MARKET ANALYSIS
DECOM TOOLS 2019

Interreg
North Sea Region
Decom Tools
European Regional Development Fund

EUROPEAN UNION

Project Partners

November, 2019

Coordinator and Editor – Hamburg Institute of International Economics

Layout and graphic design – Energy Innovation Cluster

Project Acronym:	**DecomTools**
Reference Number	**Interreg North Sea Region – Project Number: 20180305091606**
Project Title:	**Eco-Innovative concepts for the end of offshore wind energy farms lifecycle**

Research Team

Authors:

- Mirko Kruse (Hamburg Institute of International Economics)

Contributers (actively involved in the process of elaboration of the market analysis):

- Jens Christian Lindaas (Western Norway University of Applied Sciences)
- Andre Olivares (Western Norway University of Applied Sciences)
- Harm Korporaal (De Lauwershorst Group)
- Dos de Keijzer (De Lauwershorst Group)
- Heika Ring (University of Applied Sciences Emden/Leer)
- Stephan Kotzur (University of Applied Sciences Emden/Leer)
- Marcus Bentin (University of Applied Sciences Emden/Leer)
- Hamed Askari (University of Applied Sciences Emden/Leer)
- Mads Rasmussen (Maritime Cluster Fyn)
- Pernille Skyt (Energy Innovation Cluster)
- Jonas Larsen (Energy Innovation Cluster)
- Johannes Kromann Bie (Energy Innovation Cluster)
- Wim Stubbe (Port of Oostende)
- Sarina Motmans (POM)
- Ben de Pauw (POM)
- Isabel Sünner (Hamburg Institute of International Economics)
- Nina Kallio (Virol Metaal B.V.)
- Alireza Maheri (University of Aberdeen)
- Ana Ivanovich (University of Aberdeen)
- Ingrid Klinge (New Energy Coalition)
- Søren Stensgaard (Samsø Municipality)
- Henrik Carstensen (Port of Grenaa)

Overview

1. Introduction to the Project and the Participating Regions

For a successful energy transition, a significant expansion of wind power is necessary to replace fossil energy. Wind energy emits up to 175 times less CO2 than most modern gas plants. A successful transition to clean energy will not work without both onshore and offshore wind farms (Belgian Offshore Platform 2019). However, most wind turbines are designed for a life span of only 20-25 years and in the offshore sector, due to extreme weather conditions, their durability is often even lower. Therefore, a clean decommissioning process is of major importance to reduce the overall CO2 footprint of a wind farm. Producing green energy and avoiding CO2 emissions loses its sustainability effect when large fuel-powered ships are required to inefficiently take down offshore wind farms, even more if the decommissioned materials are not recyclable afterwards. Wind energy can only be called a green energy source if all parts of the cycle are ecologically optimized.

Having this in mind, the number of affected offshore wind farms to be decommissioned will steadily increase in the coming years. While dismantling processes on land are known and tested, an extensive experience in the offshore sector is still missing and an overarching and sustainable approach for dealing with offshore wind farms at the end or their life span is lacking behind. After the termination of their life span, wind turbines either have to be decommissioned or their accredited operational lifetime needs to be extended, often accompanied by repowering (partial refurbishment). So far, in the offshore wind sector a few wind turbines have been dismantled offshore: Yttre Stengrund (Sweden) and Vindeby (Denmark), plus two single near-shore turbines, namely Windfloat 1 (Portugal) and Hooksiel (Germany) as well as four offshore turbines at the Lely farm (Netherlands).

An overall sustainable approach to the offshore wind farms' end of lifecycle is still missing. The Interreg North Sea Region (NSR) project "DECOM Tools"[1] shall assist in closing this gap by devising and developing the following eco-innovative concepts:

- Reduce decommissioning costs by 20 per cent and environmental footprint by 25 per cent (measured in CO2 equivalents),
- Increase the know-how and expertise of North Sea Region (NSR) involved stakeholders.

The project consortium consists of thirteen partners from six NSR countries, namely Denmark, Germany, Belgium, The Netherlands, United Kingdom and Norway. The four-year project will conduct out research, demonstrate pilots and develop working tools in different areas such as logistics, infrastructure, ship design, safety or up-/re-cycling. Already available technologies will be combined to tackle some of the major aspects of the decommissioning challenges, including optimization of existing (port) infrastructure. Transnational cooperation and multidisciplinary cross sector competences will improve the framework conditions for innovation and technology transfer in this specific niche area and help the sector to become more eco-balanced.

[1] https://northsearegion.eu/decomtools/about/

The report at hand follows from the project initiatives and aims to describe the market situation for offshore wind energy opportunities for future offshore decommissioning projects. The report covers trends, developments and expectations for the upcoming years both in terms of offshore wind energy in general and decommissioning expectations in particular. Respectively, the report covers global trends, particularly the NSR as well as specific information on the countries participating in the DECOM Tools project. This is the reason why countries located in the NSR, such as Sweden, are only covered on the edge of the report since Sweden is not part of the project consortium. Specific country information in the report not only involves trends but also an overview of the legal framework for offshore wind operations and decommissioning. By doing so, variations of country-specific regulation as well as possible vacancies are to be presented to draw a complete picture of the offshore decommissioning industry.

2. The Offshore Wind Market in General

Climate change and the inevitable transition away from fossil fuels to green energy is one of the major challenges of the decades to come. The issue becomes even more important in the context of rising energy demand on a global scale, alternative energy sources still being researched and the time frame for emission reduction closing with alarming speed. For example, to realise the transformation in the energy sector, 80 per cent of the electricity consumed in Germany in 2050 should come from renewable energy (BMWi 2019). Other countries and the European Union have comparable targets.

Wind energy in general and offshore wind energy in particular provide some benefits that can make this energy source an important building block for tomorrow's energy market. Offshore wind farms have are more efficient than land-based wind farms since wind speeds and directions over the water are more consistent. Moreover, their location in federal waters, often beyond eyesight, avoids problems of residents' complaints. Finally, offshore wind farms do not occupy land space that could otherwise be used for other purposes such as agriculture. On the other hand, offshore wind also has some downsides, e.g. its higher effort needed for construction and maintenance or its very high material intensity of about 500t of steel and 1,000t of concrete to install 1MW of power. Moreover, other forms of conflicting use of space in maritime environment, such as aquaculture or fisheries, come into play (Cohen 2019).

Globally, offshore wind has grown to be a multi-national industry over a period of about two decades. Most of its capacity development has occurred in Europe with Asia and the US catching up slowly in recent years. It is expected that the installed capacity on a global level will reach 46.4GW until the end of 2022 whereby the largest share will be in Europe with 33.9 GW, followed by Asia with 11.3GW and North America with 1.2GW. Still, there is a consensus on the expected dominant countries: Germany and the United Kingdom in Europe, China, Japan and Taiwan in Asia and the United States in North America (NEP 2018). China alone, planning to install 10GW of offshore wind energy by 2020 and exceeding 30GW by 2030 was responsible for half of the world's $25 billion investment in offshore wind energy in 2018. Other Asian countries also have high ambitions for offshore capacity by 2030, for instance South Korea (18GW), Japan (10GW), Taiwan (5.5GW) or India (30GW) (Cohen 2018). Generally, the overall importance of internationalization in offshore wind generation and related tasks is considered to be very high as the field of large players is increasing (BMWi 2015).

The grid-connected offshore wind capacity additions amounted to 4.5GW in 2018 on a global basis. This was 15 per cent higher than in 2017 and marked a shift from Europe to Asia: While additions in the EU remained at 16 per cent, the capacity in China tripled to 1.6GW in 2018 (IEA 1028). In addition, the potential for offshore wind, e.g. in the United States, is far from being exploited to its fullest. With around 2GW of installed capacity and over 20GW of possible capacity until 2050, under favourable market and regulatory conditions, the numbers are still far away from the 22,000GW that are estimated to be possible and which would cover the current electricity consumption of the US twice (Cohen 2019). In the United States, the first large-scale offshore wind farm (Vineyard Wind) has been adjusted recently. Three 9.5MW turbines have been redesigned to extend the distance between generators and important commercial fishing areas which was made possible by a 2017 federal permit application permitting developers to specify more turbine locations than they actually planned to use increasing flexibility while doing so. The Vineyard Wind site is planned to deliver 800MW and is located 15 miles south of Martha’s Vineyard. It is expected to enter operations in 2022 (Bernthal-Hooker 2019).

Particularly in the European Union with its ambitious energy demand and electricity targets, wind energy will play a central role both onshore and offshore (NorthSEE 2017a). In 2016, already 10.4 per cent of European power demand has been generated by wind energy (onshore and offshore) (NorthSEE 2017c). The official target is to produce at least 27 per cent of final energy consumption from renewable energy sources by 2030 as an intermediate goal. This is also accompanied by targets for emission reduction (European Commission 2018). Thereby, the potential of wind energy generation in Europe is not yet fully exploited: In a central scenario, Wind Europe expects the installed capacity until 2030 to rise by 253GW whereof 70GW are to be installed offshore. Compared to 2016, this would mean an overall doubling of installed wind energy capacity and ensure that 30 per cent of EU’s power demand could be satisfied this way (Wind Europe 2017). It is to be noted that these expectations are to be considered more ambitious than other forecasts. Nevertheless, over 60 per cent of all investments in new power capacity in Europe in 2018 were invested in wind energy which strongly underlines the existing and increasing relevance of this kind of energy generation (Wind Europe 2019b).

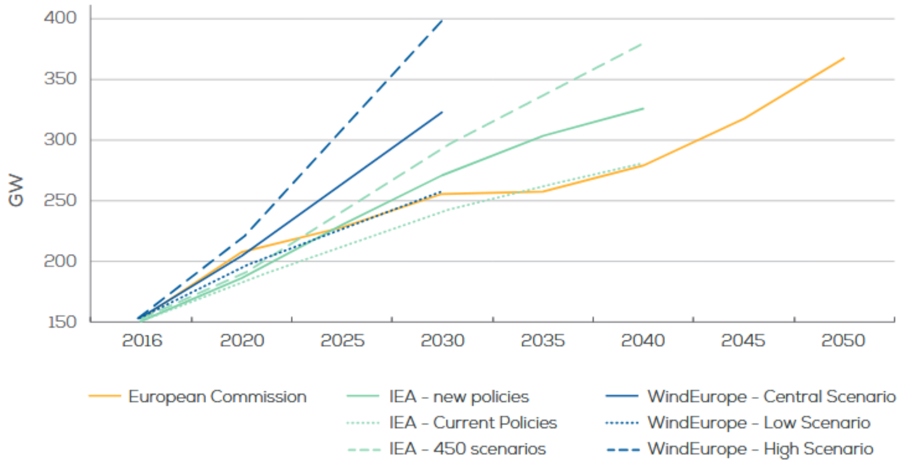

Figure 1: Comparison of different scenarios for cumulative wind power capacity in the EU

Source: Wind Europe 2017

With 2,649MW, the amount of new offshore wind power capacity connected in Europe in 2018 was 15.8 per cent lower than in 2017 which is due to the fact that 2017 was a record year (2,660MW additional capacity connected). Accumulated, the offshore wind capacity in Europe amounted to 18,400MW at the end of 2018 generated by 105 offshore wind farms and 4,543 grid-connected turbines in 11 European countries. 98 per cent of the capacity is concentrated in just five countries: United Kingdom (44 per cent), Germany (34 per cent), Denmark (7 per cent), Belgium (6.4 per cent) and The Netherlands (6 per cent) (Wind Europe 2019a).

The amount of new offshore wind investments in Europe was €10.3 billion in 2018 which marked a rise of 37 per cent compared to 2017. Still, the figures from 2016 (€18.2 billion) or 2015 (€13.1 billion) have not been met again yet although the temporary bottom of 2017 appears to be outperformed. The numbers include investments in new assets, refinancing transactions, mergers and acquisitions at project and corporate level, public market transactions and raised private equity (Wind Europe 2019b). The highest investments were reported in the UK (€5.4 billion converted, new capacity of 1,858MW), the Netherlands (€1.4 billion, 732MW capacity), Denmark (€1.1 billion converted, 605MW capacity) and Belgium (€1.8 billion, 706MW capacity). Germany (€0.4 billion, 258MW capacity) lacks behind in this context (Wind Europe 2019a). Moreover, forecasts for 2022 expect global annual expenditure for offshore wind of about €25.7 billion whereby the expenditure between 2018 and 2022 will alone be about €108.3 billion (NEP 2018). For the EU an investment sum of €239 billion by 2030 is expected (Wind Europe 2017).

At the same time, the levelised costs of offshore wind energy (expressed in € per MWh) have decreased dramatically from about €160 per MWh in 2015 to €80 in 2019 and are expected to decrease to €50 per MWh in 2030. The main reasons for the significant cost reduction are to be found in technological innovation in turbines as well as supply chain and finance optimizations. Also, competition through auction schemes and increased size of turbines reducing the number of associated components to install and maintain have helped to decrease costs. Other factors such as development costs, installation, electrical interconnection or foundations play a minor role but still contribute to cost reductions (NEP 2018). Further cost decreasing potential is to be released through expansion of the overall market giving rise to decreasing costs, optimized technologies and improved operating concepts (BWE 2019).

Moreover, it has been found that offshore wind has significant labour market effects creating jobs in different sectors such as engineering, metal and electrical industries, surface engineering and mechatronics, meteorology, geology and marine biology, skippers and machine operators, industrial climbers, professional divers and other professions (BMWi 2015). By 2030, the number of jobs created in the wind energy industry in Europe is expected to reach 569,000 people (Wind Europe 2017).

3. The Offshore Wind Market in the North Sea Region

The North Sea Region (NSR) offers particularly good potential for offshore wind energy: Its waters are relatively shallow, wind speeds are high and extraordinary storms are very rare while waves are mostly small (NEP 2018). This explains why 62 per cent of the installed capacity (1,651MW) in Europe is located in the North Sea (compared to 15 per cent in the Irish Sea, 14 per cent in the Baltic Sea and 9 per cent in the Atlantic Ocean) (Wind Europe 2019a). Of the 750,000km² of the North Sea about 3,500km² are occupied with offshore wind farms. It is expected that this number will rise to more than 8,000km² by 2030 (NorthSEE 2017d).

The focus of the upcoming analyses will be on the NSR countries with their significant share in the European offshore wind energy market (between 6 and 44 per cent), namely Belgium, Denmark, Germany, the Netherlands and the United Kingdom. This list is complemented by Norway which is not a big player in offshore wind energy but offers significant potential and, moreover, is experienced in offshore decommissioning of oil and gas facilities which will be discussed further below. These countries also constitute the project consortium of the DECOM Tools project. A rising trend in installed capacity of offshore wind energy in the NSR can be observed in almost all countries. While the Netherlands started from a relatively low basis of 357MW installed capacity in 2016, they managed to increase the capacity by 168.1 per cent to 957MW in 2017[2]. High gains are also observable in Belgium which registered an increase of 66.6 per cent between 2016 and 2018 to now 1,186MW. Denmark shows conspicuity insofar as the installed capacity between 2016 and 2018 rose by 34.6 per cent but between 2016 and 2017 the capacity was reduced by 5MW due to the decommissioning of an existing wind park (more on that further below in the report). The two

[2] This and the following numbers refer to the NSR wind parks in the DECOM Tools partner countries. If the report uses data on the North Sea Region without citing a source, the data is accumulated from the partner countries from the particular sources listed in Annex 1.

A general remark on the data: Smaller gaps in the data have occurred although the data sets are sufficient to draw a picture. If the data were too fragmented, the authors have not used the data for the report at all.

countries with the largest installed offshore wind capacity in the NSR are Germany and the UK. While Germany managed to stick to average growth rates of 31.1 per cent between 2016 and 2017 up to 5,387MW in 2017, the UK presented significantly higher numbers, both in absolute terms and in growth: Starting from 5,103MW in 2016, the UK realized a growth rate of 47.5 per cent until 2018 leading to a capacity of 7,525MW. Undoubtedly, the UK is leading the offshore wind market in the NSR. Norway is only partly represented in this context since the capacity in 2018 amounted to only 2.3MW coming from a new test site.

