany.

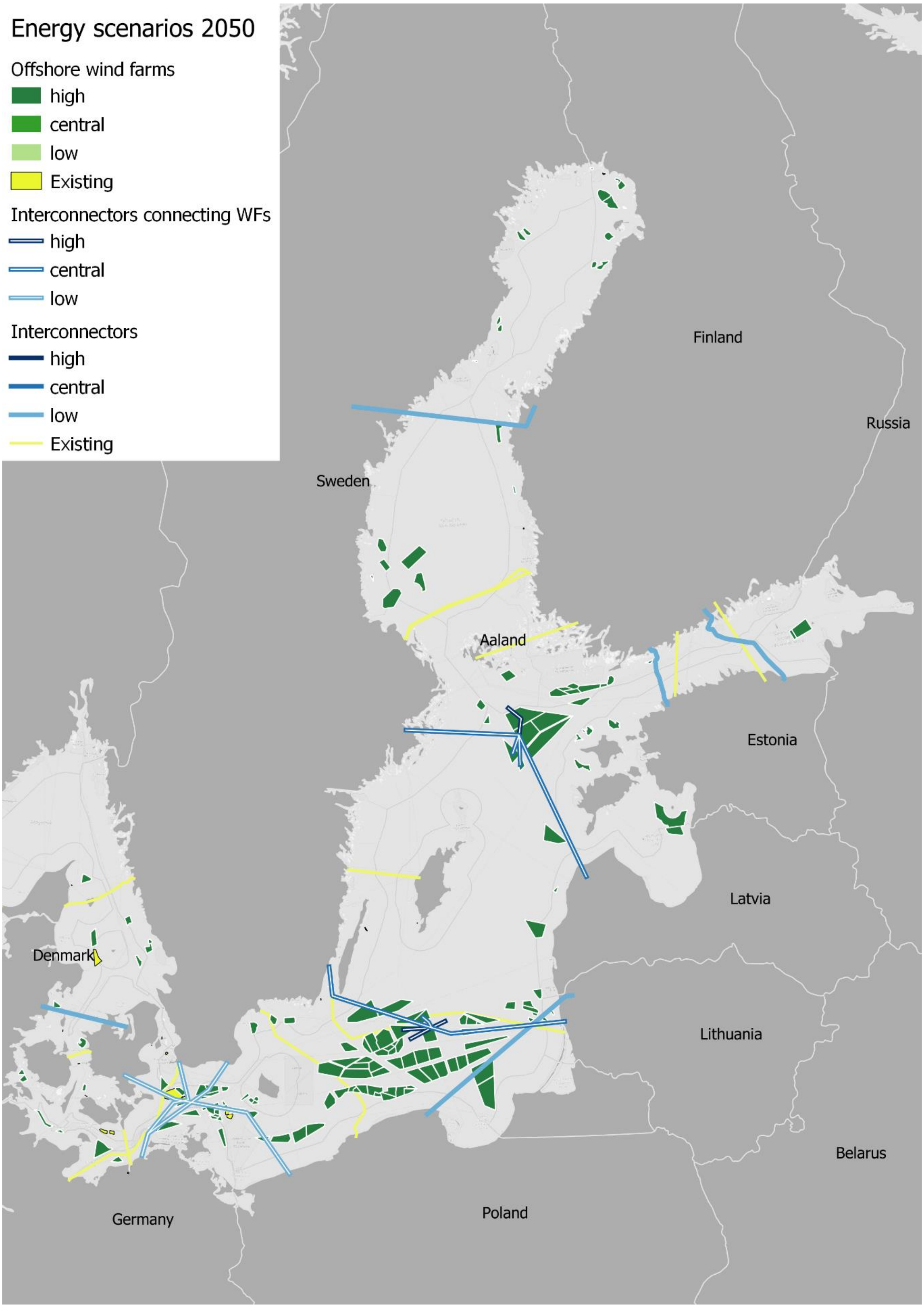


Figure 10. 2050 energy scenarios for the Baltic Sea. High, central and low scenarios for 2050 as well as currently operational installations of offshore wind power and interconnectors.

