Danish Energy Agency

OFFSHORE WIND DEVELOPMENT

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Introduction

Offshore wind power has tremendous potential for development in the coming years. Offshore wind – as a variable baseload power generation technology – will play a central role in the green transition all over the world as one of the most cost-effective energy sources. The Levelized Cost of Electricity from offshore wind has fallen sharply over the last 10 years, driven by increased volumes, massive technology developments, and stable political commitment. As a result of this development, zero-subsidy bids have been awarded in Europe.

Starting with the commissioning of the world's first offshore wind farm in 1991, Denmark has been a pioneer in offshore wind development and is today the country with the highest penetration of renewable energy from wind in the electricity production. Denmark is set to remain an offshore wind leader, leading the deployment in the North and Baltic Seas over the coming decade. The visons of the world's first energy islands in Denmark and a significant overplanting of offshore wind power to the benefit of the developing world market for e-fuels, supports this development. The plan includes using the Bornholm Island in the Baltic Sea as a hub for offshore wind energy, as well as establishing an artificial energy island in the North Sea as a hub. Through the concept of "Power-to-X", the long-term aim is to convert – when relevant – the power from the islands into green hydrogen, which can further be processed into e-fuels, allowing further reduction of greenhouse gases.

Denmark's over 30 years of offshore wind experience gives an important international role in sharing experiences, best practices and lessons learnt with other countries looking at offshore wind as a cost-competitive and reliable energy source. The global energy transition needs a collective effort of all countries around the world, and Denmark is dedicated to exchanging knowledge with other governments on the key elements needed to develop offshore wind power: long-term political commitment, stable support schemes, solid and transparent framework conditions, and a competitive industry. This report provides insights about these key elements. Because it is our ambition to spark inspiration.

Kristoffer Böttzauw, Director General at the DEA

Danish Energy Agency

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1. ENERGY TRANSITION AND OFFSHORE WIND DEVELOPMENT IN DENMARK

1.1. Political commitment and long-term strategy

40 years of energy transition

The oil crises in the 1970's was the trigger of Denmark's energy transition: before the first crisis, Denmark was dependent on imported fossil fuels for 99% of its energy demands. Surging oil prices therefore led to a severe and prolonged economic crisis in Denmark. Consequently, Denmark felt urged to focus on new energy resources in order to reduce this fossil fuel dependency. This kick-started the creation of the "Danish Energy Model" and Denmark became one of the first movers in implementing a green energy transition across all sectors.

Through dedicated efforts over the past more than four decades, impressive results have been achieved while reducing fossil fuel dependency and mitigating climate change. Denmark has built a world-class green energy system, following an integrated approach that encompasses the electricity, heat and transport sectors. The results of this energy transition have been providing considerable improvements for everyday life through more sustainable and more affordable energy, while maintaining one of the highest levels of security of supply in the world.

Danish energy policy has been characterized by long-term energy planning, development of energy efficiency measures, integration of large shares of renewable energy sources and district heating in the energy system and liberalization of the power sector, which have been fundamentals to achieve this transformation in a cost-effective and reliable way. The Danish energy policy has been also characterized by broad and long-term political agreements, which create stability, predictability and investment security. The agreements are typically supported by almost all political parties in the Parliament, and create a stable and trustworthy environment for investors. With the latest politically agreed Climate Agreement, Denmark is on track to fulfil the objective of developing a carbon neutral society no later than 2050.

Vision has moved to action and produced tangible results on the Danish electricity generation mix, where wind energy's share corresponds to half of the domestic electricity consumption. Wind power is now the main generation technology. It is common in Denmark to have days where the wind blows so much that the onshore and offshore wind turbines produce more electricity than what is needed to cover the national power consumption. The production excess is then exported to Denmark's neighboring countries (Germany, Norway, Sweden, and The Netherlands). Significant efforts have been made to enhance the capability of the Danish grid system to integrate high shares of variable renewable production, while ensuring the highest level of security of supply in Europe: the Danes experienced in 2018 only 22 minutes of outages, which means a security of supply as high as 99.99% [5].

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The early days of Danish green transition

1970's

- The Danish Energy Agency (1976) and the first Energy Ministry (1979) were created
- First Energy Plan in 1976

1980's

- Primary focus on district heating and planning of networks and infrastructure
- 100 MW onshore wind agreement (1985)
- Decision not to pursue nuclear energy (1985)

1990's

- Increased focus on climate change with the Earth Summit in Rio de Janeiro (1992) and the signature of the Kyoto Protocol (1992)
- First broad political agreement on a CO_2-emission reduction target: Reduction by 5% in 2000 compared to the corrected level for 1990 (achieved)
- EU's first power market liberalization package with focus on regulation for market liberalization (1996)

2000's

- Increased EU push and pull: 2nd and 3rd power market liberalization packages (opening up of markets, unbundling production and transmission); 20-20-20-package and EU-ETS (2007)
- Liberalization of the Danish electricity market (2003), leading to the first offshore wind tenders
- Broad political agreement on the first energy and climate package (2008)

2010's

- Political agreement on independence from fossil fuels in 2050
- Energy agreement for the period 2012-2020 (2012/2014)
- Energy agreement for the period 2020-2030 (2018)
- Climate Act (2020) with the purpose of a new target of 70% CO_2-reduction by 2030 compared to the corrected level for 1990 and climate-neutral society by 2050

Green growth

Green growth refers to economic growth that uses resources in a sustainable manner. Denmark has demonstrated that green growth in electricity consumption is achievable. The energy transition undertaken in Denmark since the 1970's has proven allowed to decouple economic growth, GHG emissions and energy consumption. Since 1990, the Danish economy has kept growing while energy consumption and CO_2-emissions have been reduced.

Next steps

The Danish government aims to develop a more market-driven and cost-effective policy approach to achieve the next ambitious steps of Denmark's energy transition.