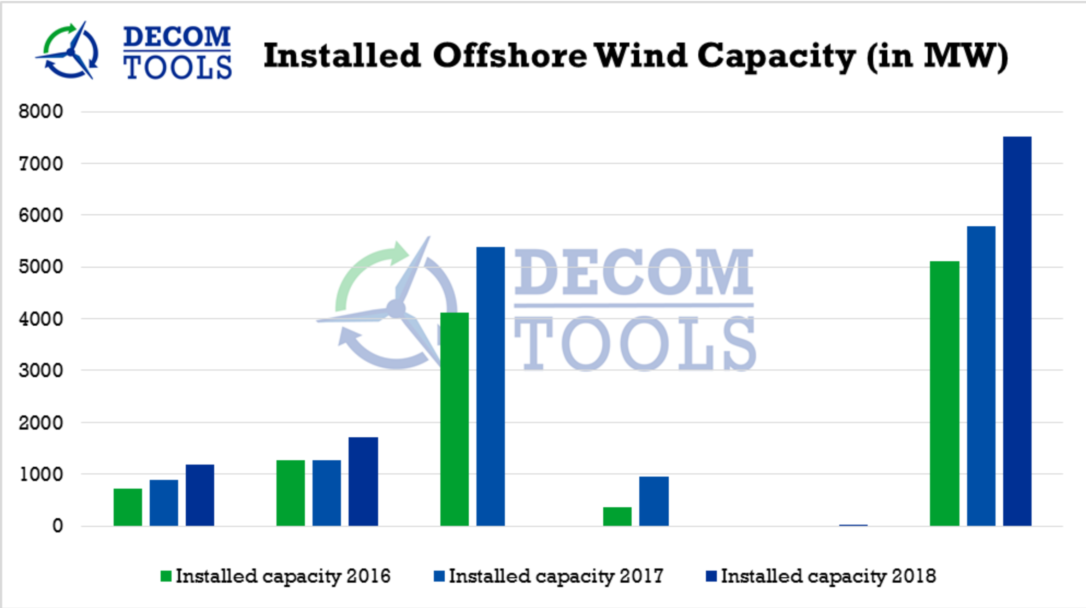

Figure 2: Installed Offshore Wind capacity in NSR (in MW) between 2016 and 2018

Source: Own depiction on basis of data presented in Annex 1

Looking at the future capacity, or more specifically the offshore wind farms currently under construction, shows some different findings. Especially Germany, listed second in terms of installed capacity in the NSR, has only 909MW under construction. This capacity under construction is equal to 16.9 per cent of its already installed capacity. Also, the UK as the leading country has only 27.4 per cent, respectively 2,064MW, of the existing capacity under construction. On the other hand, Denmark has 950MW or 55.9 per cent of its status quo under construction and Belgium even 1,076MW which is almost double of its installed capacity. The list is led by The Netherlands where the amount of capacity under construction (1,483MW) is significantly higher than the existing capacity (957MW). Catching up processes to Germany and the UK are clearly observable from the development trends. Again, Norway is out of competition since no further capacity is under construction or planned for the moment although plans are discussed.

The trend towards an expansion of offshore wind in the NSR can also be confirmed by taking a look at the target capacity for 2030. Again, Germany shows a decelerating expansion but still the capacity in 2030 (15,000MW) is planned to be 178.5 per cent higher than in 2018. Denmark reports a similar growth rate of 198.1 per cent to then 5,071MW in 2030. All other countries, except for Norway which lacks any political expansion targets, aim towards increases between 237.3 per cent (Belgium, target of 4,000MW in 2030) and 298.7 per cent (UK, target of 30,000MW for 2030). While the UK's target is extraordinary high, the planned growth rates in the Netherlands are also remarkable: In order to raise the installed capacity from 1,483MW in 2018 to 7,000MW in 2030, an increase of 631.5 per cent will be necessary. Still, due to its capacity under construction and ambitious expansion in the past, the expansion target in The Netherlands appears to be realistic. On the other side, the central scenario for offshore wind energy expansion by Wind Europe lists even 11,500MW as potential offshore capacity for The Netherlands by 2030. All other countries reach or even exceed the scenario's targets (Wind Europe 2017). A leading role, both for onshore and offshore wind energy, is predicted for Germany, UK, The Netherlands and Sweden in the NSR (NorthSEE 2017b).

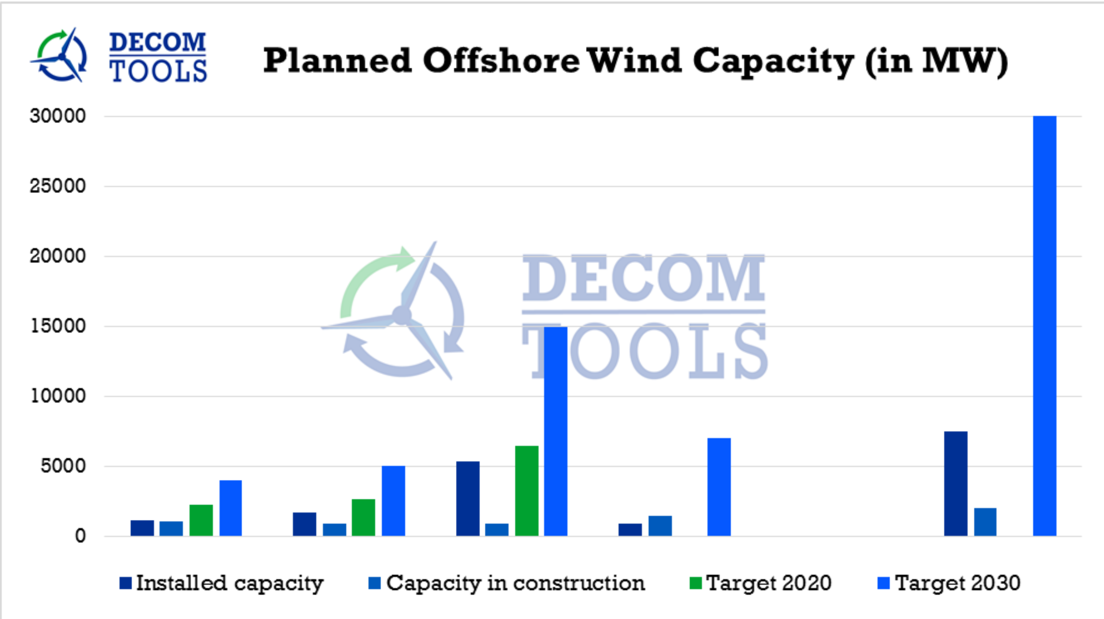

Figure 3: Planned offshore wind capacity (in MW) until 2030

Source: Own depiction on basis of data presented in Annex 1

Taking a look at the number of operating wind farms in the NSR reflects the findings regarding offshore capacity: All NSR countries have increased their number of offshore wind farms between 2016 and 2018 – apart from Denmark where one wind park was disconnected while a new one took its place. While the number of offshore wind farms is therefore constant with 14 in Denmark, Belgium completed one wind farm per year and increased the number from three in 2016 to five in 2018. Thereby, The Netherlands have been overtaken since they operate only four offshore wind parks since 2017 compared to three in 2016. Nevertheless, comparing the number of wind parks with the installed capacity shows that the electricity generated by Dutch wind farms is higher on average than in Belgian wind farms. Again, Germany and the UK lead with 23 NSR wind farms in Germany in 2018 (2016: 16, 2017: 18), respectively 34 wind farms in the UK in 2018 (2016: 27, 2017: 30). In Norway, only one recently finished floating test site is operating.

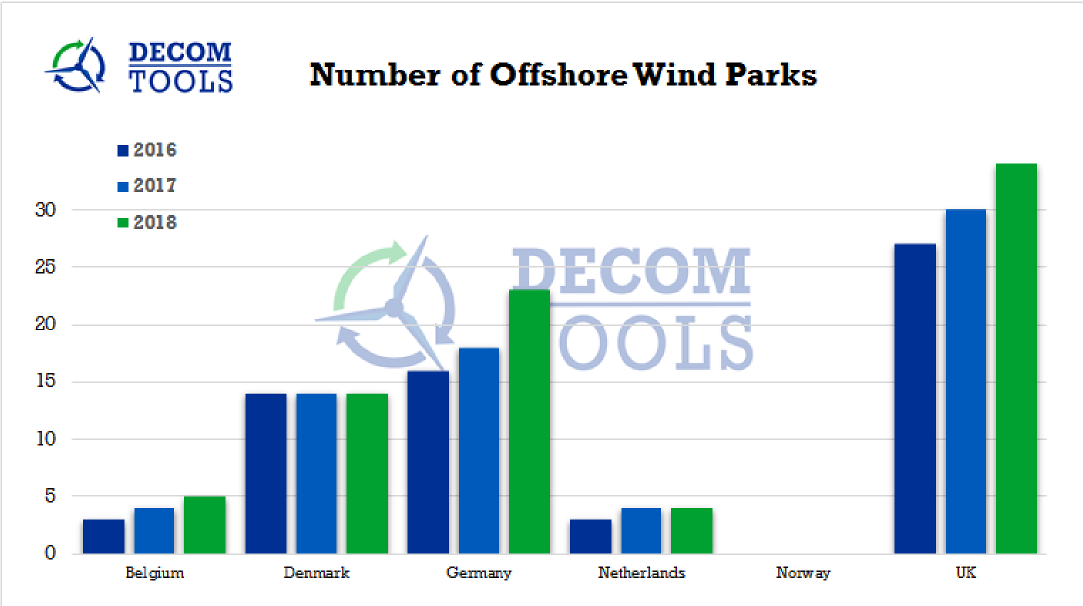

Figure 4: Number of offshore wind parks in the NSR

Source: Own depiction on basis of data presented in Annex 1

The absolute number of operating offshore turbines presents no further surprises. In 2018, the UK led the ranking with 1,876 turbines, followed by Germany with 1,151 turbines. Denmark (558 turbines), The Netherlands (289 turbines) and Belgium (274 turbines) were ranked significantly lower. The number of operating offshore turbines in Norway was one due to the operating test site.

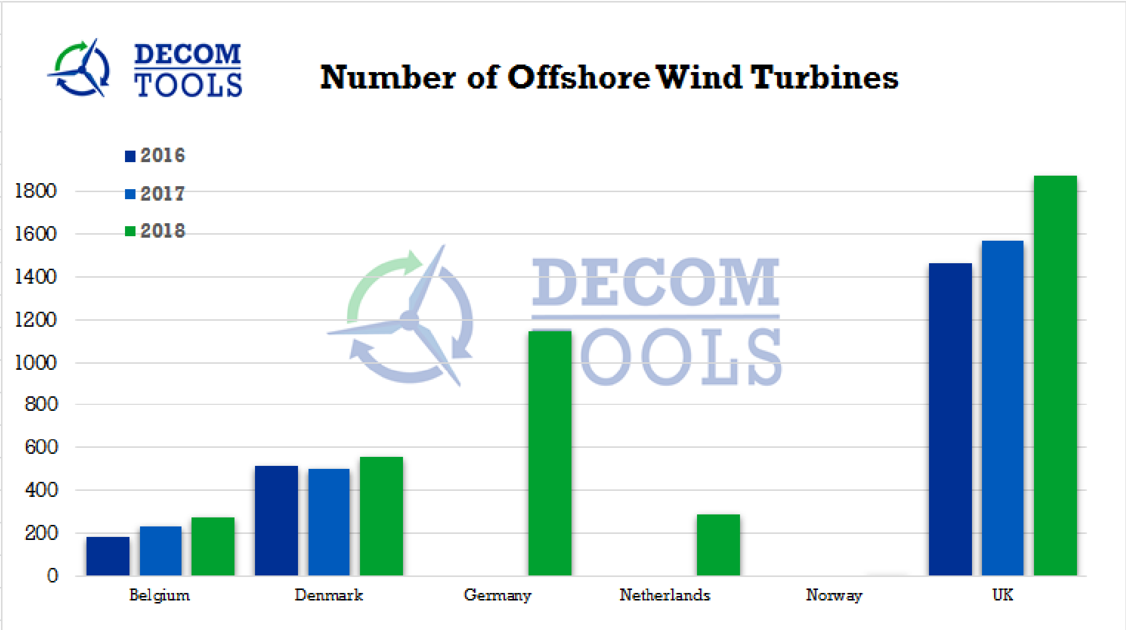

Figure 5: Number of operating offshore wind turbines in the NSR[3]

Source: Own depiction on basis of data presented in Annex 1

However, in the context of expected decommissioning dates, the age of offshore wind farms and their turbines as well as their location becomes interesting. It can be observed that those countries which were pioneers in offshore wind energy also have the oldest wind parks unless these have already been decommissioned which, however, only applies to a very small number of offshore wind parks. The oldest operating wind farm (Tunoe Knob) was erected in 1995 and is located in Denmark. Overall, Denmark possesses three of the four oldest wind parks in the NSR, built in 2000 and 2002. The fourth one is located in the UK and was erected in 2000. The oldest offshore wind park in Germany is operating since 2004 when also a UK offshore wind park began its operation. One year before, even four wind parks in Denmark and another one in the UK were completed. Afterwards, a gap can be observed with respect to construction of Danish offshore wind parks where it took six years for further wind parks to be completed, followed by another two in 2010. In the meantime, two other wind parks were erected in Germany (in 2006 and 2008), another three in the UK (in 2005 and two in 2007) and The Netherlands accessed the offshore wind business with its first two wind parks in 2007 and 2008.

In 2009, apart from the two new offshore wind parks in Denmark, the UK finished two new sites and Belgium managed to inaugurate its first wind park which was followed by another one in 2010. The same year lists one new wind park in Germany and even four in the UK just before another three were entering operation in the UK in 2012 and even five in 2013. Thereby, 2011 was the first year after 2002 without any wind park being completed in the NSR and 2012's results are also limited to the UK. The expansion trend continued again in 2013 with one wind park erected each in Germany

[3] The data for 2016 and 2017 in Germany and The Netherlands are missing.

and Denmark (apart from the five in the UK). It becomes obvious that the breakthrough of offshore wind energy in Germany is to be found in these years as with 2014 (two wind parks), 2015 (six wind parks) and 2017 (six wind parks) the majority of currently operating offshore wind parks has been erected during the last decade.

On the other hand, the UK commenced the stable expansion with a high pace: After four wind parks (2010), three (2012) and five (2013), another three were completed in 2015, three in 2017 and four in 2018. While Demark has not inaugurated any new offshore wind parks since 2013, two of the four Dutch wind parks have been completed since (one in 2015 and one in 2017) while Belgium completed even three of its existing five wind parks since (one in 2014, one in 2017, one in 2018).

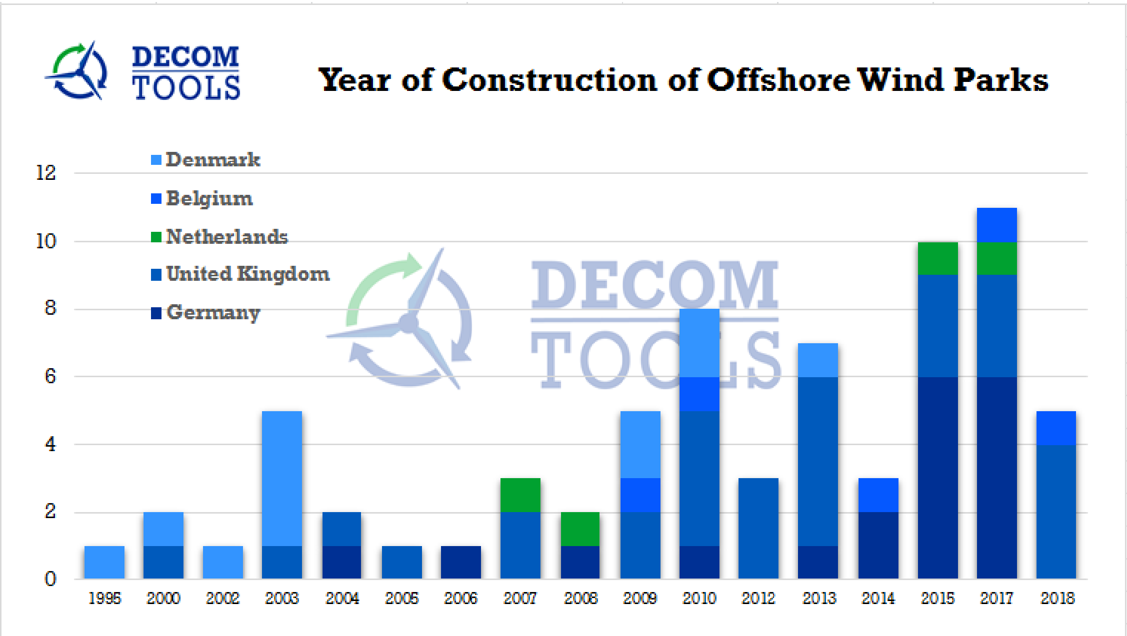

Figure 6: Year of construction of offshore wind parks in the NSR

Source: Own depiction on basis of data presented in Annex 1

The construction dates reflect the respective national cycles and development of offshore wind energy. While Belgium entered considerably late in 2009 and has built five wind parks spread equally over the years, The Netherlands started earlier in 2007 but took a longer break after 2008 and now possess four offshore wind parks. Denmark started earlier than all other NSR countries in 1995 erecting seven wind parks until 2003. Though there was a break until 2009, when in the four upcoming years five new wind parks were inaugurated, an overall number of 12 wind parks has been erected by now. Germany, as an intermediate player when it comes to the starting point in 2004 erected one wind park every two years until 2010. Then a short break appeared but between 2013 and 2015 nine new wind farms followed. The slow pace from the beginning has been overcome although another recent slowing down can be observed. The UK played an exceptional role not only in terms of the starting point in offshore wind business (2000) but also in terms of stability of expansion over the years leaving almost no gaps. An even faster pace for the last decade is obvious and continuing until today.