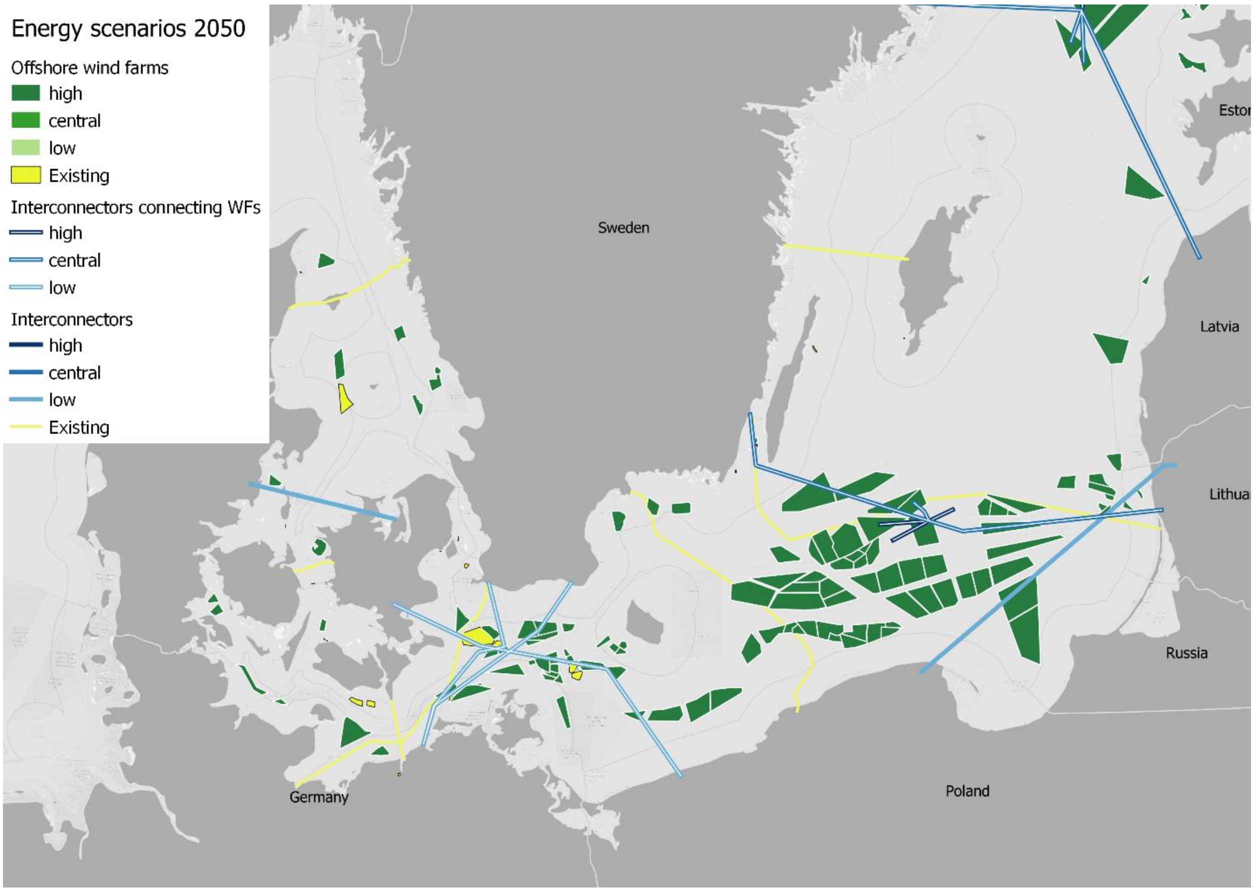


Figure 11. 2050 energy scenarios for the Baltic Sea, zoom in on southern part. High, central and low scenarios for 2050 as well as currently operational installations of offshore wind power and interconnectors.