Technological advances and competition between world leading companies to deliver renewable energy and green solutions have made it realistic to assume that green solutions can be delivered purely on commercial terms. Therefore renewable electricity is envisioned to become Denmark's predominant source of energy within the foreseeable future, as well as a primary energy source for heating and transportation. In the Danish vision, the expansion of renewable energy capacity needs to contribute to the cheapest possible future production of green energy, thus benefitting Danish society as a whole.

1.2. Offshore Wind Development

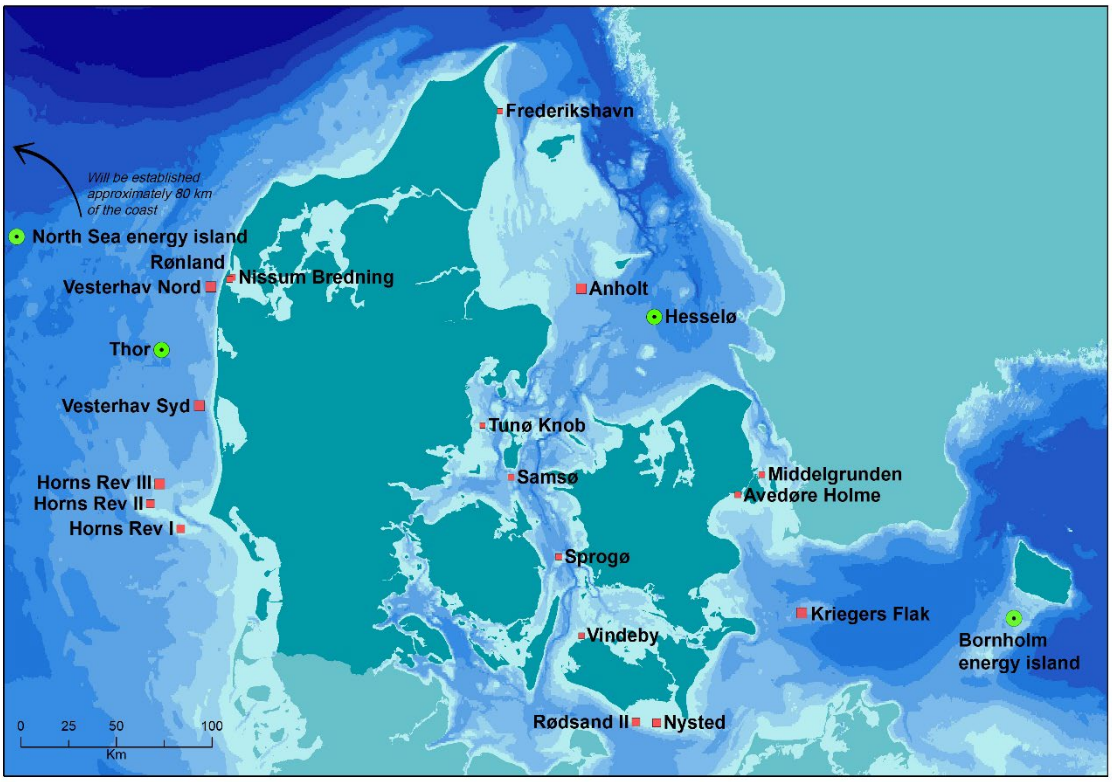


Figure 1: Danish offshore wind projects, 1991-2030.

1991 – 2003: The First Phase of Development of Offshore Wind in Denmark

In 1991 Denmark became the first country in the world to take wind turbines out to sea with 11 x 450 kW turbines in the Vindeby offshore wind farm. The wind farm was constructed as a demonstration project to prove that it was possible for turbines to exist in the harsher environment of the sea, and that their power yield would be commercially viable. The wind farm was decommissioned in 2017 after 25 years of operation. Vindeby was followed by other small demonstration projects developed on the initiatives of project developers or local residents gathered in owners associations (energy cooperatives).

Large-scale demonstration programs

In 1997, a working group with representatives from the Danish Energy Agency, the Danish Nature Agency and the power utilities published an action plan outlining the conditions for large-scale expansion of offshore wind power. The action plan underlined the need to concentrate wind power expansion in a few, relatively large areas at a distance of 7 to 40 km from the coast. On this basis, in 1998, the Danish Government entered into agreement with the two main Danish power utilities to carry out large-scale offshore wind demonstration programs. The objective of the programs was to investigate financial, technical and environmental issues to accelerate offshore development. The results led to the development and construction of Horns Rev I (2002 – 160 MW) and Nysted (2003 – 165.6 MW) offshore wind farms. The two wind farms were at that time the world's largest offshore wind farms. The programs were also a starting point for Maritime Spatial Planning (MSP) for offshore wind in the Danish waters (see section 3.2.) as well as studies of consequences to marine life.

2003 – onwards: The Evolution of the Danish Tender Model

Due to the electricity reform in 1999 and the liberalization of the European electricity market, Denmark introduced tendering as award mechanism for new offshore wind farms as a market-oriented management tool. For this reason, from 2003 all offshore wind farms in Denmark have been either tendered by the government or built under the "Open-Door" procedure. In the Open-Door procedure, the project developer takes the initiative and inherent risks to establish an offshore wind farm and then submits an unsolicited application to the Danish Energy Agency (DEA). No commercial scale projects have been commissioned under the open door procedure as of yet.

Horns Rev II & Rødsand II: the first tendered projects

In 2005, the DEA released simultaneously the first two tenders – Horns Rev II (209.3 MW) and Rødsand II (207 MW). Both tenders included prequalification and negotiations with the prequalified tenderers in order to endure a competitive process. The awarding criteria for both projects were a composite of the price per kWh for the production corresponding to 50.000 full-load-hours, the park design as well as the timeline for the execution of the project.

The tender was based on the one-stop-shop regime and included a license to conduct the pre-investigation, a license to construct an electricity power plant and a license to produce electricity from an electric power plant. The Environmental Impact Assessment (EIA) was carried out by the winner of the tender as it was resolved that the EIA would allow the winner of the tender to develop a better micro-siting and wind farm layout.