Looking at the absolute number of turbines constructed in the NSR over the years complements the picture since the wind parks' size has also been subject to change. While the first offshore wind park in Denmark from 1995 had only ten turbines, the average number of turbines per offshore wind park in 2018 was almost 70. In between, the average number of turbines rose to almost 97 in 2014 when two large German wind parks were completed and even to 133 turbines on average in 2010 due to four large UK wind parks. Moreover, it can be seen that from 2009 onwards the number of turbines newly constructed rose significantly. After a first peak in 2003, the number of new turbines in 2009 was already higher than in the five previous years combined, before in 2010 the number again more than quadrupled and marked a peak which has not been reached again yet. Afterwards, the number of new turbines fluctuated on a significantly higher level than before but without being able to compete with the 2010 numbers. Interestingly, in 2017 the average number of turbines declined to about 55 per wind park so that the highest number of finished wind parks in this year does not come along with the highest number of turbines. Nevertheless, the absolute number does not give information about the performance of the turbines which means that a smaller number of turbines can be explained by the erection of larger, more efficient turbines.

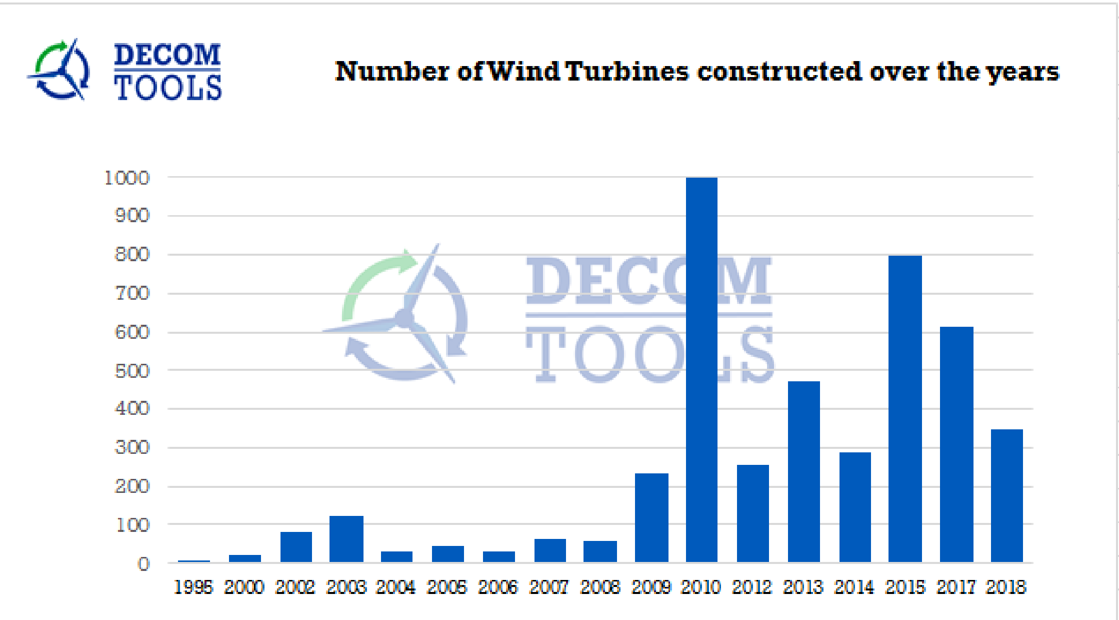

Figure 7: Number of offshore wind turbines constructed over the years in the NSR

Source: Own depiction on basis of data presented in Annex 1

Respectively, the investment sum for new offshore wind parks in the NSR project area has reached new highs almost every year. Starting with a first wind park in 1995 which cost €11.5 million converted, the amount for two wind parks in 2000 rose to already €53 million. In 2012, the UK alone invested €3,613 million converted whereby in 2015 €4,165 billion were invested in five wind parks in the UK (3x), The Netherlands (1x) and Germany (1x). Because costs of particular wind parks have not been made publicly available, a full list cannot be provided. Nevertheless, the exemplary data give an idea of the tremendous turn the industry has taken. Of course, the higher investment sum also refers to more less feasible projects due to in deeper waters at higher distances with larger turbines.

With respect to the wind turbines themselves a trend of increasing sizes can be observed: While in 2012, the average size of grid connected turbines was 4MW the capacity increased to 4.8MW in 2016. Turbines with capacities over 8MW are already in use. Moreover, over the course of one decade, the average size of installed wind farms in the North Sea Region has increased 8-fold compared to an average wind farm size of now 379.5MW. Since current projects have a planned capacity of 700MW on average and projection of planned projects exceeding 1,000MW indicated that the average capacity will most likely increase further. Spatial restrictions might make the use of fewer but more powerful turbines more feasible (NorthSEE 2017a). Also, the wind turbines were subject to changes over the last decades. While the average height of a wind turbine in 2000 was between 62m and 75m, the range in 2010 was 75m to 87m and in 2018 their height increased to 98m or even 196m. The same trends holds for the rotors' diameter which was limited to 66m to 72m in 2000, increased to 90m to 116m in 2010 and finally to 108m to 154m in 2018.

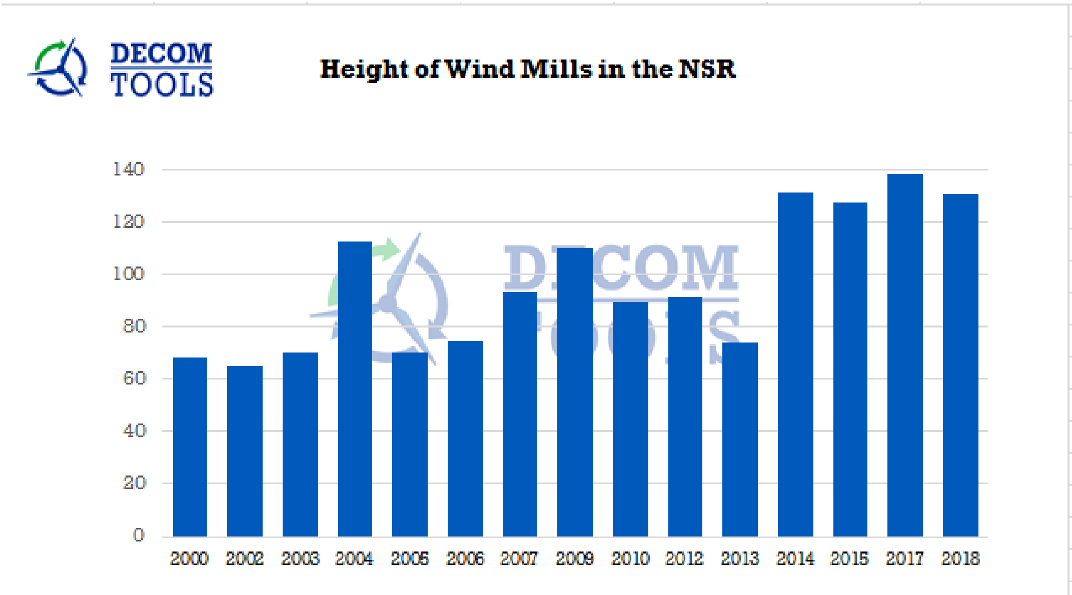

Figure 8: Development of average height of wind mills in the NSR

Source: Own depiction on basis of data presented in Annex 1

Note: All numbers reflect the average of all wind turbines completed in the given year in the respective regions

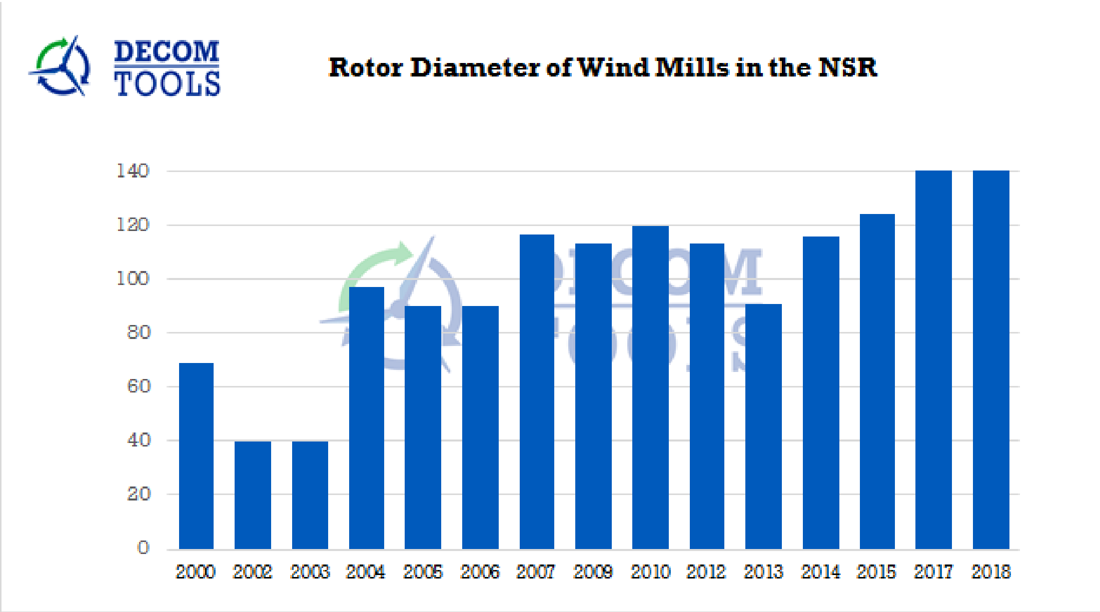

Figure 9: Development of average rotor diameter of wind mills in the partner regions

Source: Own depiction on basis of data presented in Annex 1

Note: All numbers reflect the average of all wind turbines completed in the given year in the respective regions

Due to technical limitations, most of the current foundations of offshore wind farms are limited to a water depth of 40-50m whereby 66 per cent of the North Sea's water is deeper than 50m and goes down to a depth of 200m (on a European level 80 per cent of the offshore wind resource is located in waters of 60m and deeper). In 2016, the average water depth of offshore wind farms in the North Sea was 29.2m and the average distance to shore was 43.5km. To compare, in 1995 the depth of wind farms in the project area in the NSR was between 0.8 and 5m whereby in 2000 the range increased to 2m to 11m before in 2010 depths between 4m and 27.5m were realized. In 2018, the range of depth was between 6m and 36m showing that significant increases could be noted over the last years and further rises can be expected in the future. Moreover, floating wind farms are expected to become viable solutions to be used in deeper waters to avoid fixed foundations in increasing depth (NorthSEE 2017a). Also, in terms of offshore wind farms' distances to shore, significant increases have been noted: While the first wind park in 1995 was located already 6km from the Danish shore, the distance decreased slightly in 2000 with a range between 1.6km and 2km. In 2010, the distance moved to 7km to 46km which has been topped as a maximum only by few wind parks in the following years: Nobelwind (Belgium, 2017, 47km distance to shore), Gemini Windpark

Buitengaats (Netherlands, 2017, 85km to shore) as well as several German high sea wind parks such as Veja Mate (Germany, 2017, 130km to shore).

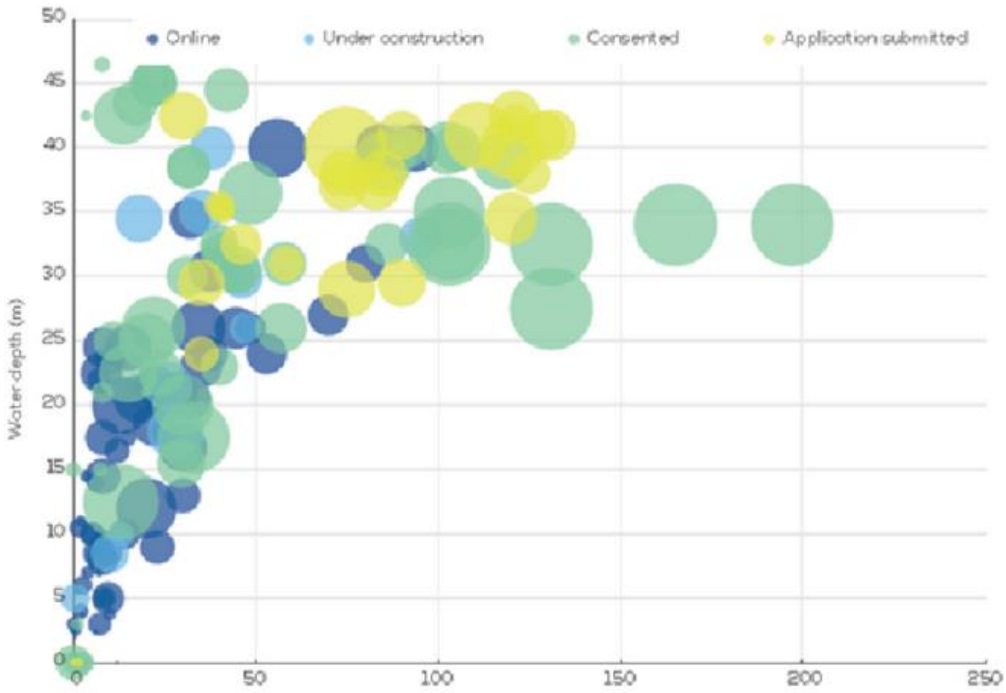

Figure 10: Average water depth, distance to shore of bottom-fixed, offshore wind farms by development status. The bubble size indicates the overall capacity of the site.

Source: NorthSEE 2017a

Since the conditions for offshore wind turbines differ significantly depending on their location also factors such as their foundation have been handled flexibly. Different kinds of foundations have been used over the years whereby monopiles proved to be to be suitable for most conditions at manageable cost. Therefore, almost 90 per cent of the offshore wind mills in the project area are based on monopile foundations. Almost five per cent of the foundations in use are Jackets, three per cent Tripods and two per cent Tripiles (three-leg jacket). Other versions such as Suction Buckets (0.3 per cent) or floating structures (0.1 per cent) are used but in much smaller numbers and mostly in certain areas that restrict using other foundations. For instance, due to water depths the first offshore wind turbine in Norway is constructed floating. A correlation between used foundation and construction date and / or country only exists partly: For instance, jacket foundations (four-legged) are mostly used in the UK whereby tripiles and tripods are mostly to be found in German waters. Moreover, recently erected foundations almost always have monopole structures which appear to become established.