4.3.1 Scenario Definition

The 2050 central scenario is a weighted average of 20 % 2030 central scenario, and 26.6 % each of ECOFYSBaltic2045, BIG2050 upside and StanfordWWS2050 scenarios. The ECOFYSBaltic2045, BIG2050 upside and StanfordWWS2050 scenarios are derived with different purpose and different rationale and including all of them makes for a balanced prediction. Combined they can be considered optimistic why the 2030 central scenario is also in the mix. It is the starting point in extrapolating from 2030 to 2050 and it keeps the central scenario realistic. Norway and Russia are not covered in the BIG2050 upside and ECOFYSBaltic2045 scenarios. For Norway the 2050 central scenario is defined as the weighted average of 70 % 2030 low and 50 % StanfordWWS2050 scenarios. For Russia the 2050 central scenario is defined as the weighted average of 73.3 % 2030 central scenario and 26.6 % StanfordWWS2050 scenario, a rather pessimistic number compared to the rest of the BSR. However, Russia is not expected to lead the energy transition and in any way contributes with a smaller part of the capacity in the BSR why a moderate underestimate of the Russian quota will have limited impact on the MSP process.

The offshore wind power high scenario for 2050 is defined as the StanfordWWS2050 scenario, which is well aligned with the intent of the high scenario. In today's perspective the scenario can be considered very progressive or even challenging and there is a significant difference between the low and central scenarios on the one side and the high scenario on the other. But the scenario is the only one aiming to fulfil the Paris agreement and limit global warming to 1.5 °C.

The 2050 low scenario is a weighted average of 50 % 2030 low scenario, 20 % each of ECOFYSBaltic2045 and BIG2050 upside scenarios and 10 % StanfordWWS2050 scenario. As the scenario signifies stagnation compared to the central and high scenarios the 2030 point on the trajectory has large impact. Also, the two less optimistic of the 2045/2050 scenarios are given double the impact compared to the most optimistic StanfordWWS2050 scenario. For Norway the 2050 low scenario is defined as the weighted average of 80 % 2030 low and 20 % StanfordWWS2050 scenarios. For Russia the 2050 low scenario is defined as the weighted average of 90 % 2030 low scenario and 10 % StanfordWWS2050 scenario. Just as for the central scenario the assumption for the Russian quota is a bit pessimistic but the impact on MSP by underestimation is limited.

4.3.2 Allocation of Wind Farms and Interconnectors

Based on the information collected for this study the most suitable areas for offshore wind have been derived. Based on the wind resources in the whole region, the most suitable areas for offshore wind in each country have been chosen. Environmentally sensitive areas have been judged as non-suitable as well as the main fairways into ports and the different basins of the Baltic. With support of available information on future development and based on the existing onshore grid, suitable routes for offshore transmission assets have been derived, connecting offshore wind with onshore grid and interconnecting countries whenever feasible. Feasibility implies dissolving congestions in the grid while combining with offshore wind transmission. Within this report it is assumed that the water depth does not affect costs to a high extend anymore and floating wind will be as cost efficient as bottom fixed wind at most places.

Subsea cables are assumed to still be a cost driver based on the size and distance to shore for the wind farms. To make interconnectors and offshore wind connections more cost efficient, these are combined at appropriate locations. It is cost efficient at certain locations to build smaller parks close to shore, but the bigger farms further offshore will be the main sites of future build-out due to better economy of scale, possibly better wind resources as well as assumed less disturbance by visual impact from shore. Wind farms will be constructed especially in the Southern Baltic Sea, where ice coverage is seldomly occurring, and wind conditions are best.

The location of the farms has been based on environmental impact assessments avoiding the MPA (marine protected areas) and UNESCO heritage sites in the region as well as the main shipping lanes. Transmission assets can pass MPAs under certain circumstances (i.e. that avoiding the MPA implies extensive cable lengths). Electricity connection is assumed to be established at existing infrastructure onshore at most places, but certain reinforcements are needed even there. It is assumed that the individual permit processes will have an impact on certain locations and the park layout might have to be adjusted or the size might have to be reduced. As the space requirement for the wind farms have been calculated conservatively, there are some margins to cover up for these reductions.

Offshore wind transmission assets and interconnectors are assumed to be connected to the closest substations or fossil-based power plant onshore based on the current grid layout. This is motivated by the quite significant costs for new substations and cables.