Horns Rev II became a milestone for the Danish offshore wind industry as it proved that it was possible to generate offshore wind power on a large scale, far from shore, and in waters with high waves.

For Rødsand II, the winner of the tender decided to withdraw after completing the EIA, realizing that the low bid price would not allow the company to develop the project as expected. The main consequence of the withdrawal of the winner was that the Danish Energy Agency had to retender the Rødsand II wind farm.

Anholt

The DEA adjusted the tender framework in 2009 for the 400 MW Anholt wind farm by:

- including the EIA in the tender material provided to the bidders;
- narrowing down the award criterion to the price only;
- adding a risk of penalty in order to reduce the risk of withdrawal of the winner.

Only one company submitted an offer, with a bidding price that was higher than expected. This high bidding price was due to supply constraints on wind turbines and installation vessels combined with both a very tight and politically decided project delivery schedule combined with significant penalties for delays imposed in the tender material.

At that time, Anholt wind farm was the world's largest wind farm and it remained the largest one in Denmark until 2019.

Horns Rev III

The tender process was improved again in 2014 for Horns Rev III 400 MW wind farm by inviting the offshore wind industry to a transparent dialogue on the tender framework, in order to align the tender conditions with the terms of the market and therefore allow for more competition than for the Anholt project. The main purpose of this process is still today to ensure that the tender documents are attractive and flexible in order to receive the expression of interest of several competent bidders. As a result of the dialogue, the sizes of the penalties as well as the time allocated to the development of the Horns Rev III project were adjusted. The result was positive since the bid price was significantly lower than the one obtained for the Anholt wind farm.

Nearshore projects and Kriegers Flak

After the tender process for Horns Rev III, the DEA was simultaneously carrying out two tender processes:

- Two nearshore wind projects (350 MW)
- The large-scale offshore wind farm Kriegers Flak (600 MW)

Nearshore projects

The main rationale behind the nearshore wind projects was to bring down further the costs of offshore wind power thanks to shorter distance to shore (between 4 and 10 km). The award bid price of 64 €/MWh turned out to be considerably lower than expected. However, the development of one of the 2 awarded nearshore projects (Vesterhav Syd and Nord) have suffered from opposition from local residents, which has finally resulted in moving the project further away from shore (min. 8 km).

Kriegers Flak

The tender material for Kriegers Flak offshore wind farm (600 MW) was published by DEA in 2015. As the project is located at a distance higher than 18 km from shore, contrary to the nearshore projects the project has not been met by public opposition from the local residents.

With a bidding price of only €49.9/MWh in 2016, Kriegers Flak won at that time the record for the world´s lowest bid price for offshore wind. Kriegers Flak is also the world's first hybrid offshore wind project with an interconnector between two countries. The interconnector allows electricity to be traded in both directions – from Denmark to Germany and from Germany to Denmark. The project was commissioned in 2021.

Thor & Hesselø

The latest offshore wind farm to be tendered out in Denmark is Thor. The development of Thor was decided in the Energy Agreement of June 2018. Thor offshore wind farm is to be located in the North Sea at a distance of min. 20 km from the shore on relatively shallow water. The wind farm will have a capacity of min. 800 MW and max. 1.000 MW, and will be connected to the grid between 2025 and 2027. The Thor project is the first tender to yield a tender price below zero and generate revenue to the state.

Hesselø offshore wind farm is the same size as Thor and the second offshore wind farm that all political parties in the Energy Agreement of June 2018 have agreed to build. With the Climate Agreement of June 2020, it was decided to advance the time table of the tender so that Hesselø is to be fully commissioned by the end of 2027 – at the same time as Thor. However, the preliminary investigations show that the seabed conditions makes it difficult to build and the project has as of late 2021 been subject to further investigations.

Denmark and world-class R&D facilities

The success of the Danish wind energy sector is built on a unique collaboration between academia, industry, society and the political decision makers. It is the combined ability of a supply chain with decades of experience, a strong academic community producing a first-class education to future offshore wind employees, state-of-the-art research as well as a political system providing a cost-efficient regulatory framework that continues to make Denmark the preferred place for the largest players in the offshore wind industry. Maintaining this public-private collaboration at a competitive level requires continuous support and state-of-the-art Research and Development facilities. The necessary research, test and demonstration facilities must be available to develop, test and validate new solutions including test centers for offshore wind turbines.

Denmark's Energy Islands

With the Climate Agreement of June 2020, Denmark becomes the first country in the world to begin construction of two energy islands, marking the beginning of a new era for large-scale offshore wind power. The energy islands are scheduled for completion by 2030 and will have a total capacity of landing several GW of offshore wind power. The energy island in the North Sea will be owned and developed in a public-private partnership between the Danish state and private companies, with the State owning at least 50.1 percent of the island.

The energy islands will serve as hubs – or green power plants – that gather electricity from the surrounding offshore wind farms and distribute it to the electricity grid in Denmark as well as directly to other countries. This allows electricity produced in an area with vast wind resources to be more easily routed to areas that need it the most, while also ensuring that the energy generated from the turbines is utilized as efficiently as possible in terms of electricity demand. Furthermore, through the concept of "Power-to-X", the long-term aim is to convert the power from the islands into green e-fuels allowing further reduction of greenhouse gases.