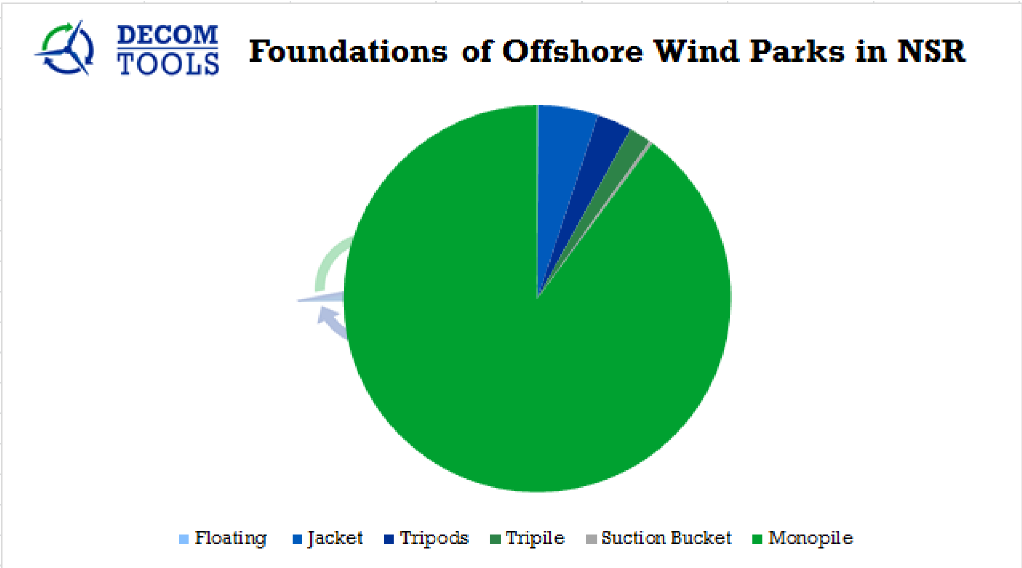

Figure 11: Foundations of offshore wind turbines in the NSR

Source: Own depiction on basis of data presented in Annex 1

Information on the most relevant suppliers of offshore wind turbines in the NSR will be of interest when it comes to the blue prints, technology and materials used. This knowledge will play an important role when the wind farms reach their end of lifecycle and considerations on decommissioning and recycling will become necessary (see further below). Here, it becomes clear that the vast majority of the turbines in use in the project area are models produced by Siemens (65 per cent or 2,562 turbines), followed by Vestas (25 per cent or 987 turbines). Apart from that, a variety of smaller suppliers, partly not operating anymore, have also contributed to the production of offshore wind turbines in the NSR: For instance, Senvion (4.4 per cent or 174 turbines), Bard (2.0 per cent or 80 turbines), Adwen (1.2 per cent or 40 turbines), Repower (0.9 per cent or 38 turbines), Bonus (0.8 per cent or 35 turbines), Arewa (0.01 per cent or six turbines), Nordex (0.005 per cent or two turbines) and Samsung (0.003 per cent or one turbine).

Thereby, at the beginning of the 2000s the variety of turbine brands was significantly higher. Almost all turbines produced by smaller suppliers have been erected within this time period whereas since 2013 almost only Vestas and Siemens models were used. This poses a challenge when it comes to decommissioning of the older wind farms since they are even less homogeneous as current wind mills. A higher diversity of producers, sizes, foundations comes along with different materials used, different construction techniques applied and therefore different challenges to be overcome for decommissioning the different wind farms.

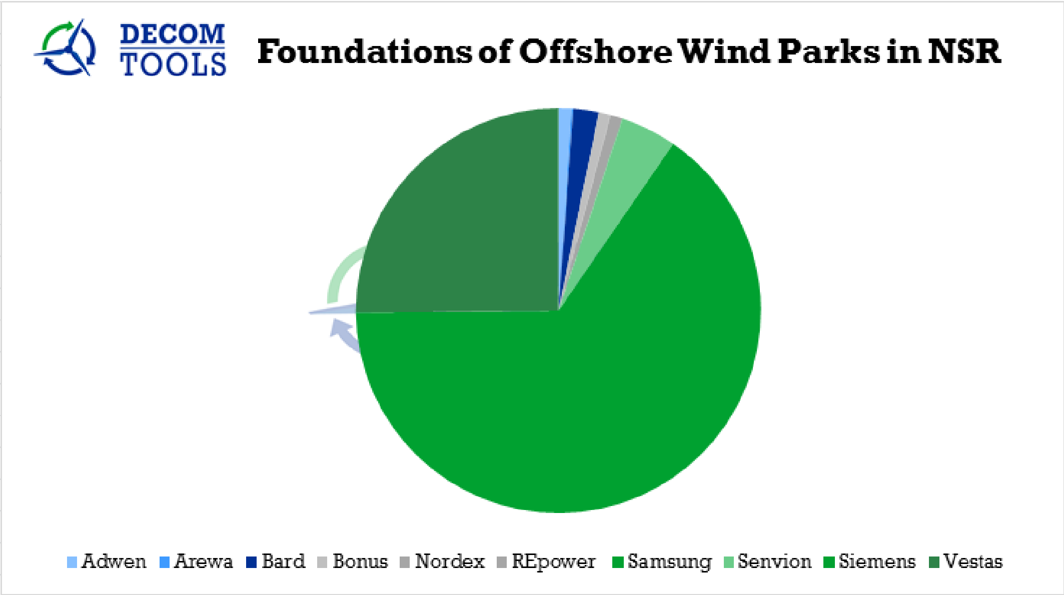

Figure 12: Suppliers of offshore wind turbines in the NSR

Source: Own depiction on basis of data presented in Annex 1

Moreover, new sorts of energy generation at sea come into discussion: Wave energy is still in development phase in the North Sea Region whilst tidal energy is taking up with already five projects fully in place in the NSR. Pilot projects of single tidal devices are located in the Netherlands, Norway as well as in Scotland, UK whom possesses an overall leading role in this context. Also alternatives to the current single rotor offshore wind turbines are researched at the moment. For instance, Denmark already tested a single 4 rotor wind turbine. Although this construction is tested onshore, plans to move the multi-rotor idea to offshore applications are already discussed, for instance in the context of the EU project Innwind. Benefits such as increased energy capture or fewer foundations causing less environmental impact can make the new technology a plausible advancement (NorthSEE 2017a). Another interesting technological development is the world's first battery storage system of 1.25MW for offshore wind energy that has been developed for the Scottish Hywind floating wind farm and that will act as a model for similar plans in Massachusetts in the US (Cohen 2019).

3.1 Belgium

For offshore wind farms, a zone of 238km² in the Belgian part of the North Sea has been designated to the production of renewable energy under the Marine Spatial Plan of 2014 of which 198km² are outside of safety zones and can effectively be used. The first Belgian offshore wind farms were installed in 2009 and the distance to shore of all modern offshore wind parks ranges between 22 and 54km. In 2018, the installed capacity of offshore wind energy was 1,186MW dispersed among five wind parks and 274 turbines overall. Currently in 2019, 1,556MW of offshore wind power are operational in Belgium. All of these numbers indicate a clear trend towards offshore wind energy: Belgium managed to double its annual installations in 2018 compared to the previous year (Belgian Offshore Platform 2018). By 2020, the installed capacity is planned to reach 2,292MW, with a production of 8.5TWh per annum electricity which amounts to about 10 per cent of the electricity demand and half of the Belgian renewable energy goal of 2020 (Wind Europe 2019a).

The existing and rising economic relevance of the offshore wind energy business in Belgium is also reflected by the expectation that in the time between 2010 and 2030 about 16,000 jobs will be created through development, construction, maintenance and dismantling of offshore wind farms and their electrical infrastructure. Being represented by three national interest organisations for offshore wind energy as well as four cluster organisations the sector is also embattled soundly (Belgian Offshore Platform 2019). Operators of Belgian offshore wind farms include C-Power, Norther, Parkwind and Otary.

The legal framework for the planning and development of offshore wind in Belgium is the Marine Spatial Plan which has been drawn up for the period 2014-20, as set in the Royal Decree of 20.03.2014 to establish the Marine Spatial Plan. This plan allocates specific areas in the Belgian part of the North Sea to specific activities. In addition, the designated area also serves for the so-called plug at sea, a high-voltage-station at sea which bundles the cables from the offshore wind farms and connects them with the mainland, now under construction. Nevertheless, due to its organisation as a federal state, a high number of regulations in Belgium is conducted on the regional levelIn 2020, a new Marine Spatial Plan will enter into force for the period 2020-26. This plan will designate an additional zone of 281km² for offshore wind. By 2030, the total installed capacity for offshore wind in the Belgian part of the North Sea shall equal 4.6GW.

For the development of an offshore wind farm in Belgium, a domain concession and an environmental permit are required. To obtain a domain concession for the proposed project area for a wind farm project, an application has to be submitted at the General Energy Directorate of the Federal Public Service Economy, SMEs, Self-Employed and Energy which advises the federal minister responsible for energy. The domain concession for the proposed area is granted by the Federal Minister for Energy. A domain concession may be granted before the environmental permit but will not come into effect until the environmental permit is in place.

The procedure for obtaining a permit is subject to the law on the Protection of the Marine Environment and two royal decrees (KB VEMA concerning the procedure for licensing and authorizing the activity and KB MEB concerning rules on the assessment of the environmental impact). The procedure for a permit to build and operate a wind farm entails the submission of an environmental impact study by the applicant, a public consultation, and an environmental impact assessment by the Scientific Service “Management Unit of the North Sea Mathematical Models and the Scheldt estuary” (MUMM). It then advises the federal secretary of state, responsible for the protection of the marine environment who then decides whether or not to grant the environmental permit. The full permit procedure takes about six to eight months. Both domain concessions and the environmental permits are limited in time.

3.2 Denmark

Not only was Denmark the first country to construct an offshore wind farm in 1991 (Vindeby), moreoverthe country has become a world leader in offshore wind energy by now. Over 40 per cent of all electricity consumed in Denmark comes from wind power and a rise to a share of 50 per cent until 2020 is expected. In 2018, 1,701MW were produced by offshore wind energy after a slight decrease in 2017 (1,264MW) compared to 2015 (1,271MW). The number of wind farmss accounted to stable 14 since one decommissioned wind park has been replaced by a new one so that also the number of turbines in 2018 (558) was significantly larger than in 2017 (504) and 2016 (515) (Energistyrelsen 2019). Also, 2018 marked the first year since 2013 that Denmark established new connections with a capacity of 61MW (Wind Europe 2019a). This rise can be interpreted as a new cycle for offshore wind energy as long as the upcoming years confirm the positive expansion trend. Recently, in June 2018, the Danish government, supported by a broad political majority, adopted a new Energy Agreement. With regard to offshore wind, the new Energy Agreement stipulates that three offshore wind farms with a total capacity of at least 2400MW will be established in Danish waters until 2030. It is expected that these new offshore wind farms will also be less expensive than previous farms. The distance of Danish offshore wind parks to shore ranges between 0.8 and 30km.

The Danish offshore wind sector is important for Denmark not only in terms of know-how, a thriving supply chain and exporting expertise and technology all over the world. With 30,000 people employed and annual revenue of DKK 90 billion accounting to about 2 per cent of the Danish BNP in 2017, the wind energy sectors is also a major economic factor for Denmark (Power Technology 2017). Danish offshore wind parks are operated by different companies such as SE Blue Renewable, HOFOR, Orsted, Vattenfall, Driftsselskabet Rønland Havvindmøllepark I/S and E.ON. Particularly domestic companies such as Orsted are very common in Denmark.

3.3 Germany

Germany constitutes the second largest market for offshore wind energy in Europe after the United Kingdom. Over 20 per cent of the German electricity demand has been met by wind energy (both onshore and offshore) in 2018 (BWE 2018). The installed capacity was 5,387MW in 2017 and is likely to reach 9.4 GW by the end of 2022 (Statista 2018). This corresponds to an annual growth of 200W to 1,200MW until 2022. With 969MW, the new capacity connected in 2018 was slightly lower than in 2017 (Wind Europe 2019a). It can be seen that the construction speed of new offshore wind energy plants significantly decreased due to a change in regulation and political construction goals (see below). Still, the number of wind parks has risen distinctly, going up from 16 in 2016 to 18 one year later and 23 in 2018 (Offshore Windindustrie 2017). 75 per cent of all German offshore capacity is located in the North Sea Region whereby the remaining 25 per cent are located in the Baltic Sea (NEP 2018).

North Sea wind parks are mostly located in the “Ausschließliche Wirtschaftszone” (exclusive economic zone), an economic zone that lies beyond the shore area and can amount to 200 sea miles from the baseline. German offshore wind parks are generally constructed in larger distance to shore than in other NSR countries: The range covers distances between 0.1 and 130km. This way, the potential aesthetical downsides of wind parks at the coast are minimized and larger plants with a higher electricity generation become feasible. On the other hand, costs and complexity of German high sea wind parks are also higher compared to near shore sites. The overall expenditure on offshore wind across all supply chain activities is likely to increase to about €3.5 billion in 2022, whereby the turnover already amounted to €2.6 billion in offshore wind industry in 2016 and €12.5 billion in wind energy in general (NEP 2018; Destatis 2016).

Currently, around 27,000 people are employed in the German offshore wind energy business. These are not only limited to the coastal areas but also Southern and Western German regions benefit due to industrial value chain interconnections (BWE 2019). Over the last decades not only the number of offshore wind parks and turbines has gone up but also their size, power and efficiency. The data for onshore wind energy plants give an idea of the development: While the plants in 2017 were 71m high, had a rotor diameter of 58m and 1,115KW power, modern plants in 2018 are on average were 132m high, had a rotor diameter of 118m and produced 3,233KW each (BWE 2018). Although offshore wind parks differ from their onshore counterparts, a comparable trend can also be observed here.

The German offshore wind parks operating or under construction are managed by ENOVA, DOTI (EWE, E.ON, Vattenfall), Ocean Breeze Energy, WindMW GmbH, Wetfeed Offshore Energy, Vattenfall, Stadtwerke Munich, RWE, Trianel Windkraftwerk Borkum, wpd, Orsted, E.ON, Highland Group, Siemens Financial Services, Copenhagen Infrastructure Partners, OWP Nordergründe GmbH & Co. KG, Northland Power Inc., Innogy SE, ONP Management GmbH, Stadtwerke Zurich, EnBW and Enbridge, sometimes in different combinations and collaborations with each other. The main players in the German offshore wind energy market are considered to be Orsted (formerly Dong), WPD, EnBW, Northland Power, E.ON, HypoVereinsbank, Global Infrastructure, ABB, and Engie Fabricom (NEP 2018). It can be seen that the variety of different players is relatively high in the German offshore wind industry sector compared to other NSR countries. On the other hand, the number of cluster organisations or interest organisations for this sector is relatively limited in Germany.

The German offshore wind industry underlies some specific regulations, particularly when it comes to nature protection and to minimize the impact on the landscape. In order to comply with these standards, German offshore projects must be realized in locations far away from the coast in often deeper waters compared to British or Scandinavian offshore wind projects. Many of the suitable locations for German projects are located within the 12-seamile-zone in the “Ausschließliche Wirtschaftszone” (AWZ). The distance of at least 22.2 km to the shore thereby gives rise to higher technical complexities in terms of fundaments, cables, logistics and maintenance. Moreover, corrosion tends to be more aggressive in greater distances making the project’s maintenance more complex and important (BWE 2019).

The strategy for the development of offshore wind energy in Germany is set-out in different regulations. These regulative tasks from the national level are then interpreted and transformed into practical politics at the level of the federal states and regions. For instance, tapproval approve of planned offshore projects in the AWZ is a competence of the Bundesamt für Seeschiffahrt und Hydrographie (BSH, Federal Maritime and Hydrographic Agency of Germany) whereby all projects within the 12-seamile-zone fall into the responsibility of the particular federal states (BWE 2019).

The pivotal strategy for the expansion of offshore wind energy in the area of offshore wind is stated in the renewable energy law ("Erneuerbare Energiegesetz", EEG) that names specific targets for the share of renewable energies compared to the total energy production. The law states that offshore wind energy is a key technology to reach the target of minimum 80 per cent renewable energy in Germany until 2050. Accordingly, the actual target for offshore wind energy is 6.5GW for 2020 and 15GW for 2030. The EEG forms a framework for the offshore wind energy market by prescribing quotas for wind energy expansion which is controlled by specific funding rates. Recently, the EEG was adjusted insofar that the expansion corridor was strictly limited compared to previous market expansions. According to the EEG extension in 2017, all offshore wind projects willing to take up their work up from 2021 have to apply for funding in tender processes. The first round of tenders will take place in March 2021, whereby 3.1GW installed capacity with an operating begin between 2021 and 2025 have been tendered until 2018. The plan is that up from 2021, 700 to 900MW shall be tendered each year so that the goal of 16GW installed capacity will be reached by 2030 (BEW 2019). The renewed regulation is considered to be the reason for declining offshore wind growth in Germany.