The cluster of wind farms located north of Poland, especially in the central and high scenarios, are combined with an interconnector between Sweden and Lithuania. One might think that it would be natural to also connect Poland to Sweden to facilitate electricity trade further. Considering the amount of offshore wind power capacity that is connected to the central north parts of Poland as well as the interconnection to Lithuania, there is already a high concentration of electric power in the transmission system here. It would be challenging to increase the transmission capacity even further. With the interconnection in the north west of Poland there is already capacity for transmission between Poland and the Sweden/Denmark. In case the decision is made to put an interconnector from Sweden to the central north of Poland, in contrast to the scenarios presented, there are already cable routes deployed covering nearly all the way and the marine spatial planning consequences would be small or negligible.

4.4 Scenarios Summary

The installed offshore wind power capacity and the area occupied by offshore wind farms, per country and total, for all scenarios is presented in the tables and figures below. The currently installed capacity in Europe is 18 GW, mainly in the North Sea (WindEurope, 2019). A little less than half of that will be installed in the Baltic Sea by the 2030 central scenario.

Table 8: Installed offshore wind power capacity, corresponding energy production and required area and share of the Baltic occupied by offshore wind energy production for 2030 and 2050 energy scenarios.

MW*	2017	2030 Low	2030 Central	2030 High	2050 Low	2050 Central	2050 High
Denmark	880	1 620	1 770	2 170	2 370	3 160	5 490
Germany	689	3 240	3 500	4 390	7 970	13 120	29 680
Sweden	206	390	760	1 160	5 000	10 040	26 050
Finland	90	240	450	540	2 920	6 990	23 780
Poland	-	1 460	1 730	3 410	8 130	14 920	35 280
Estonia	-	230	430	900	900	1 530	2 880
Lithuania	-	-	50	100	960	1 960	4 950
Latvia	-	-	-	130	620	1 290	3 470
Baltic EU	**1 858**	**7 180**	**8 690**	**12 800**	**28 870**	**53 010**	**131 580**
Norway	-	-	-	-	250	620	1 240
Russia	-	220	430	1 040	1 880	4 820	16 900
Total	**1 858**	**7 400**	**9 120**	**13 840**	**31 000**	**58 450**	**149 720**
TWh	7.8	30	36	55	120	230	600
Km2	372	1 400	1 700	2 600	5 700	10 800	27 700
% Baltic	0,10%	0.4%	0.4%	0.7%	1.5%	2.9%	7.4%