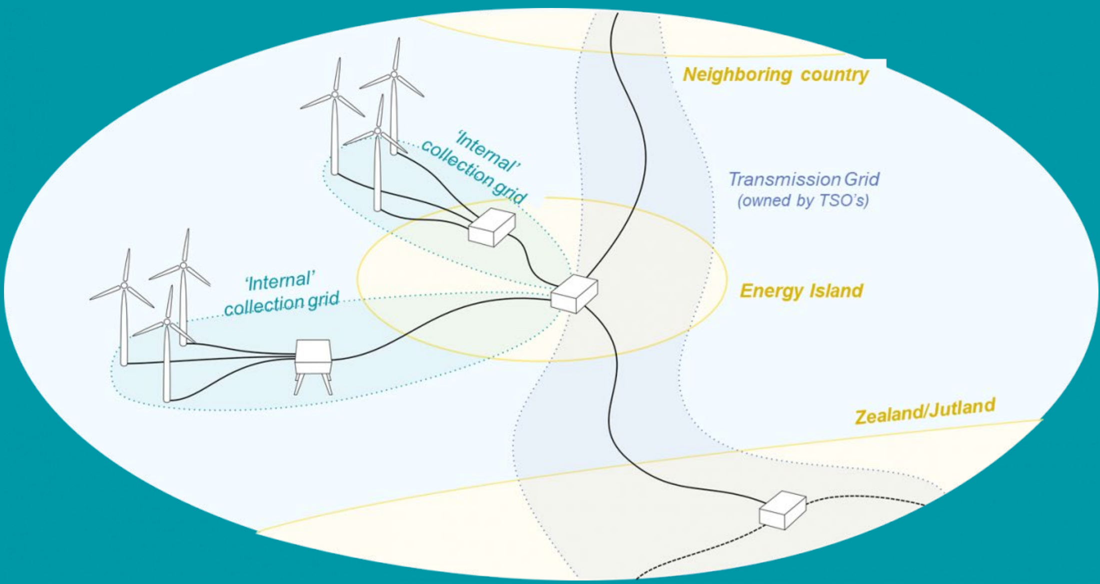


Figure 2: Long-term vision for energy islands.

2. ECONOMICS OF OFFSHORE WIND

2.1. Support schemes

As for onshore wind power, the economics of offshore-located wind farm are characterized by a high initial investment cost compared to many other power generation technologies.

In a Danish context, offshore wind power is still more expensive than onshore wind generation based upon cost-assessments made by the Danish Energy Agency in the official *technology catalogues* [4]. The cost of offshore wind is currently higher primarily because construction, operation and maintenance costs at sea are higher. These factors are, however, somewhat compensated by better wind resources at sea both in term of higher average wind speeds, more constant and better quality wind (low turbulence, etc). Compared to onshore wind in Denmark, the average power generation for offshore wind projects is about 40% higher, and offshore wind projects produce power for more than 80% of the time, making it useful as baseload power generation technology.

Due to site-specific conditions such as water depth, seabed conditions and distance to shore there is a bigger variation in offshore wind projects costs than normally seen for onshore wind projects. Based on the DEA's levelized cost of energy assessment, offshore and onshore wind power generation are lower than both new coal and new natural gas power generation. With Denmark's high population density, the need for space for new wind power sites have made offshore wind in the relative shallow and windy Danish waters an obvious choice for deployment of new large scale capacity.

Cost effective support schemes

Because of the high cost of the early offshore wind projects in Denmark, the policies to support it was mainly based on project-specific support schemes. The majority of the Danish offshore wind capacity has been awarded through project-based auctions.

To reduce development risks, the Danish Energy Agency have learned to actively clear the way for projects through a collaborative pre-planning process and by securing smooth consenting during the deployment process. This is a way of de-risking the large investments undertaken and provides lower socio-economic costs.

A Contract for Difference (CfD) model further de-risks by stabilizing the income for the owner of the project. This can promote lower capital costs for the investors as the projects become more bankable (i.e. the repayment risk on the loan is lower). When capital costs account for a large part of the investment costs, reducing financing costs can assist in order to make offshore wind attractive to investors. The stability of the financial conditions and regulatory framework for offshore wind has attracted a growing number of institutional investors such as pension funds to invest in offshore wind projects.

Contract for Difference

Historically, the subsidy scheme in Denmark has been a fixed price per kWh based on Contract for Difference (CfD) for the electricity generated during 50,000 full-load-hours, corresponding to approximately 11-12 years of operation depending on the site and the technical solution. The remaining years of production are on the electricity market price conditions.

The CfD strike price is defined by the winning bid price, where the subsidy is determined as a variable premium covering the difference between the fluctuating spot price and the fixed strike price. During the CfD-period, no support is given in hours with a negative spot price. Hence, the fixed tariff consists of the spot market price plus (or minus) a premium totaling the fixed price. Thus, the developer is not exposed to market price risk during the tenure of the CfD.

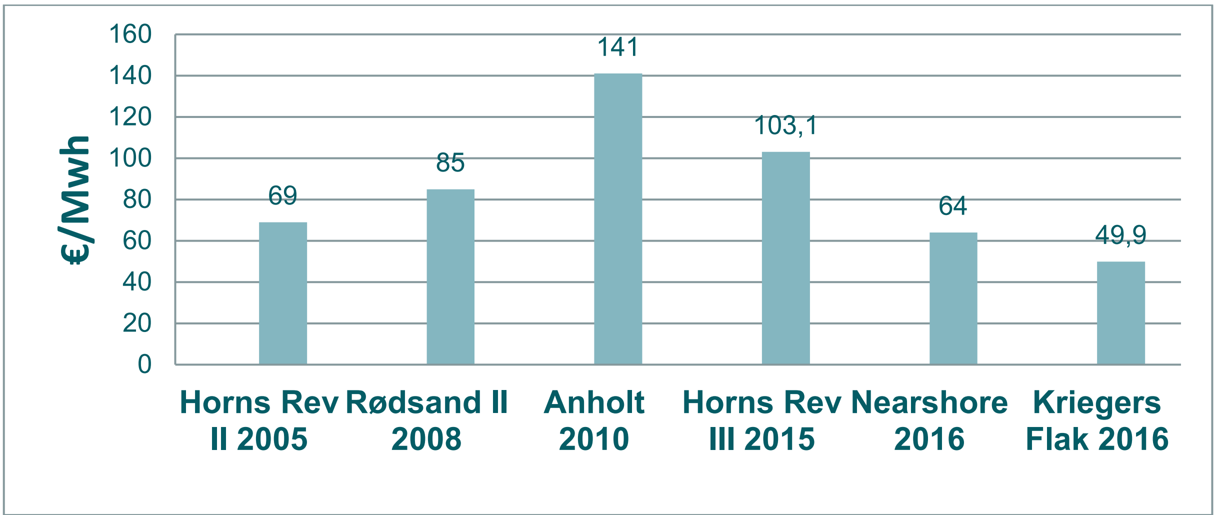


Figure 3: Evolution of the bidding prices. Feed-in prices for winning bids for offshore wind tenders in Denmark. The prices are not directly comparable as the projects do not contain the same element and have different sizes. However, the trend reflects the general development of the global market prices. Note that the 1,000 MW Thor project is not shown here, as the project's revenue is based on pure electricity market prices. Source: Danish Energy Agency.