The EEG is complimented by the offshore-grid development plan 2030 (Offshore-Netzentwicklungsplan 2030, O-NEP). This is an official offshore-grid development plan commissioned and approved by the "Bundesnetzagentur" (BNetzA, Federal Network Agency) and published by the four German network operators, 50Hertz, Amprion, TenneT and TransnetBW. The O-NEP is part of the national grid development plan (NEP) to achieve countrywide transportation of renewable energies. The latest version of the O-NEP was published in 2017 and will be replaced by the offshore area development plan (Flächenentwicklungsplan, FEP) due to the new wind-energy-on-sea-law (Windenergie auf See-Gesetz, WindSeeG) from 01.01.2017. The FEP will be published by the Bundesamt für Schifffahrt nd Hydrographie in close cooperation with the BNetzA and the Bundesamt für Naturschutz (BfN) in 2019. In this process, the four grid operators can submit their comments and statements for a realistic expansion plan. The FEP will be responsible for the offshore development from 2026 onwards and for updates every four years.

The O-NEP describes the development of the German offshore wind parks' grid connection in the North and Baltic Sea until the year 2030/35 in two different scenarios. The expansion and construction activities set in this plan are binding and have to be realized in the mentioned time period. Basis for the development of the O-NEP are three conditions (1) the definition of the existing offshore grid whereupon the offshore grid will be further developed. (2) approval of a realistic scenario of possible energy production of the offshore wind parks and the energy consumption by the four grid operators and the BNetzA. (3) The third condition that has influence on the creation of O-NEP is the "Bundesfachplan Offshore" (BFO) which defines the corridors and locations for export-cables as well as transform- and conversion platforms for future offshore developments. Subsequently, a specific grid development plan will be created by the grid operators and improved after consultations with the BNetzA. Similar to the O-NEP, the process for the FEP includes also consultations between different governmental institutions, grid operators and the public.

3.4 The Netherlands

The Dutch North Sea is more than one and a half times larger than the size of the country's land surface and, at present, plays a role both as a source of energy, food and as a natural region. Due to its relatively shallow waters, favourable wind climate and proximity of good ports and (industrial) energy consumers, the Dutch North Sea provides opportunities to facilitate energy transition. The location of offshore wind parks ranges between 15 and 85km from the coast in the Dutch North Sea.

In 2017, 957MW of electricity were produced by offshore wind energy marking a significant increase compared to the previous year(357MW). The power is generated by 289 turbines in four wind parks whose number remained stable since the last wind park was completed in 2016. The capacity of the most recent wind park, Gemini (600MW), was higher than all other Dutch wind parks combined (357) and all plants together can now provide electric energy to over a million households (NEA 2019).

The scenarios of the PBL Netherlands Environmental Assessment Agency range from 12 to 60 or even 75GW in 2050. It is through this ambition set out in the Coalition Agreement – which would result in approximately 11.5GW of installed capacity in 2030 – that the government will be charting a course corresponding closely to the more ambitious PBL scenarios. This scale would only make sense if the wind farms were not solely used to meet the energy demand for electricity and light but also for the replacement of oil and gas as fossil fuels and raw materials in transportation, heating and industry. In 2018, the Netherlands did not grind-connect any additional offshore wind energy. Nevertheless, 2019 is expected to become a record year with about 1GW of new installations (Wind Europe 2019a). The wind parks in the Dutch sea are operated by Vattenfall, Eneco, Northland, Orsted, TenneT, Shell and others.

The Coalition agreement of the Dutch government contains the task of using offshore wind energy to realise an additional reduction of carbon dioxide emissions by four megatons by 2030 relative to the baseline set out in the 2016 National Energy Outlook. This task translated into a total scale of offshore wind farms of approximately 11.5GW by 2030. Taking into account the existing wind farms (approximately 1GW) and the wind farms to be realized under the current offshore wind energy roadmap to 2023 (approximately 3.5GW), this means that between 2024 and 2030, wind farms will have to be added in order to achieve a total energy proeuction of 7GW. This is in line with the 2016 Energy Agenda which assumed the roll-out of approximately 1GW per year for this period.

The development of offshore wind energy in the Netherlands takes place within the context of a broader transition towards a sustainable energy supply by 2050 and the role of the North Sea within that project. Here, the North Sea is subject to highly intensive use and is one of the busiest seas in the world. A vision is currently being developed in the form of a North Sea Strategy for 2030. The Offshore Wind Energy Roadmap 2030 will be a key starting point. This provides initial insight into the preconditions necessary from the perspective of the North Sea and a sustainable energy source as well as the corresponding further growth of offshore wind energy beyond 2030 moving towards 2050. This provides initial insights into the preconditions necessary from the perspective of the North Sea as a sustainable energy source and the corresponding further growth of offshore wind energy beyond 2030 moving towards 2050. The key preconditions relate to ecology, the interference with other interests in the North Sea, the integration on land of the connections with the high-voltage grid and the coordination with energy demand. The challenge faced is to find sustainable solutions for these issues with food production (fisheries and aquaculture) and the conservation and restoration of ecology and biodiversity.

The national government is working with the Energy Union to realise further integration of the energy market and to increase the sustainability of energy production. In addition, the Netherlands are working alongside nine neighbouring countries within the North Seas Energy Cooperation in order to learn from another, achieve better coordination of plans and to facilitate joint projects. In short, the fact that the North Sea is shared by multiple neighbouring states provides additional opportunities to achieve synergy with each other's wind energy activities during the implementation of the Roadmap.

The Netherlands are committed to achieve economic benefits through their bilateral contacts with neighbouring countries and the North Sea Energy Programme. Given the scope and complexity of energy transition challenges in general and the role of the Dutch North Sea in this regards, the Roadmap 2030 requires an implementation agenda that sets out the first crucial steps and through which knowledge is collected for the period beyond 2030. This will also involve a review of all possibilities of (re-)use of carbon dioxide storage infrastructure (CCS). The Dutch government will produce a CCS Roadmap in due course which will be developed in close cooperation with the market; review of the need for adaptation of the applicable law concerning offshore grids in consideration of any direct connections to the grid for industrial customers, conversion installations (e.g. power2gas), oil and gas platforms (electrification) and CCS installations. This will take shape within the framework of the legislative agenda.

The government's efforts will largely focus on the integration of wind energy into the energy system and demand management to allow fossil fuels and raw materials to be replaced by alternatives that can be produced using electricity generated by offshore wind farms. This will form part of the national Climate Agreement. In addition, the government plans to intensify international and regional cooperation in relation to sustainable energy in the North Sea, inter alia in form of an exploratory review conducted jointly with neighbouring North Sea countries regarding the combination of wind farm connection and offshore interconnection. The Offshore Wind Energy Roadmap 2030 is emblematic for the next steps the Netherlands are taking to achieve valuable and responsible use of the North Sea in terms of nature conservation, food supply and the transition to a low CO2 energy supply by 2050.

Also, the Dutch government currently reviews whether a number of gas and oil platforms that will remain in the North Sea for a longer period of time will be able to draw the required energy for the installations on those platforms from the offshore wind farms. This way, additional savings in CO2 emissions could be achieved. Given the estimated distance between the wind farm zones and most mining platforms, the required additional investment and the brief time period expected within which wind farms will be present while the mining platforms are still operational, there is a real chance that electrification of the oil and gas platforms would ultimately make no economic sense in most cases. The announced revision and integration of the Electricity Act 1998 (Elektriciteitswet 1998) and the Gas Act (Gaswet) into a new Energy Act 11 should allow offshore mining platforms to be connected to the grid.

3.5 Norway

Until now, no offshore wind park has been installed on the Norwegian Continental Shelf. However, a floating wind turbine prototype (“Hywind”, 2.3MW), designed for deep waters of 200m and above, has been installed at the Western coast of Norway. Since energy production in Norway traditionally focuses more on technologies such as water power the demand to invest in research and demonstration cases of offshore wind energy is relatively low. The total Norwegian electricity demand of 13,281GW is mostly satisfied by hydropower providing about 94 per cent of the overall energy demand. Another 3.7 per cent is provided by wind energy. As a results,Norway’s energy consumption relies on almost 98 per cent renewable sources under good conditions (SSB 2019).

Nevertheless, in 2016 a white paper (“Power for Climate, Energy policy by 2030”) called for the government to take further steps towards offshore wind energy by providing a subsidy scheme for offshore demonstration projects and other marine renewable energy technologies (NEP 2018). Still, Norway is very committed to onshore wind energy which amounted to an installed capacity of 1,188MW in 2018 so that the basic competencies for wind power are present (NVE 2018). In 2017, total investment into the offshore wind sector in Norway amounted to NOK440 million which is about €45 million converted (Norcowe 2017).

In December 2017, the Norwegian parliament approved a resolution for one or possibly two offshore demonstration sites for floating wind energy. Still, little has happened since. One important reason for this is that to a large extent the electricity production in Norway is covered by hydro-power (approximately 94 per cent) and the price for electricity is low compared to European standards. Moreover, the current government in Norway has stated that they will not subsidize wind parks. Also, there is still potential for the installation of land-based wind parks which would be less costly compared to offshore wind parks. Correspondingly, their share of electricity production rose from 1.7 per cent in 2016 to 2.4 per cent in 2017. The increasing amount of produced electricity will mainly be exported since the demand in Norway is already well covered. Nevertheless, new dynamics for offshore wind is expected since the Norwegian Ministry of Petroleum and Energy plans an open hearing on the potential of offering an area at the coast of Rogaland for offshore wind energy. Moreover, additional input is to be gathered on another area of the Southern North Sea. Both areas combined could generate up to 3.5GW of offshore wind (Russel 2019b).

A new possibility for offshore wind parks is now arising as they may be directly connected to the offshore production facilities for oil and gas and thereby reduce the environmental footprint from these activities. It is also worth mentioning that several Norwegian companies, such as Equinor (former Statoil), Statkraft, DeepOcean and several ship owners are engaged in installation and operation of offshore wind parks in other parts of the world. Particularly cable installations have been an important market segment for Norwegian companies in the offshore area. In 2017, Equinor opened the world's first floating offshore wind farm "Hywind Scotland".

3.6 United Kingdom

The United Kingdom is Europe's largest market for offshore wind energy with 49 per cent of Europe's gross capacity brought online in 2018 (Wind Energy 2019). In 2018, the UK had 7,525MW of installed capacity and will likely reach 13.6GW by the end of 2022. The increase from 5,793MW in 2017 and from 30 wind parks with 1,571 turbines to 34 wind parks with 1,878 turbines in 2018 shows that these ambitious goals are far from being unrealistic (Russel 2019a). The electricity demand of the UK is met by renewable energy sources to an extent of about 27.9 per cent.

Between 2019 and 2022, the annual installed capacity is likely to be between 400MW and 1,700MW expressed in an annual growth rate of 5.7 per cent (NEP 2018). Expenditure in offshore wind energy across all supply chain activities in 2022 will be about €6,600 million converted, respectively €30,000 million converted between 2018 and 2022 (NEP 2018). The UK's relevance for offshore wind energy is also reflected by the fact that the world's largest operational wind farm (Walney 3 extension, 657MW) is located in the UK. Still, with 1,312 MW the connection of new offshore wind in 2018 was slightly lower compared to the previous year (Wind Europe 2019a). Moreover, the world's first floating wind farm (Hywind pilot park) is also located in Scotland, UKy consisting of 5 turbines producing 30MW combined. The floating technology allows the wind park to be erected in waters with a depth of 95-120m which would not be accessible with regular foundations. Moreover, with Kincardine Floating Offshore Windfarm, Scotland has another floating wind farm of eight turbines 15km south east of Aberdeen. Here, the water depth is around 60-80m and the wind park extends to an area of 110km² (NorthSEE 2017a). Comparable to Germany, wind parks in the UK part of the North Sea are located in greater distances from the shore, ranging between 17 to 164km.

The sites for offshore wind are located in UK territorial waters and in the UK's exclusive economic zone. Moreover, offshore wind projects in England and Wales are considered nationally significant infrastructure projects and therefore are examined by the Planning Inspectorat. In Scotland, possible applications are examined by Marine Scotland. The list of operators of British wind farms in the NSR includes Orsted, SSE Renewables, Talisman Energy, E.ON, Statoil, Vattenfall, Siemens, RWE, Npower, Stadtwerke Munich, GIB, Equinor, Masdar, Centrica, TCW, Centrica, Ore catapult levemouth (originally Samsung), Statkraft, EDF-EN, Marubeni and Scottish Power. The operators regularly act in consortiums or with subsidiaries of the large players. The main players in overall UK offshore wind are considered to be Orsted (formerly DONG), Statoil, Vattenfall, Scottish Power Renewables, SSE, Innogy, Siemens Gamesa, MHI Vestas, Seajacks and MPI Offshore (NEP 2018).

The UK presents favourable conditions for offshore wind in the decades to come. Starting from a turnover of £2.99 billion in 2018, the UK offshore wind sector has the potential to become one of strategic importance to the UK supporting a thriving UK supply chain and exporting expertise and technology all over the world. In 2020/21, under a strong growth scenario, the sector could deliver up to£7 billion Gross Value Added (GVA) to the UK economy (excluding exports) and support over 30,000 full time equivalent UK jobs. In 2016, already 5,500 people in the UK were employed in the British offshore wind industry. Moreover, it has been estimated that by 2030 offshore wind could increase net exports by £7-18 billion.

The UK government strategy to support sustainable development and growth of the offshore wind industry can be summarized in five bullet points:

(1) Providing market confidence and demand visibility. The UK government put in place a framework to maintain the UK's position in the offshore wind industry through an electricity market reform which will offer industry guaranteed price support until the 2030s and which helps to provide the certainty needed to underpin long term investment.

(2) Building a competitive supply chain. The MAS Offshore Wind Supply Chain Growth Programme (GROW: Offshore Wind) is a new, jointly led, service delivered by the Manufacturing Advisory Service (MAS), with Grant Thornton, RenewableUK and the Advanced Manufacturing Research Centre (AMRC), supported by the Regional Growth Fund. The program will focus on SMEs already acting in the sector looking to increase capacity and on those with the capability to enter the offshore wind manufacturing supply chain. It will provide them with market insights into customer needs and will offer a comprehensive package of support delivered by specialists.

(3) Finance. As well as the business support program described above, the government has a number of initiatives, delivered in partnership with the private sector, to help businesses access the finance they need to grow. These are part of the Business Bank program. In addition, the UK government allocates support for infrastructure projects via the UK Guarantees Scheme which would provide up to £40 billion in guarantees for priority infrastructure projects. Waterside manufacturing locations for renewable energy projects are considered eligible so the scheme could be used to guarantee debt finance for a port or other waterside location to upgrade its infrastructure.

(4) Building a highly skilled workforce. Future growth in the industry will result in more demand for highly skilled staff. Based in Energy & Utility Skills Ltd Work Force Planning Model and Working for a Green Britain vol2, delivering a high growth scenario in offshore wind would result in massive job growth in highly skilled roles. There are several government and industry-led programs to develop and retain skills, such as the Talent Retention Solution, an industry-led initiative to retrain and redeploy engineers, the Talent Bank, and the Renewable Training Network. There is also an employer-led National Skills Academy for Power as well as government funding for apprenticeships, with additional support for smaller employers.

(5) Supporting innovation. By supporting innovation by 2050, offshore wind innovation has the potential to deliver cost savings of £45 billion as well as business creation within the UK worth £18 billion. The Technology Strategy Board has funded the Offshore Renewable Energy (ORE) Catapult over its first five years of operation.

The consequences of the Brexit in terms of energy supply in the UK and future links to the rest of Europe are still unclear (NorthSEE 2017a).