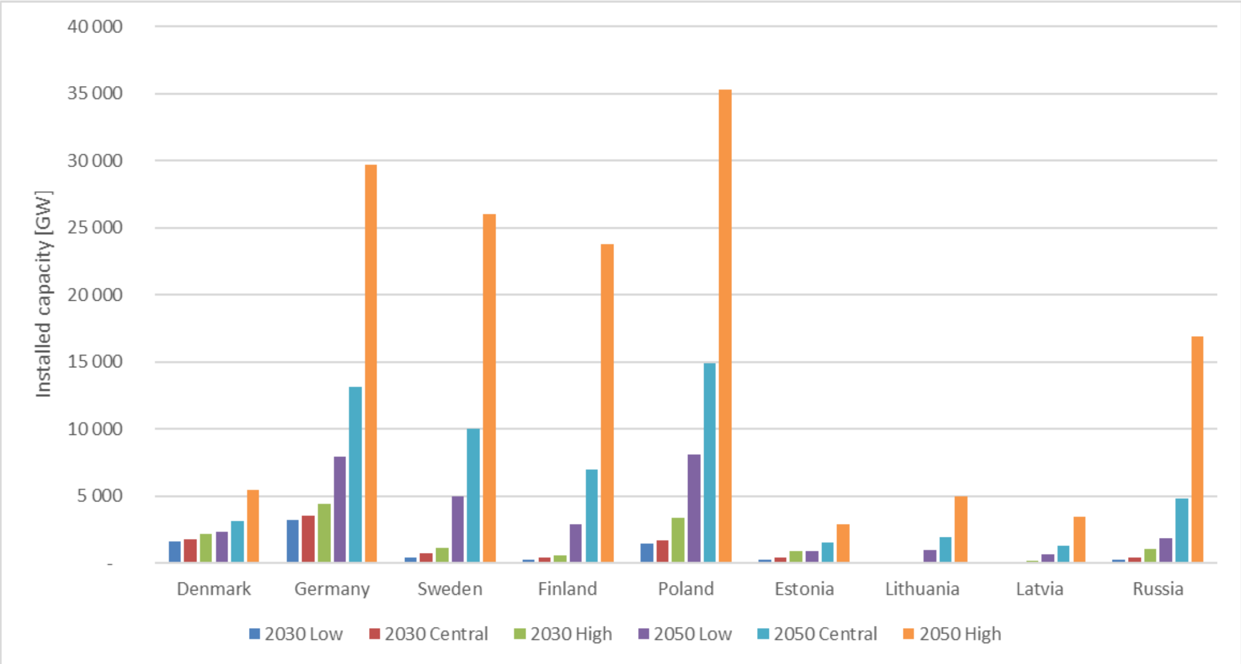


Figure 12. Installed offshore wind power generating capacity per scenario and country in the BSR.

Fraction of national sea area (territorial waters and EEZ) required for national scenario quotas of offshore wind power is presented in Table 9. It is rather moderate for most countries. In German and Polish water thought more than 20 % of the sea surface space is covered and spatial planning consideration will be significant.

Table 9: Area covered by offshore wind of the territorial waters and EEZ based on the 2030 and 2050 energy scenarios. Norway is left out since it does not border the Baltic including Skagerrak and Kattegatt.

% Space	2017	2030 Low	2030 Central	2030 High	2050 Low	2050 Central	2050 High	Total av. area [km^2]
Denmark	0.55%	0.93%	0.31%	0.38%	1.36%	1.81%	3.15%	32 247
Germany	0.93%	4.05%	1.15%	1.44%	9.95%	16.37%	37.04%	14 839
Sweden	0.03%	0.06%	0.11%	0.16%	0.74%	1.48%	3.85%	125 262
Finland	0.02%	0.05%	0.10%	0.12%	0.67%	1.62%	5.49%	80 178
Poland	-	0.84%	0.96%	1.89%	4.68%	8.59%	20.31%	32 167
Estonia	-	0.12%	0.21%	0.45%	0.48%	0.80%	1.52%	35 170
Lithuania	-	0.00%	0.14%	0.29%	2.90%	5.87%	14.86%	6 172
Latvia	-	0.00%	0.00%	0.09%	0.42%	0.87%	2.34%	27 461
Baltic EU	**0.11%**	**0.38%**	**0.45%**	**0.67%**	**1.51%**	**2.78%**	**6.89%**	**353 496**
Norway		-	-	-	-	-	-	-
Russia	0.00%	0.16%	0.33%	0.79%	1.48%	3.80%	13.31%	23 504
Total	**0.10%**	**0.36%**	**0.45%**	**0.68%**	**1.52%**	**2.87%**	**7.35%**	**377 000**

* Total av. area [km^2] indicates the total sea space available for the different countries

5 Conclusions

Offshore wind power is on the rise and so are efforts to create one integrated European energy market. Based on the analysis presented in the report, it can be concluded that most of the countries in the BSR 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 decrease the environmental impact and drive 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.

EU ambition and targets evolve in a positive direction. Lately 2030 targets have been revised upwards and as there is a good chance that the targets will be increased by 2023 during the next revision. The ever-increasing ambition along with decreasing cost of electricity for renewable energy sources, including offshore wind power, push countries in the BSR, Europe and globally to strive towards a completely fossil free, renewable energy supply. The question is; how long will it take?

Attempting to answering that question, three trajectories for offshore wind power and grid infrastructure in the BSR have been developed in this work; central, low and high. The central trajectory is a plausible prediction of where we most likely end up. The low represents a decrease in ambition and the high is the way to reach the 2-degree target and fulfil the Paris agreement. Scenarios have been defined for 2030 and 2050 following these trajectories.