As shown above the prices have been declining quite significantly in recent years, reflecting the maturing of both the technology and the operation of offshore wind farms but also the financial stability that the framework conditions have been offering to both investors and banks. Economy of scale is also contributing significantly.

Offshore wind power is becoming more price competitive

It is not only in Denmark that we have seen offshore wind generation costs come down. Numerous international studies point in the same direction. As shown from a study by IRENA, offshore wind is becoming much more competitive when compared to both conventional and other renewable energy sources. As shown below, the cost improvement is both a result of higher average energy generation (capacity factor) and lower installation costs. As for installation costs, bigger offshore-specific wind turbines, development of more standardized foundations and, last but not least, more effective construction and installation methods have helped reduce the important initial costs that accounts for more than half of the total generation costs. Additionally, cost optimized operation and maintenance are reducing costs for offshore wind generated electricity.

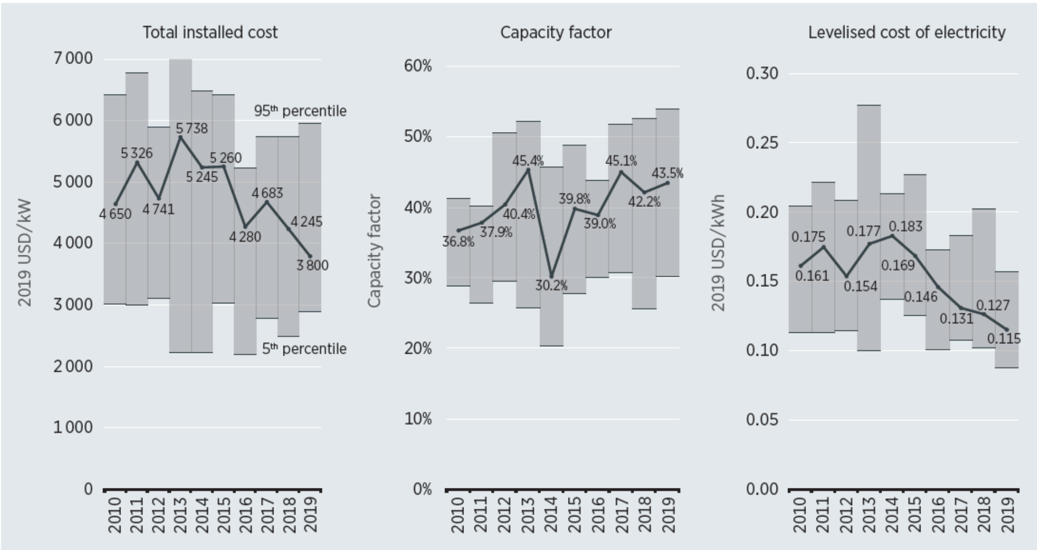
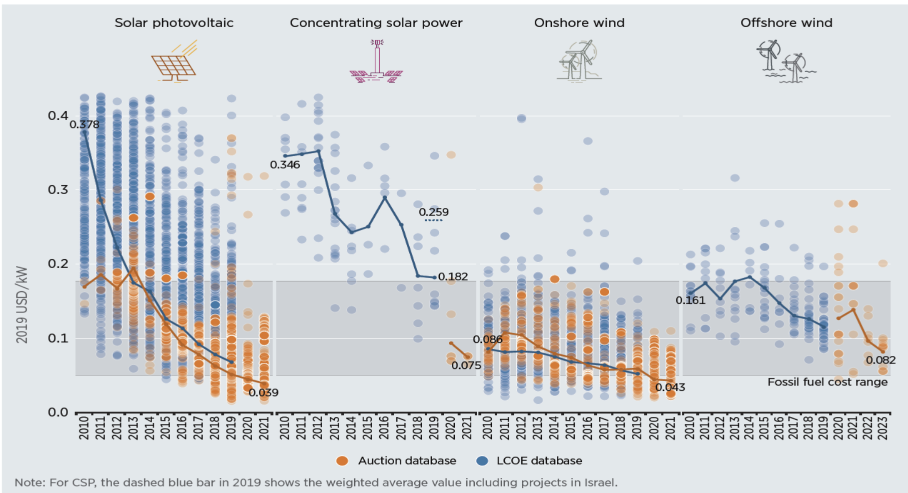


Figure 4: Evolution of the installation costs, capacity factors and LCOE for offshore wind (IRENA) [8].

As seen from international auction prices, the decline of offshore wind generation costs is expected to continue in the coming years, according to the IRENA database, as shown below.



Source: IRENA Renewable Cost Database.

Note: Each circle represents an individual project LCOE (blue dots), or an auction result (orange dots), where there was a single clearing price at auction, for the actual or estimated year of commissioning respectively. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, the real WACC is 7.5% for OECD countries and China, and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Figure 5: Auction results for renewable technologies (IRENA) [8].