4. Decommissioning of Offshore Wind Turbines in General

Different methods of decommissioning can be found in literature, namely partial and total removal of the offshore wind foundations. Moreover, 21 criteria have been identified that might influence the results falling under the four categories economic, environmental, social and technical[4] (Kerkvliet 2015). Meanwhile outdated calculations for the UK led to the conclusion that about £40,000 was the average expectable cost for decommissioning of one MW of offshore wind energy. This would have amounted to about 2.5 per cent (undiscounted) of the total project costs which were assumed to be £1.5 million per MW or about 2 per cent of operating costs when spread over the project's lifetime (Climate Change Capital 2010). New calculations operate with significantly higher estimated costs from £100,000 to £300,000 per MW for modern wind parks which consist of larger structures and are located in deeper waters in greater distances from the shore. The structure of costs is calculated in such way that 40 per cent of the overall decommissioning cost are offshore preparation, 35 per cent foundation removal, 19 per cent vessel mob/demobilisation and 6 per cent disassembly. Decommissioning time is estimated to range from 0.7 to 1.7 days per MW depending on the site structure and decommissioning technique (Topham/McMillan 2017).

Overall, there is no one-size-fits-all approach to decommission all offshore sites since the requirements of a decommissioning scheme are considered to be unique to each site (Topham/McMillan 2017). Still, a variety of questions arising from the decommissioning process and which are shared challenges to be faced by all sites have not been addressed yet. For instance, the blades are large parts in a wind plant but being constructed from composite materials proper recycling currently is near to impossible (Liu/Barlow 2017). Moreover, decommissioning schemes will not only be useful when it comes to taking down offshore wind sites but also for transformer platforms, meteorological masts and other offshore infrastructure. Different solutions need to be found for all different kinds of infrastructures including foundations, subsea structures or export cables (Topham/McMillan 2017).

The challenges in how to deal with offshore wind turbines at the end of their lifecycle do not only arise in Europe but also come into play in other regions with turbines in a similar state. Nevertheless, most experience is limited to onshore wind farms which are more than 20 years old. For instance, the United States mostly discuss replacing or refurbishment of turbines since their sites have the best

[4] *Economic:* Cost of decommissioning; monitoring costs; maintenance costs; liability costs
Environmental: Increase in biodiversity; increase in biomass; invasive species; benthic impacts; water quality; emissions during decommissioning; impact on marine mammals
Social: opportunities for commercial fishing; opportunities for recreational industries; navigation; public access; risks; employment creation
Technical: Repowering possibility of the site; track record

wind resource areas and transmission access is already established. New technology can then ensure that upgraded wind farms operate at both lower cost and higher output (AWEA 2018). In this context, repowering, meaning the complete removal and update of turbines and foundations, becomes financially attractive after about 20-25 years of service compared to an investment in a greenfield site (Lantz et al. 2013). Cases of complete decommissioning were rare in the U.S., even in the onshore sector: In 2017, only 43MW of installed onshore wind capacity were decommissioned, mostly limited to sites that had been established in the 1980s. The cost and other responsibilities for decommissioning rely on the company side which has to sign a legally-binding contract to lease land before the project is realized and which involves restoring the land as it was before. Neither landowners nor the government must deal with the expenses of decommissioning. Due to economic reasons, recycling of valuable machines and resources is often conducted by the companies but not put down as a requirement in legal contracts (AWEA 2018).

The United States are also dealing with questions of decommissioning offshore wind turbines which is reflected in a 2014 report prepared by the Bureau of Ocean Energy Management (BOEM). The report estimates the decommissioning cost of the Cape Wind Energy Project under the current regulatory regime. With information on size, quantities and types of materials to be decommissioned as well as the equipment and vessels needed to perform the decommissioning process, the costs are likely to range in a corridor between $71,073,507 and $125,550,261 (respectively €78,031,603 and €137,841,631 converted) whereby the expected cost are calculated to be $103,299,968 (€113,413,034 converted). The report found that factors contributing most significantly to total decommissioning cost were (1) type, quantity and day rates of equipment and vessel suites, (2) estimated time to complete each work process and (3) time required to transport and dispose all quantities and types of materials. On the other hand, potential salvage for recycled materials is also to be taken into account and was estimated to be $22,875,920 for the U.S. case study (BOEM 2014).

5. Decommissioning of Offshore Wind Turbines in the North Sea Region

In 2018, one wind farm of seven turbines and a capacity of 10.5MW was decommissioned in Europe, more specifically Utgrunden I wind farm in Sweden. The wind farm was commissioned just in 2000 underlining that decommissioning can also come into question before the expected life cycle of 20-25 years has expired (Wind Europe 2019a). After the wind park Yrre Stengrund this was the second decommissioning project successfully conducted in Sweden. Other decommissioning projects were realized in the UK in 2017, 2004 and 2000 as well as in Germany (Hooksiel) and Denmark (Vindeby). Apart from that, the number of decommissioned wind farms in the NSR is rather limited. Also, the experience differs significantly between the different NSR countries as well as the relevance of decommissioning offshore wind farms due to different construction dates and operating ages.

As it has been shown above, the year of decommissioning of a wind farm depends on various factors. On the one hand, mechanical attrition and the expected repair cost play a major role when considering how long a wind plant shall operate. Another factor is the legal allowance determining a specific year for decommissioning which might be delayed in certain cases. Moreover, expiring funding for wind plants might also be a reason to antedate decommissioning. All in all, we assume a life expectancy of 20 years for the following considerations. Although modern offshore wind farms list a life expectancy of 25 or even 30 years it can be expected that their relatively longer life expectancy builds on the experience gathered through early wind farms which again lack this experience and will therefore not last as long as the modern ones. Based on this assumption, figure 13 shows that the number of turbines coming into question for decommissioning will steadily increase from 2020 onwards. 22 turbines in 2020, 80 turbines in 2022 and 123 turbines in 2023 will raise the question of how decommissioning must be organised, which infrastructure is existent and which needs to be established until then and how unsettled legal questions in the relatively new field of offshore wind farm decommissioning will to be resolved.

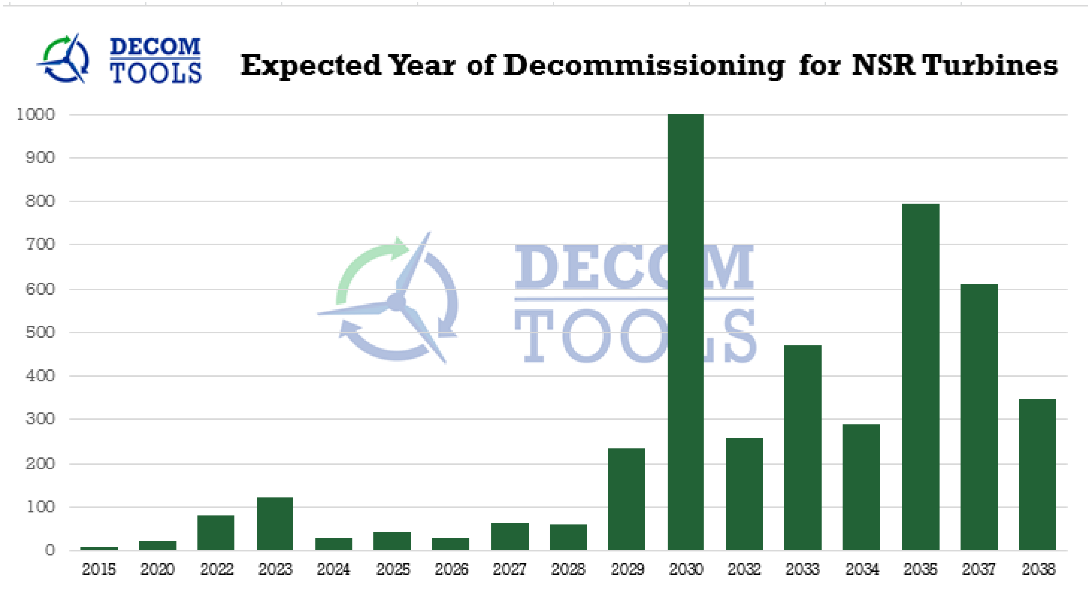

Figure 13: Expected year of decommissioning of wind turbines in the NSR

Source: Own depiction on basis of data presented in Annex 1

Since experience with decommissioning is rare and legislation as well as technologies, skills and infrastructure still need to be developed, it appears fruitful to look at the current regulation, debates and possible outlooks. Particularly the question how radical decommissioning is to be carried out will play a major role in the future not only when it comes to decommissioning costs but also with respect to ecological aspects, repowering or infrastructural requirements.

In the text below the current overall regulation and legislation regarding decommissioning is described as well as country-specific experience if available.

5.1 Belgium

Specific legislation dealing with decommissioning does not exist in Belgium and new processes for decommissioning will need to be developed in the upcoming years. The current permits for offshore wind farms refer only in general terms to the requirements regarding decommissioning given the high uncertainty concerning techniques, processes and principles for decommissioning in the next years. Instead, they allow for consultation so new evolutions and circumstances can be taken into account at the actual time of decommissioning.

For the moment, the individual permits for offshore wind farms contain the following obligations concerning the decommissioning per project:

- A bank guarantee for decommissioning is established and is a condition to use the permit
- The site's restoration to its original condition is taken up in the permit. However, the need for consultation concerning the practical implementation of this requirement and how far this can go is also included. Decommissioning will be the subject of further studies and consultation to consider all possible aspects. For example, a possibility is that new projects are permitted to use the site and that possible aspects such as the removal of erosion protection will need further investigations
- The system and timing of decommissioning as well as possible alternatives will need the approval of the different governments / governance levels.

All these elements will be discussed at the appropriate time in each of the supervisory committees for these permits but also within the broader framework, such as the new Marine Spatial Plan, the award of possible new concessions and the renewable energy goals of Belgium.

At least one port in Belgium is considered to be suitable for decommissioning projects so that required infrastructural adaptations for offshore wind decommissioning will mostly include port infrastructure and logistical aspects.

5.4 Denmark

In September 2017, one of the world's first offshore wind sites, the demonstration project Vindeby, consisting of eleven turbines operated by Orsted, has been decommissioned after almost 27 years of operation. The wind farm was the first ever offshore wind farm and mainly built to test the operability of wind turbines in harsh environments such as the sea as well as to test their commercial value. The eleven wind mills were placed between 1.5km and 3km from the shore, displayed a height of 54m and produced 0.45MW each adding up to 5MW in general. The mills were built on gravitational concrete foundations from an artificial dock nearby. The turbines came in one piece and were erected using cranes. The overall procedure was much more basic compared to the modern highly-developed mega projects (Power Technology 2017).

Not only was Vindeby the first offshore wind farm but also the first one to be decommissioned in 2017. The decision on decommissioning was taken when the consent expired. Although extending the consent was a possibility, the gears' condition showed significant need for refurbishment so that the decommissioning decision was taken due to economic reasons. The procedure might have been different if the number of turbines and therefore the amount of invested capital had been higher. Accordingly, modern wind farms operate under different circumstances leading to possibly other considerations.

The decision on which techniques should be used for the decommissioning of Vindeby was taken on the basis of a tender for industry which was asked to come up with ideas on how to take the wind park down. The chosen concept was chosen that appeared to be most feasible in terms of technical and financial aspects, whereby recycling was realized as far as possible for instance of steel or concrete rubble. Problems were reported due to a partial lack of documentation or the demolition of the concrete foundation which turned out to be more massive than expected. On the other hand, extracting the cables showed to work effortlessly. Since modern wind mills are based on monopiles rather than concrete foundations and also modern models are hardly comparable in size, construction or material, knowledge gathered from this first offshore decommissioning project is to mostly expect the unexpected and to make sure documentation is on point (Power Technology 2017).

The decommissioning of Vindeby has increased awareness for a new market opportunity of offshore decommissioning in Denmark. Generally, decommissioning activities are regulated by both international rules and national legislation and are specified in the "Decommissioning Permit" granted by the Danish Energy Agency (DEA) to the concessionaire of the specific offshore wind farms planning to be decommissioned. The "Construction License" from the DEA, granted to the concessionaire prior to installation of an offshore wind farm states that the concessionaire is obliged at its own account to restore the area to its former condition, including to carry out the necessary remediation and clean up. The entire electricity production plant has to be decommissioned and disposed pursuant to a decommissioning plan approved by the DEA. As soon as the electricity production license expires, the plant is not maintained or destroyed, the plant is no longer used as a wind farm or the terms and conditions of the license granted are not being complied with or not being met. The DEA can require the concessionaire to remove the plants in full or in part in accordance with a timetable stipulated by the DEA.

The concessionaire is required to submit a plan for decommissioning of the turbines and the cables to seek approval from the DEA. The plan has to be submitted no later than two years before the electricity production license expires or two years before the date at which one or more facilities are expected to have served their purpose. The plan has to contain an account of how the plant facilities will be removed as well as a proposal for a timetable. If only partial removal of the plant is required, this may be accompanied by a requirement that no remaining parts of the foundations become exposed as a consequence of natural, dynamic changes in the seabed sediment. Moreover, it is likely that there will be requirements to use the best available technology and the best environmental practice when removing the plant.

A further detailed assessment of possible environmental impacts entailed by the plan must be submitted together with the decommissioning plan. The assessment gives the DEA a decision basis for whether an EIA report needs to be prepared. If no EIA report is required, the DEA will make its decision available to the public and will grant authorization to the application at the same time. The decommissioning plan and the assessment of the environmental impacts will be used by the DEA for consultation with relevant authorities in order to set specific terms for decommissioning. This can include terms of safety of navigation, marking and buoying or environmental protection.

The concessionaire is also required to provide an adequate guarantee for decommissioning the plant which needs approval by the DEA. The guarantee must be provided within12 years after the first turbine was connected to a grid and started producing energy.. This corresponds to roughly half of an offshore turbine's lifecycle. This also applies in the event that a duty to decommission the plant arises earlier than that. The guarantee must be at least DKK 600 million (about €80 million) unless the DEA approves a lower amount. If the concessionaire does not meet the duty to clean up the area, the expenditures for clean-up will be paid for by the guarantee to the extent that the guarantee covers these expenditures. If by no later than 11 years and six months after grid connection of the first turbine the concessionaire can document that cleaning up costs are likely to be less than the DKK 600 million, the DEA may decide to reduce this amount. A third party verification of the assessment of dismantling cost may be required by the DEA:

At least DKK 100 million of the guarantee must be provided in form of a guarantee from a financial institution, insurance company or other that has to meet special requirements. These will be set by the DEA in good time before the deadline for provision of a guarantee. The remainder of the guarantee may be provided in form of a parent-company guarantee if the guarantee covers all potential costs associated with cleaning up. In this case, financial capacity documentation of the parent company must be provided to the DEA every five years so that the financial capability can be assessed regularly.

5.3 Germany

The current development plans for offshore wind energy in Germany exclude decommissioning or renewal aspects of aging turbines. For the moment, the focus of German national and regional policies on offshore wind energy lies on providing a framework for expansion and organizing its expansion by targets and financial support such as guaranteed energy prices for wind energy. Questions of decommissioning are coming into play but mostly by the motivation of wind companies that are obliged to decommission their facilities at some point. Accordingly, decommissioning activities such as projects or conferences are mainly organised by companies or scientific institutions (see e.g. "Conference on Maritime Energy" or the projects "SeeOff" and "DecomTools").

Decommissioning of onshore wind parks in Germany is regulated differently depending on the federal states of Germany and their legal framework. For instance, it remains an open question whether the foundation has to be removed entirely or only partially when different interpretations of an unclear national regulation come into play as well as specific arrangements in building contracts. Although land decommissioning is already established but still lacks a clear regulation. Something similar is to be expected for the regulation of offshore decommissioning in Germany. The same holds for regulations on recycling where a definite national regulation does not exist yet. Moreover, older wind parks were not designed to be recycled so that problems in this context due to a lack of regulation are to be expected – both for land and for offshore decommissioning.

One of the first decommissioning projects of an offshore wind plant in Germany was pursued in 2016 with the demonstration site Hooksiel. The site erected in 2008 consisted of only one turbine and was located in a nearshore location only 400m from the shore. The wind mill produced by Bard had a hub height of 90m, a rotor diameter of 122m and a capacity of 5MW. The decision to take down the facility was made after public subsidies expired and refurbishment was not considered to be economically feasible. The decommissioning promises important information for further deconstruction projects since the site was constructed similarly to the Bard 1 offshore wind site finished in 2013 and consisting of 80 wind turbines (Hanz 2016).