5.1 Gap Analysis and Uncertainties

For the 2030 perspective most of the deployment for both offshore wind power and grid infrastructure will be projects that are already in planning or development due to the amount of time required to develop a project from idea to commissioning. Also, the technologies to be used are known, the development of EU and national targets can be accurately predicted even though there is yet to be firm commitment on quotas etc. The level of electrification and energy demand can also be foreseen. Thus, the uncertainties are limited, which is manifested in the relatively small spread between the central, low and high scenarios. The low scenario is 19 % below the central scenario and the high scenario is 52 % higher than the central scenario.

For the 2050 scenario the spread is larger. Corresponding numbers are 47 % lower for the low scenario and 160 % higher for the high scenario. The reason is larger uncertainties looking much further into the future. The geopolitical climate, EU and national policies and commitments, electrification and energy demand as well as technical and market advancements can change much more. Also, the areas to be deployed are yet to be selected and possible conflicts of interest to be identified. Even during the course of writing this report significant amounts of new information has been published and taken into account as the work has progressed. This just highlights that the scenarios presented are a snapshot in time depending on the information available at the time of creation. However, by looking at a range of scenarios rather than just one, and updating the scenarios over time, this kind of forecasting is a good tool to understand what is coming and prepare for it.

The scenarios developed by RISE are based on scenarios by WindEurope, Baltic InteGrid, ECOFYS and Stanford WWS scenarios. Some lack information on offshore wind for one or more of the Baltic countries (Estonia, Latvia and Lithuania). Zero deployment has been assumed in these instances. For the countries with low exploitation of offshore wind in the maritime space the implications on MSP are small, since there should be redundant space for the quantities in the current forecasts. Thus, an increase from these lower levels of offshore wind development should not pose a problem.

5.2 Scenario Conclusions

In the 2030 scenarios the amount of offshore wind power in the Baltic is moderate, covering less than 1 % of the sea surface area in total and less than 2 % of any national waters for an individual country. Thus, there is redundancy in the amount of areas required for offshore wind power. The challenges for MSP are limited and more focused on local conflicts of interest than global planning of use of the Baltic sea. There is some concentration of projects in the south areas between Denmark, Germany and Sweden where this may not be true and the planning will be more complex and challenging. Handling the interconnectors will probably be more important. Even though limited in numbers the complexity due to border crossing and working with multiple authorities is anticipated to be higher.

In 2050 the deployment rate of the sea is significantly higher, reaching 1.5, 3.8 and 13 % area coverage in the low, central and high scenarios respectively, with concentration in the southern parts. In the 2050 high scenario the German capacity quota corresponds to 37 % of the German Baltic sea area and for Poland the number exceeds 20 %. This implies that generating capacity of one country may be placed in the national waters of another. Considering also the increase in interconnectivity and combination of interconnectors with wind farm export cabling the need for coordinated MSP in the BSR, especially in the south, will be considerably higher than in 2030. Dealing with authorities of multiple countries will be more of common practice than an exception.

To comply with the Paris agreement we will have to reach the 2050 high scenario. Suggested measures, derived by RISE during this study, to do that:

- Clear targets for offshore wind in all countries in the Baltic Sea Region complemented by a development plan
- Centralized licensing system that connects the site development more closely to the MSP and subsidy systems at least on national level, possibly even on trans-national level.
- Dedicated areas for offshore wind power development
- More harmonized approaches to decide in MSP processes on priorities and interaction of various occupations/ stakeholders.

The 2050 high scenario is optimistic for the year 2050. But is it still optimistic for 2060, 2070 or 2080? The drive for clean renewable energy will likely persist. It is probably also fair to say that we will not compromise, at least not to a large extent, with our current standard of living. Hence there will be a need for new renewable energy capacity. Wind power, onshore and offshore, will likely provide a large portion of that energy. Especially in the northern parts of Europe, e.g. the BSR, where the capacity of solar power is limited. Considering the lack of space on land, especially in continental Europe, a large chunk of the wind power to be installed will be offshore. Rather than talking about low, central and high scenarios, one can reason that something similar to the 2050 high scenario will be the reality at some point in time. It is a good idea to prepare for it to pave the way for the transition to clean and renewable energy.

6 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

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