2.2. Levelized Cost of Energy

In a Danish context offshore wind power has also become a competitive option for adding new capacity to the Danish power system. For energy planning purposes the Danish Energy Agency has developed a power technology catalogue focusing on the overall levelized cost of electricity (LCoE) for various relevant technologies. Offshore wind power is a very competitive source of power generation technology. This is also the case even if we can utilize heat in the district heating system using combined heat and power plants. In addition to declining wind turbine prices and construction costs, offshore wind projects offers higher and more stable wind resources than onshore sites. In our LCoE calculation for offshore wind power we are operating with 4,400 full load hours or a capacity factor of more than 50% vs. 3,100 full load hours or a capacity factor of 35% for a typical onshore wind project. Not only does this mean that going offshore adds more electricity, but it also increases the system value of offshore wind compared to onshore as the resource is a more stable source for the power system. Typically a Danish offshore project will produce power more than 80% of the time making it a more stable source for the Danish transmission system operator.

Performance of offshore wind farms in Denmark

A recent study carried out by DEA in 2020 on 66 offshore wind farms covering 7 countries reveals that the Danish wind farms were the best performing assets in terms of capacity factors, when weighted for capacity and lifetime. A clear trend towards higher capacity factors over time can be observed, showing that lessons learned have been valuable for siting and technology development, etc. Denmark has been able to capitalize on its ample wind resource and a conducive framework, to ensure that each wind farm is maximizing its generation over the entire lifetime.

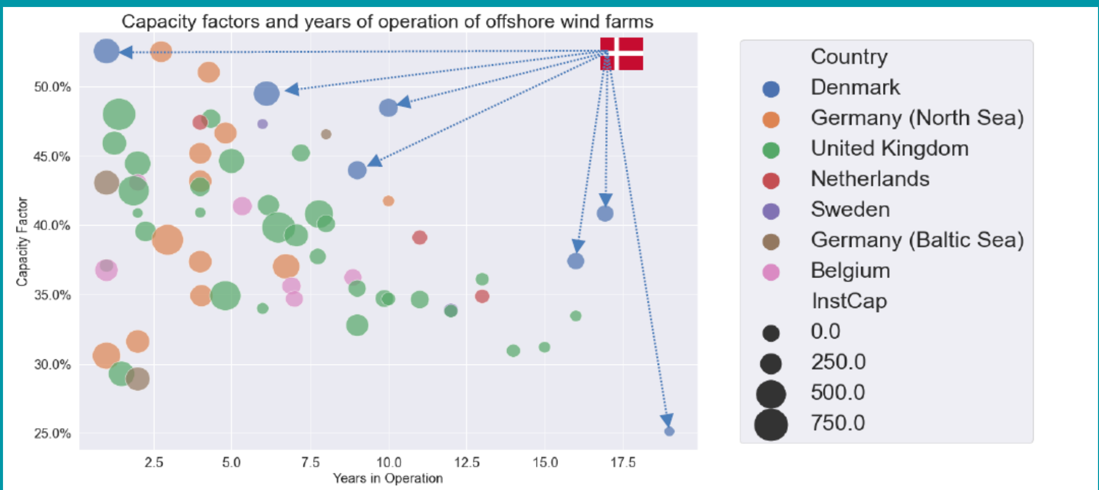


Figure 6: Capacity factor by installed capacity, years of operation and country. Note the size of the circles refers to the installed capacity of the wind farm. Other offshore wind farms were only included if they had more than 1 year of publically available data, and more than 30 MW capacity. Source: Wood Mackenzie & Danish Energy Agency.

3. REGULATORY FRAMEWORK FOR OFFSHORE WIND DEVELOPMENT

3.1. One Stop Shop

Consenting offshore wind projects requires thorough planning and coordination amongst involved authorities in order to reduce risks to developers and investors. In Denmark, a streamlined and transparent process contributes to reduce uncertainties and delays, which can otherwise hamper the development of offshore wind projects. The concept of a single point of access – a so-called **One Stop Shop** – is an important organizational approach mitigating this regulatory risk.

The DEA has the mandate to both plan and issue permits for offshore wind projects both in the territorial sea and in the exclusive economic zone. The DEA acts as a One Stop Shop – meaning that the DEA is the first and primary contact window for offshore wind projects and is in charge of the coordination with the relevant stakeholders. This process is not defined by law, but is an administrative procedure. The DEA is, however, given the mandate to issue the licenses to offshore wind projects. In order to facilitate the implementation of that mandate the approval process has been designed in a one-stop-shop approach.

The DEA coordinates the granting of the licenses with the relevant authorities that provide the DEA with their respective regulatory inputs. In this process, the DEA conveys relevant project specific knowledge to the other authorities in order to mitigate conflicting interests. The coordination and communication with a large number of authorities is often a challenging part of consenting an offshore wind farm itself as well as the grid connection. The One-Stop-Shop approach significantly reduces the regulatory risk and ease communication, since the developer does not have to approach all relevant authorities themselves to get the individual permits required for the development of the offshore wind farm.

More information about the One Stop Shop can be found in the factsheet: The Danish Energy Agency as a one-stop-shop authority [2].

3.2. Maritime Spatial Planning

Offshore wind farms cannot be seen in isolation from the environmental and anthropogenic constraints that surround them. Maritime Spatial Planning (MSP) is essential to take into account the multitude of interests at sea and reduce the risks of conflicts. MSP secure the appropriate sites for offshore wind farms while respecting both the environment and the other users of the sea space at the same time.

MSP is under the overall responsibility of the Danish Maritime Agency, which coordinates on behalf of and in coordination with all relevant authorities. The MSP includes two set of data:

- As-is data: Data describing current offshore interests (Maritime Spatial Data Infrastructure, MSDI)
- To-be data: Data describing the expected situation on a specific time (e.g. 2030, 2040)

The MSDI is a collaboration between 11 state agencies such as the Ministry of Defence, the Coastal Authority, the Maritime Authority, Danish Energy Agency etc., and is used to:

- Provide offshore related datasets;
- Create knowledge network of data experts;
- Provide an online platform with visual interactive map.

The result of the MSP in Denmark is the maritime spatial plan which is published in the form of a digital executive order and consists of an interactive GIS map with comments. This can be found here: www.havplan.dk (published in Danish and English) [10].