All in all, 367 offshore wind turbines have been decommissioned in Germany until 2017 and it is expected that this number is going to go up to at least 2,000 until 2040 (Fraunhofer IWES 2018; FIS 2013).

5.4 The Netherlands

Regulation on offshore decommissioning in the Netherlands states that offshore wind farms and the cables used to connect them to the onshore grid have to be removed once they are not in use anymore. This also holds for other materials that ended up in the area of the OWF during construction, exploitation or decommissioning. All this is regulated in the Water Decision. However, under specific circumstances, it is possible to obtain permission from the responsible minister to leave the installation of cable in place. Moreover, the minister can decide that the export cable has to be left in place if its removal would lead to "damage to the marine environment or to other rightful usages of the sea".

The removal of offshore wind farms or export cables follows a removal plan which the project developerdrafts at least four weeks before the start of the removal phase. Once the offshore wind farm or cable is removed, this has to be notified to the responsible minister. This system allows for a for the minister's margin of appreciation to decide to what extent decommissioning should take place.

By now, one Dutch wind farm has been repowered.

5.5 Norway

In Norway, offshore decommissioning activities are already a well-established industry although almost completely related to the oil and gas installations, both topside and subsea. This activity is regulated by both international and national rules and regulations. Most likely, these rules will also shape potential decommissioning processes of offshore wind parks on the Norwegian continental shelf – although this is not relevant yet since no offshore wind parks are in place for now.

Basically, the rules and regulations state that all installations have to be removed when they are not in operation anymore. In the past, some exceptions weremade for big concrete structures that were impossible or very difficult to remove. Buried cables and pipelines that are not in conflict with fisheries or other activities may be allowed to remain in the seafloor after flushing to remove any hydrocarbons or toxic substances.

The main removal method was to cut the installations into smaller or larger sections / modules, depending on the lifting capacity of crane vessel, and then to transport the pieces ashore on deck of barges or by towing. Subsequently ashore, special receiving facilities have been established to dismantle the sections / modules for reuse or recycling the components and materials. Strict regulations state how to deal with toxic material and other possible pollution sources. These receiving facilities often are former construction yards where offshore installations were built in the past. They are sited in sheltered waters, typically in a fjord, with deep-water quay facilities enabling them to accommodate large vessels.

Since three Norwegian ports are suitable for decommissioning projects (Stord base, AF Decom, Sognefjørn) the infrastructural basis for further projects is already established. Although the ports have been used for decommissioning of oil and gas platforms already, only minor adaptations should be required in order to make their infrastructure also fit for offshore wind decommissioning.

5.6 United Kingdom

The last practical decommissioning projects of offshore wind farms in the UK were the 80MW site North Hoyle in 2004, respectively the two-turbine 4MW site Blyth in 2000 (Richard 2018). Nevertheless, decommissioning activities in the UK are, up to now, limited mostly to oil and gas installations as well as pipelines. These are regulated through the Petroleum Act 1998 which covers the United Kingdom Continental Shelf (UKCS). Owners of oil and gas installations and pipelines are required to decommission their offshore infrastructure at the end of an oil field's lifecycle. The measures to decommission installations and pipelines are to be discussed in decommissioning programs listing all items of equipment, infrastructure and materials that were installed or drilled together with a description of decommissioning solutions for each.

Despite most offshore wind farms in the NSR having a marine license for 25 years which will expire afterwards, only the UK has a fully-coasted decommissioning program in place. Prior to licensing, this program explains how the developer plans to remove the installation after the end of the lifecycle and how the costs will be dealt with (NorthSEE 2017a).

When it comes to decommissioning of oil and gas infrastructures, a waste hierarchy is applied. This means that options for dealing with waste in terms of their sustainability exists beginning with the generation of waste, re-use either for the same or a different purpose ahead of recovering value from the waste through recycling. Only if none of these options work, disposal should be considered. Regulation also states how to deal with different sorts of installation (oil and gas). While complete removal on land is an option for all kinds of infrastructure (fixed steel <10,000, fixed steel >10,000, concrete – gravity, floating and subsea), only concrete – gravity might be left wholly in place or disposed at sea. Moreover, subsea and floating infrastructures disqualify for partial removal to land, whereby all kinds of infrastructure are open for re-use. Still, only foundations or part of the foundations may be left in place. Above any partially removed installation a minimum water clearance of 55m is required as well as not to project above the sea surface and all measures need to be considered by the decision of the responsible ministry (Department of Business, Energy & Industrial Strategy 2018a).

Due to a lack of past experience regarding large scale offshore decommissioning projects, there is a high amount of uncertainty regarding the cost of decommissioning offshore wind farms in the UK. A study implies a cost range of £1.03 billion to £2.94 billion for the department of business, energy and industrial energy in case the developers might not able to fund the decommissioning process themselves. The sum would cover the decommissioning of the 37 offshore wind farms operating or under construction at that time. The balance of between £250 million and £690 million would have to be paid by the Crown Estate and the Scottish government. Thereby, costs can vary significantly depending on which vessels are used or on the duration of the project. However, the risk that public bodies have to pay for decommissioning instead of the developers is considered not to be high (Department of Business, Energy and Industrial Strategy 2018b).

In order to close the gap in research on decommissioning, the Centre for Advanced Sustainable Energy (CASE), a new industry driven research centre, will look into a number of key areas including decommissioning of offshore wind farms.

6. Sources

American Wind Energy Association (AWEA) (2018): Decommissioning. [Online]. Available at: https://www.awea.org/policy-and-issues/project-development/state-and-local-permitting/decommissioning. [Accessed May 13th 2019].

Belgian Offshore Platform (2018): Projecten. [Online]. Available at: https://www.belgianoffshoreplatform.be/nl/projecten/. [Accessed May 27th 2019].

Belgian Offshore Platform (2019): FAQ – Economy. [Online]. Available at: https://www.belgianoffshoreplatform.be/en/faq/. [Accessed May 27th 2019].

Bernthal-Hooker, J. (2019): Vineyard moves three turbines. [Online]. Available at: https://www.4coffshore.com/news/newsItem.aspx?nid=13850. [Accessed July 1st 2019].

Bureau of Ocean Energy Management (BOEM) (2014): Decommissioning Cost Estimation for the Case Wind Energy Project. Prepared by PCCI – Marine and Environmental Engineering.

Bundesministerium für Wirtschaft und Energie (BMWi) (2015): The energy transition – a great piece of work. Offshore wind energy – An overview of activities in Germany.

Bundesministerium für Wirtschaft und Energie (BMWi) (2019): Technologien, Windenergie auf See, Ziele. [Online]. Available at: https://www.erneuerbare-energien.de/EE/Navigation/DE/Technologien/Windenergie-auf-See/Ziele/ziele.html. [Accessed May 7th 2019].

Bundesamt für Schifffahrt und Hydrologie (2017): Bundesfachplan Offshore für die deutsche ausschließliche Wirtschaftszone der Nordsee 2016/2017 und Umweltbericht, Bundesamt für Schifffahrt und Hydrologie, Hamburg.

Bundesamt für Schifffahrt und Hydrologie (2018): Vorentwurf Flächenentwicklungsplan 2019 für die deutsche ausschließliche Wirtschaftszone der Nord- und Ostsee, Bundesamt für Schifffahrt und Hydrologie, Hamburg.

Bundesverband Windenergie (BWE) (2018): Zahlen und Fakten. [Online]. Available at: https://www.wind-energie.de/themen/zahlen-und-fakten/. [Accessed May 28th 2019].

Bundesverband Windenergie (BWE) (2019). Offshore: Windenergiegewinnung auf See. [Online]. Available at: https://www.wind-energie.de/themen/anlagentechnik/offshore/. [Accessed April 29th 2019].

Climate Change Capital (2010): Offshore Renewable Energy Installation Decommissioning Study, Final Report. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608023/900-offshore-renewable-installation-decom.pdf. [Accessed July 2nd 2019].

Cohen, A. (2019): As Global Energy Demands Grows, So does Appetite For Offshore Wind. [Online]. Available at: https://www.forbes.com/sites/arielcohen/2019/03/26/as-global-energy-demands-grows-so-does-appetite-for-offshore-wind/#36e4dab365e7. [Accessed June 21st 2019].

Department of Business, Energy & Industrial Strategy (2018a): Guidance Notes – Decommissioning of Offshore Oil and Gas Installations and Pipelines.

Department of Business, Energy & Industrial Strategy (2018b): Cost Estimation and Liabilities in Decommissioning Offshore Wind Installations. Public Report.

Destatis (2016): Wirtschaftsfaktor Windkraft: 17,7 Milliarden Euro Umsatz im Jahr 2016. [Online]. Available at: https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2018/06/PD18_216_325.html. [Accessed May 28th 2019].

Energistyrelsen (2019): Eksisterende havvindmølleparker og aktuelle projekter. [Online]. Available at: https://ens.dk/ansvarsomraader/vindenergi/eksisterende-havvindmoelleparker-og-aktuelle-projekter. [Accessed May 27th 2019].

European Commission (2018): Renewable energy – Moving towards a low carbon economy. [Online]. Available at: https://ec.europa.eu/energy/en/topics/renewable-energy. [Accessed June 3rd 2019].

Forschungs-Informations-System (FIS) (2013): Rückbau von Offshore-Windenergieanlagen. [Online]. Available at: https://www.forschungsinformationssystem.de/servlet/is/405907/. [Accessed May 28th 2019].

Fraunhofer IWES (2018): Rückbau und Repowering. [Online]. Available at: http://windmonitor.iee.fraunhofer.de/windmonitor_de/3_Onshore/2_technik/rueckbau-und-repowering/. [Accessed May 28th 2019].

Freiberg, K.-B. (2018): Presentation at the Global Wind Summit in Hamburg, 25th of September 2018. Speaker: Norway's minister of Petroleum and Energy.

Hanz, M. (2016): Abbau der Testanlage vor Hooksiel beginnt. [Online]. Available. At: https://www.nwzonline.de/friesland/wirtschaft/abbau-der-testanlage-vor-hooksiel-beginnt_a_31,0,166376402.html. [Accessed June 11th 2019].

HM Government (2013): Offshore Wind Industrial Strategy Business and Government Action. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/243987/bis-13-1092-offshore-wind-industrial-strategy.pdf. [Accessed Mai 9th 2019].

HM Government (2017): The Clean Growth Strategy: Leading the way to a low carbon future. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf. [Accessed May 9th 2019].

International Energy Agency (IEA) (2018): Offshore wind – Tracking Clean Energy Progress. [Online]. Available at: https://www.iea.org/tcep/power/renewables/offshorewind/. [Accessed June 17th 2019].

INTPOW (2016): Norwegian Opportunities in Offshore Wind. [Online]. Available at: https://www.eksportkreditt.no/wp-content/uploads/2017/02/Norwegian-Opportunities-in-Offshore-Wind_ny-versjon.pdf. [Accessed May 9th 2019].

Kerkvliet, H. (2015): Offshore Wind Farm Decommissioning: Introducing a Multi-Criteria Decision Aid Approach. Dissertation at the Uppsala University, Department of Earth Sciences, Sweden.

Lantz, Eric; Leventhal, Michael; Baring-Gould, Ian (2013): Wind Power Project Repowering: Financial Feasibility, Decision Drivers and Supply Chain Effects. NREL – National Renewable Energy Laboratory.

Liu, P.; Barlow, C.Y. (2017): Wind turbine blasé waste in 2050. In: Waste Management 62 (2017), pp. 229-240.

MUMM: Offshore wind farms in Belgium. [Online]. Available at: https://odnature.naturalsciences.be/mumm/en/windfarms/ . [Accessed November 8th 2018]

Netherlands Enterprise Agency (NEA) (2019): Existing wind farms in the North Sea. [Online]. Available at: https://english.rvo.nl/subsidies-programmes/offshore-wind-energy/existing-wind-farms-north-sea. [Accessed May 28th 2019].

Norcowe (2017): Norwegian Centre for Offshore Wind Energy – Final Report. [Online]. Available at: http://www.norcowe.no/doc//Annual%20Reports/Final%20Report%20NORCOWE-low%20version.pdf. [Accessed May 29th 2019].

Norwegian Climate and Pollution Agency (2011): Decommissioning of offshore installations. TA 2761, 2011.

Norwegian Energy Partners (NEP) (2018): Global Offshore Wind Market Report 2019. David S. Ottensen, Director Wind.

NorthSEE (2017a): Future Energy Industry Trends. [Online]. Available at: https://northsearegion.eu/northsee/e-energy/future-energy-industry-trends/. [Accessed May 17th 2019].

NorthSEE (2017b): Offshore renewable energy industry outlook – 2030 and beyond. [Online]. Available at: https://northsearegion.eu/northsee/e-energy/offshore-renewable-energy-industry-outlook-2030-and-beyond/. [Accessed May 20th 2019].

NorthSEE (2017c): Offshore renewable energy developments – Offshore Wind. [Online]. Available at: https://northsearegion.eu/northsee/e-energy/offshore-renewable-energy-developments-offshore-wind/. [Accessed May 20th 2019].

NorthSEE (2017d): Analysis of future outlook. [Online]. Available at: https://northsearegion.eu/northsee/e-energy/analysis-of-future-outlook/. [Accessed May 20th 2019].

Norges vassdrags- og energidirektorat (NVE) (2018): Rapport nr. 10-2018.

Offshore Windenergie (2017): Windparks in Deutschland. [Online]. Available at: https://www.offshore-windindustrie.de/windparks/deutschland. [Accessed May 28th 2019].

Power Technology (2017): Full circle: decommissioning the first ever offshore windfarm. [Online]. Available at: https://www.power-technology.com/features/full-circle-decommissioning-first-ever-offshore-windfarm/. [Accessed May 14th 2019].

Richard, Craig (2018): Offshore decommissioning could cost UK £3.8bn. [Online]. Available at: https://www.windpoweroffshore.com/article/1487845/offshore-decommissioning-cost-uk-36bn. [Accessed May 10th 2019].

Rippel, K.M.; Hörchens, U. (2017): Offshore-Netzentwicklungsplan Version 2017, Bundesnetzagentur, Berlin.

Russel, T. (2019a): Record year for UK offshore wind generation. [Online]. Available at: https://www.4coffshore.com/news/record-year-for-uk-offshore-wind-generation-nid12442.html. [Accessed May 29th 2019].

Russel, T. (2019b): Norway to open wind talks. [Online]. Available at: https://www.4coffshore.com/news/newsItem.aspx?nid=13817. [Accessed June 24th 2019].

Søviknes, T. (2018): Presentation at the 2018 Energy Outlook conference in Arendal, an annual conference hosted by GCE NODE, The Norwegian Oil and Gas Association and The Federation of Norwegian Industries. Speaker: Norway's minister of Petroleum and Energy.

Statistisk sentralbyra (SSB) (2019): Elektrisitet. [Online]. Available at: https://www.ssb.no/energi-og-industri/statistikker/elektrisitet. [Accessed May 29th 2019].

Statista (2018): Installierte Offshore-Windenergieleistung in Deutschland in den Jahren 2013 bis 2018 (in Megawatt). [Online]. Available at: https://de.statista.com/statistik/daten/studie/270822/umfrage/installierte-windenergieleistung-auf-see-in-deutschland/. [Accessed May 28th 2019].

Topham, E.; McMillan, D. (2017): Sustainable decommissioning of an offshore wind farm, In: Renewable Energy, 102 (2017), pp.470-480.

United Kingdom Government (2013): Guidance - Oil and gas: decommissioning of offshore installations and pipelines. [Online]. Available at: https://www.gov.uk/guidance/oil-and-gas-decommissioning-of-offshore-installations-and-pipelines. [Accessed May 9th 2019].

Wind Europe (2017): Wind energy in Europe: Scenarios for 2030.

Wind Europe (2019a): Offshore Wind in Europe – Key trends and statistics 2018.

Wind Europe (2019b): Financing and investment trends – The European wind industry in 2018].