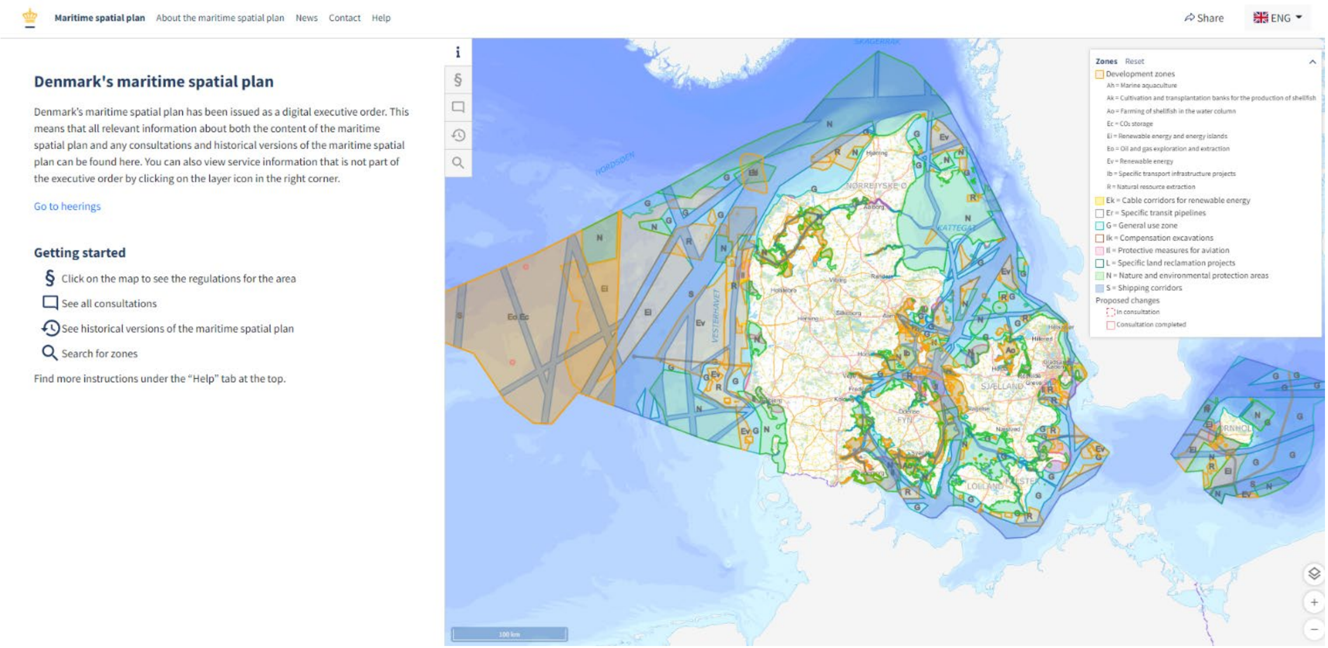


Figure 7: Denmark's maritime spatial plan.

In order to keep the maps updated, the DEA is in continuous dialogue with all relevant authorities through the MSDI. The planning of offshore wind sites is therefore now a dynamic process, in which the authorities provide updated inputs via the MSDI: newly installed sea cables, modifications of navigation routes, revised environmental protected areas, new concerns regarding national security, etc. All this data is used to create a base map for the planning of future offshore wind projects.

The MSP executive order is subject to public hearing by the Danish Maritime Authority.

Early preparation of areas for offshore wind development

In the past when the DEA delineated large-scale scenarios for identifying offshore wind the following constraints were typically used:

- >20 km from shore to avoid visual disamenities;
- Area large enough to accommodate >800MW (0.22km2/MW) of wind power capacity with at least 30% of margin to allow for flexibility within the site;
- Water depth ≤ 50m to favor the use of traditional and less costly monopile foundations;
- Available access to grid connection.

Based on previous experience, the designated areas in the MSP are significantly larger than the areas required for generating the offshore wind power. These gross areas will therefore provide many opportunities for optimization (cost reduction, etc.) in a fine-screening of the sites within the gross area through incorporating, e.g. local environmental conditions, etc. Restricted areas such as shipping routes, Natura 2000 sites, defense restriction areas, have been already been excluded.

Once an area has been appointed in the maritime spatial plan for offshore wind development, the Danish Energy Agency is responsible for preparing a more detailed mapping of the area and designate the more specific use of the space for offshore wind. This mapping called fine screening will narrow down the more specific areas suitable for the development of offshore wind.

Fine-screening for the final selection of offshore wind sites for future tenders

The DEA is responsible to carry out a fine screening in order to investigate the possibility of establishing both individual offshore wind farms and several offshore wind farms connected to an energy island (clustering). The purpose of the screening is to determine specific site locations within the large-scale scenarios and to provide financial calculations to compare these site locations.

Local site conditions are evaluated in a desk study for each potential site location. In this phase existing knowledge is used and no further site investigations are done.

- Seabed conditions: how suitable are the local geophysical and geotechnical conditions to install monopole foundations?
- Environmental and social conditions: how are the locations impacted by environmental and social constraints (fishing activities, bird migration routes, etc.)?
- Wind conditions: what would be the expected energy production of an offshore wind farm in each site location?
- Grid connection: how far is the connection point? How many offshore cables should be installed and how easy would it be to install them?
- Costs: what would be the estimated capital expenditures (CAPEX) and operational expenditures (OPEX) to build and operate an offshore wind farm in each site location?

These local conditions are then used to estimate the Levelized Cost of Energy (LCoE) of each site location, and the locations are finally ranked based on this expected LCoE. This economic ranking allows to first develop the most attractive sites.

The early MSP processes in Denmark

In the late 1990's, a first spatial planning committee for offshore wind was established. The committee was led by the Danish Energy Agency and consisted of government authorities responsible for the environment including visual interests, for safety and navigation at sea, for offshore resources extraction, and for grid transmission conditions. The committee included also expertise within the technical fields of wind power to ensure the most relevant planning of future offshore wind sites.