Annex 1: Sources of data on particular wind parks

Belgium C-Power https://www.belgianoffshoreplatform.be/nl/projecten/ http://www.c-power.be Belwind https://www.belgianoffshoreplatform.be/nl/projecten/ http://www.belwind.eu/nl Northwind https://www.belgianoffshoreplatform.be/nl/projecten/ https://www.thewindpower.net/windfarm_en_16047_northwind.php Nobelwind https://www.belgianoffshoreplatform.be/nl/projecten/ http://www.nobelwind.eu/ Rentel https://www.belgianoffshoreplatform.be/nl/projecten/ https://rentel.be/nl
Denmark Tunø Knob https://ing.dk/artikel/vindmolle-fest-pa-tuno-knob-13739 https://en.wikipedia.org/wiki/Tun%C3%B8_Knob_Offshore_Wind_Farm http://www.ewea.org/fileadmin/ewea_documents/documents/statistics/OperationalOffshoreFarms2009.pdf Middelgrunden https://ens.dk/sites/ens.dk/files/Vindenergi/godkendelse_af_middelgrunden.pdf http://www.middelgrunden.dk/?q=node/7 https://www.hofor.dk/pressemeddelse/hofor-koeber-vindmoeller-paa-middelgrunden-tilbage/ Horns Rev. 1 https://ens.dk/sites/ens.dk/files/Vindenergi/hornsrev_godkendelse.pdf https://corporate.vattenfall.dk/vores-vindmoller-i-danmark/vindmolleparker/horns-rev-1/ Rønland https://ens.dk/sites/ens.dk/files/Vindenergi/godk_havmoller_roenland.pdf http://www.hmis-roenland.dk/r%C3%B8nland-vindm%C3%B8llepark http://www.roenland.dk/ https://www.thewindpower.net/windfarm_de_7393_ronland.php

Nysted https://ens.dk/sites/ens.dk/files/Vindenergi/godkendelse_roedsand.pdf https://orsted.com/-/media/WWW/Docs/Corp/COM/Our-business/Wind-power/Wind-farm-project-summary/Nysted_DK_2018.ashx?la=da&hash=E8FFA1CBAE89708963B8BFB6128057D0 Samsø https://www.4coffshore.com/windfarms/sams%C3%B8-denmark-dk01.html Frederikshavn https://ens.dk/sites/ens.dk/files/Vindenergi/frederikshavn_godkendelse_160202.pdf https://www.thewindpower.net/windfarm_de_9615_frederikshavn.php Horns Rev. 2 https://ens.dk/sites/ens.dk/files/Vindenergi/dong_energy_ansoegning_produktionsan_ont06.pdf https://www.thewindpower.net/windfarm_de_7064_horns-rev-2.php Avedøre Holme https://ens.dk/sites/ens.dk/files/Vindenergi/etableringstilladelse.pdf Sprogø https://www.4coffshore.com/windfarms/sprog%C3%B8-denmark-dk12.html Rødsand 2 https://www.thewindpower.net/windfarm_de_7400_rodsand-ii.php Anholt https://de.wikipedia.org/wiki/Offshore-Windpark_Anholt https://de.wikipedia.org/wiki/Offshore-Windpark_Anholt
Germany Offshore Project Ems-Emden (Pilot-WEA) https://www.4coffshore.com/windfarms/enova-offshore-project-ems-emden-germany-de77.html https://www.proplanta.de/Maps/Offshore-Windkraftanlage+ENOVA+Offshore+Ems-Emden_poi1411375959.html Breitling (Pilot-WEA) https://www.offshore-windindustrie.de/2-uncategorised/232-windenergieanlage-breitling Hooksiel (Pilot-WEA) https://www.offshore-windindustrie.de/windparks/deutschland https://www.4coffshore.com/windfarms/hooksiel-germany-de76.html https://www.thb.info/rubriken/single-view/news/ein-pionier-windrad-verlaesst-hooksiel.html https://www.thewindpower.net/windfarm_de_10350_hooksiel.php https://www.nwzonline.de/friesland/wirtschaft/abbau-der-testanlage-vor-hooksiel-beginnt_a_31,0,166376402.html Alpha Ventus

https://de.wikipedia.org/wiki/Offshore-Windpark_alpha_ventus
https://www.4coffshore.com/windfarms/alpha-ventus-germany-de01.html
https://www.4coffshore.com/windfarms/alpha-ventus-germany-de01.html

Bard Offshore 1
https://de.wikipedia.org/wiki/BARD_Offshore_1
https://www.4coffshore.com/windfarms/bard-offshore-1-germany-de23.html

Meerwind Süd/Ost
https://de.wikipedia.org/wiki/Offshore-Windpark_Meerwind
https://www.4coffshore.com/windfarms/meerwind-s%C3%BCd-ost-germany-de07.html

Riffgat
https://www.offshore-windindustrie.de/news/nachrichten/artikel-25621-ewe-meldet-netzanschluss-fuer-offshore-windpark-riffgat
https://de.wikipedia.org/wiki/Offshore-Windpark_Riffgat
https://www.4coffshore.com/windfarms/riffgat-germany-de21.html

Global Tech 1
https://www.offshore-windindustrie.de/news/nachrichten/artikel-29596-offshore-windpark-global-tech-i-geht-ans-netz
https://de.wikipedia.org/wiki/Offshore-Windpark_Global_Tech_I
https://www.4coffshore.com/windfarms/global-tech-i-germany-de09.html

Dan Tysk
https://www.offshore-windindustrie.de/news/nachrichten/artikel-28716-gabriel-weiht-offshore-windpark-dantysk-ein
https://de.wikipedia.org/wiki/Offshore-Windpark_DanTysk
https://www.4coffshore.com/windfarms/dantysk-germany-de02.html

Nordsee Ost
https://www.offshore-windindustrie.de/news/nachrichten/artikel-28780-rwe-weiht-offshore-windpark-nordsee-ost-offiziell-ein
https://de.wikipedia.org/wiki/Offshore-Windpark_Nordsee_Ost
https://www.4coffshore.com/windfarms/nordsee-ost-germany-de06.html

Trianel Windpark Borkum
https://www.offshore-windindustrie.de/news/nachrichten/artikel-29269-adwen-nimmt-trianel-offshore-windpark-borkum-in-betrieb
https://de.wikipedia.org/wiki/Trianel_Windpark_Borkum
https://www.4coffshore.com/windfarms/trianel-windpark-borkum-i-germany-de27.html

Butendiek
https://www.offshore-windindustrie.de/news/nachrichten/artikel-29642-offshore-windpark-butendiek-offiziell-eingeweiht
https://de.wikipedia.org/wiki/Offshore-Windpark_Butendiek
https://www.4coffshore.com/windfarms/butendiek-germany-de08.html

Riffgrund 1
https://www.offshore-windindustrie.de/news/nachrichten/artikel-29866-siemens-offshore-windpark-borkum-riffgrund-1-offiziell-eingeweiht
https://de.wikipedia.org/wiki/Offshore-Windpark_Borkum_Riffgrund

Amrumbank West
https://www.offshore-windindustrie.de/news/nachrichten/artikel-29958-e-ons-nordsee-windpark-amrumbank-west-ist-vollstndig-am-netz
https://de.wikipedia.org/wiki/Offshore-Windpark_Amrumbank_West
https://www.4coffshore.com/windfarms/amrumbank-west-germany-de05.html

Gode Wind 1
https://de.wikipedia.org/wiki/Offshore-Windpark_Gode_Wind_I
https://www.4coffshore.com/windfarms/gode-wind-1-and-2-germany-de13.html

Gode Wind 2
https://de.wikipedia.org/wiki/Offshore-Windpark_Gode_Wind_II
https://www.4coffshore.com/windfarms/gode-wind-1-and-2-germany-de13.html

Sandbank
https://www.offshore-windindustrie.de/news/nachrichten/artikel-34145-offshore-windpark-sandbank-geht-offiziell-in-betrieb
https://de.wikipedia.org/wiki/Offshore-Windpark_Sandbank
https://www.4coffshore.com/windfarms/sandbank-germany-de12.html

Veja Mate
https://www.offshore-windindustrie.de/news/nachrichten/artikel-33805-offshore-windpark-veja-mate-ist-fertig
https://de.wikipedia.org/wiki/Offshore-Windpark_Veja_Mate
https://www.4coffshore.com/windfarms/veja-mate-germany-de36.html

Nordergründe
https://www.offshore-windindustrie.de/news/nachrichten/artikel-34913-offshore-windenergie-nordsee-one-und-nordergruende-gehen-in-betrieb
https://de.wikipedia.org/wiki/Offshore-Windpark_Nordergr%C3%BCnde
https://www.4coffshore.com/windfarms/nordergr%C3%BCnde-germany-de20.html

Nordsee One
https://www.offshore-windindustrie.de/news/nachrichten/artikel-34913-offshore-windenergie-nordsee-one-und-nordergruende-gehen-in-betrieb
https://de.wikipedia.org/wiki/Offshore-Windpark_Nordsee_One
https://www.4coffshore.com/windfarms/nordsee-one-germany-de28.html

Borkum Riffgrund 2
https://www.offshore-windindustrie.de/news/nachrichten/artikel-35237-groesste-turbine-im-offshore-windpark-borkum-riffgrund-2-installiert
https://www.4coffshore.com/windfarms/borkum-riffgrund-2-germany-de30.html
https://de.wikipedia.org/wiki/Offshore-Windpark_Borkum_Riffgrund

Merkur Offshore
https://www.offshore-windindustrie.de/news/nachrichten/artikel-32063-finanzierung-fuer-meeres-windpark-merkur-steht
https://de.wikipedia.org/wiki/Offshore-Windpark_Merkur

Trianel Borkum (Phase 2)
https://www.offshore-windindustrie.de/news/ticker/borkum-ii-trianel-startet-bauphase-fuer-offshore-windpark-artikel692
https://de.wikipedia.org/wiki/Trianel_Windpark_Borkum#Trianel_Windpark_Borkum_II_(Phase_2)

Albatros (Phase 1)
https://de.wikipedia.org/wiki/Offshore-Windpark_Albatros
https://www.4coffshore.com/windfarms/owp-albatros-germany-de39.html

Hohe See
https://www.offshore-windindustrie.de/news/nachrichten/artikel-35173-groesstes-deutsches-offshore-windprojekt-im-bau
https://de.wikipedia.org/wiki/Offshore-Windpark_Hohe_See
https://www.4coffshore.com/windfarms/hohe-see-germany-de11.html

Deutsche Bucht
https://de.wikipedia.org/wiki/Offshore-Windpark_Deutsche_Bucht

The Netherlands

Egmond aan Zee
https://nl.wikipedia.org/wiki/NoordzeeWind
www.noordzeewind.nl
http://egmondonline.nl/activiteiten/bezoek/offshore-windpark-egmond-aan-zee/
https://www.informatiehuismarien.nl/projecten/windmolenpark-egmond/
https://www.4coffshore.com/windfarms/egmond-aan-zee-netherlands-nl02.html

Princess Amalia Windpark
https://nl.wikipedia.org/wiki/Prinses_Amaliawindpark
https://www.enecogroep.nl/projecten/prinses-amaliawindpark/https://www.vanoord.com/nl/nieuws/2008-film-prinses-amalia-windparkhttps://zoek.officielebekendmakingen.nl/stcrt-2018-22895.html
https://www.4coffshore.com/windfarms/prinses-amaliawindpark-netherlands-nl01.html

Luchterduinen
https://www.4coffshore.com/windfarms/eneco-luchterduinen-netherlands-nl32.html
https://www.eneco.nl/over-ons/projecten/windpark-luchterduinen/
https://nl.wikipedia.org/wiki/Luchterduinen
https://www.vanoord.com/nl/nieuws/2015-windpark-eneco-luchterduinen-operationeel

Gemini Windpark Buitengaats
www.geminiwindpark.nl

https://www.4coffshore.com/windfarms/gemini-netherlands-nl18.html https://nl.wikipedia.org/wiki/Gemini_(windmolenpark) https://www.deingenieur.nl/artikel/gemini-windpark-in-gebruik-genomenhttps://energiekaart.net/gemini-windpark-operationeel/ Borssele 1+2 https://www.4coffshore.com/windfarms/borssele-1-and-2-netherlands-nl0b.html Borssele 3+4 https://www.4coffshore.com/windfarms/borssele-3-and-4---blauwwind-netherlands-nl0j.html
Norway Hywind Test Site https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us.html
United Kingdom Barrow https://de.wikipedia.org/wiki/Offshore-Windpark_Barrow Beatrice demonstrator https://en.wikipedia.org/wiki/Beatrice_Wind_Farm Blyth Offshore https://www.thewindpower.net/windfarm_de_16663_blyth-offshore.php https://en.wikipedia.org/wiki/Blyth_Offshore_Wind_Farm Burbo Bank https://en.wikipedia.org/wiki/Burbo_Bank_Offshore_Wind_Farm Burbo Bank Extension https://www.4coffshore.com/windfarms/burbo-bank-extension-united-kingdom-uk59.html https://en.wikipedia.org/wiki/Burbo_Bank_Offshore_Wind_Farm Dudgeon https://en.wikipedia.org/wiki/Dudgeon_Offshore_Wind_Farm European Offshore Wind Deployment Centre https://corporate.vattenfall.co.uk/projects/operational-wind-farms/european-offshore-wind-deployment-centre/ https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/EOWDC https://corporate.vattenfall.co.uk/projects/operational-wind-farms/european-offshore-wind-deployment-centre/innovation/ Greater Gabbard https://en.wikipedia.org/wiki/Greater_Gabbard_wind_farm

Gunfleet Sands 1+2
https://en.wikipedia.org/wiki/Gunfleet_Sands_Offshore_Wind_Farm

Gunfleet Sands 3 – Demonstration Project
https://en.wikipedia.org/wiki/Gunfleet_Sands_Offshore_Wind_Farm

Gwynt y Môr
https://en.wikipedia.org/wiki/Gwynt_y_M%C3%B4r

Humber Gateway
https://en.wikipedia.org/wiki/Humber_Gateway_Wind_Farm

Hywind Scotland
https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/Hywind
https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us.html

Kentish Flats
https://en.wikipedia.org/wiki/Kentish_Flats_Offshore_Wind_Farm

Lincs
https://en.wikipedia.org/wiki/Lincs_Wind_Farm

London Array
https://en.wikipedia.org/wiki/London_Array

Lynn and Inner Dowsing
https://en.wikipedia.org/wiki/Lynn_and_Inner_Dowsing_Wind_Farms

Methil- Levenmouth Demonstration Turbine
https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/FifeEnergyPark
https://ore.catapult.org.uk/testing-validation/facilities/levenmouth/

North Hoyle
https://en.wikipedia.org/wiki/North_Hoyle_Offshore_Wind_Farm

Ormonde
https://en.wikipedia.org/wiki/Ormonde_Wind_Farm

Race Bank
https://en.wikipedia.org/wiki/Race_Bank_wind_farm

Rampion
https://en.wikipedia.org/wiki/Rampion_Wind_Farm

Rhyl Flats
https://en.wikipedia.org/wiki/Rhyl_Flats

Robin Rigg

https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/Robin-Rigg

Scrobny Sands
https://en.wikipedia.org/wiki/Scroby_Sands_Wind_Farm

Sheringham Shoal
https://en.wikipedia.org/wiki/Sheringham_Shoal_Offshore_Wind_Farm

Teesside
https://en.wikipedia.org/wiki/Teesside_Wind_Farm

Thanet
https://de.wikipedia.org/wiki/Offshore-Windpark_Thanet

Walney
https://en.wikipedia.org/wiki/Walney_Wind_Farm

Walney Extension
https://en.wikipedia.org/wiki/Walney_Wind_Farm

Westermost Rough
https://de.wikipedia.org/wiki/Offshore-Windpark_Westermost_Rough

West of Duddon Sands
https://de.wikipedia.org/wiki/Offshore-Windpark_West_of_Duddon_Sands

Beatrice Offshore Windfarm Ltd.
https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/Beatrice
http://sse.com/whatwedo/ourprojectsandassets/renewables/beatrice/

Kincardine Offshore Windfarm Floating
https://www2.gov.scot/Topics/marine/Licensing/marine/scoping/Kincardine
https://www.4coffshore.com/windfarms/windfarms.aspx?windfarmId=UK2H