The committee assessed on a regular basis the siting of offshore wind farms with respect of other interests at sea and appropriate sea uses. The committee was tasked with finding appropriate sites for offshore wind farms, i.e. sites where the impacts on the environment and other sea uses were expected to be low, whilst suitable for harvesting offshore wind power.

The committee moved gradually to GIS mapping. Each governmental authority had their own reserved areas charted in a layered GIS map, such as sailing routes and environmental protection sites, cables, wind resources, etc. When the maps are collated on top of each other, a picture of the areas with no reservations becomes apparent. These areas were then evaluated in relation to distance to shore, wind speeds, water depth, etc., in order to identify available and suitable sites for offshore wind farms according to wind speed, grid transmission, naval and air navigation, nature, landscape, raw material extraction. Finally, the sites were assessed according to the anticipated cost of establishing and operating the offshore wind farms. The committee attached importance to a planned and coordinated expansion of both wind power

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and the transmission network in order to obtain the greatest possible economic benefits from the greatest wind speeds and the lowest construction costs.

Subsequently, the suggested sites were discussed with relevant authorities and the affected municipalities onshore. When all public authorities agreed on the siting of offshore wind farms, the final validation steps were a written consultation and a hearing of relevant neighbouring countries.

3.3. Procedures for establishing offshore wind farms

The establishment of large-scale offshore wind projects follows a tendered procedure run by the Danish Energy Agency (DEA). The offshore wind farms in Denmark are established after a centralised procedure in order to:

- align the development with the political targets;
- optimize the use of resources at sea;
- realize new offshore wind farms at the lowest possible socio-economic cost.

All tenders are decided in broadly agreed political Energy Agreements. The DEA has historically announced a site-specific tender for an offshore wind farm of a specific size, e.g. 1,000 MW and invited applicants to bid a tariff price per kWh, which represents the price they will need to get for producing electricity in a determined number of full-load hours. The owner of the wind farm sells the electricity on the market, and according to the terms of the contract for difference, the owner will get a flexible premium to cover the difference between the market price and the fixed bid price, if the market price is lower than this tariff. The bid price (strike price) differs from project to project due to different tender results. Thus, the result of a tender depends on the project location, the wind conditions at the site, the competitive situation in the market at the time, etc.

The Danish tender model has evolved over the years since the first tender in 2002. The transformations are the results both of lessons learnt throughout the different tenders, and of the development of the offshore wind market through the years. More details about the evolution of the model can be found in the publication: The Danish Offshore Wind Tender Model [3].

The current Danish model for tendering new offshore wind farms is the result of many years of experience in planning and executing large-scale wind farm tenders. The strength of this model lies in a front-loaded, de-risking approach, which allows decreasing uncertainties and perceived execution risks for the bidders to tender, and therefore ensuring to obtain the lowest bidding price possible. The risk of the project is directly reflected in the cost of the financing. The higher the risk, the higher the cost of capital. The project owner is responsible for limiting the risks, but governments can also prepare the project in the planning stages in a way that successfully mitigates risk, e.g. by reducing consenting risks and by providing a comprehensive “data pack” on the site before final bids are prepared. This systematic approach aims to reduce risk premiums in business cases prepared by the bidders.

The Danish tender model is also characterised by its transparency and fairness in order to ensure that all potential applicants are treated equally. The main elements of the Danish tender model are described below.

Tender Preparation

One Stop Shop

The DEA acts as the single point of access during the whole procedure as explained in part 3.1. The single point of access is called “One-Stop-Shop” model and it ensures a smooth tendering process as both potential bidders and other authorities have only one authority to refer to and can ask questions regarding the project.

Maritime Spatial Planning

The sites to tender have been previously identified through Maritime Spatial Planning, as explained in part 3.2. The fact that other government authorities have been involved early in the process of identifying sites for new offshore wind farms and have approved the final site, increases certainty for the potential bidders by neutralizing potential future conflicts of interest over the selected area.

Grid connection

The construction and operation of the offshore substation and of the grid connection from the offshore to the onshore substation is now included in the scope of the tender. This was not always the case when the market and the competition was less developed. Energinet, the Danish Transmission System Operator (TSO), is responsible to construct, reinforce and operate the 400kV transmission grid.

The rationale behind the political decision to include (most of) the grid connection elements in the tender is to stimulate critical innovation in design, construction and operation of the grid connection, and ultimately foster competition to lower total cost of the entire offshore wind farm project. Furthermore, the EIA requirements dictate that the project is analysed and evaluated as a whole.

Preliminary surveys and studies

Energinet, the Danish Transmission System Operator (TSO), supports the DEA in the execution of the preliminary surveys incl. the geophysical and geotechnical surveys as well as metocean studies to be carried out in the planning phase ahead of the call for tender. A strategic environmental survey is also carried out up front, such as studies of protected species, migrating birds, etc. These in-depth studies of the physical features of the site deepen the knowledge of the site, and give future investors an insight into the technology choices they can select in the bidding procedure. This early action is implemented in order to reduce the length of the approval process and to give applicants better possibilities to offer a price that is real-cost based. At the same time it provides potential bidders with a high investment security and thus supports a reduced risk premium, particularly in the financing of the capital costs. Decreasing the overall risks of the project by minimizing unnecessary costs – even in a zero subsidy regime – will also decrease the socio-economic cost.

Environmental Assessments

The evolution of the process over the completion of the Environmental Impact Assessment (EIA) of the tendered offshore wind farm is a striking example of the lessons learnt over all the tenders carried out since 2002. Since the tender of Anholt, the final and complete EIA of the tendered offshore wind farm has been completed before tender award. The EIA was based on a project description that took into account the worst-case scenario regarding each specific potential environmental impact. However, this project description was not based on the actual final specifics of the project (unknown at the pre-bidding stage), but contained a range of the final project specifications (number, height and size of the turbines, types of foundations, etc., a so-called Rochdale Envelope). This model was successfully applied in all tenders for offshore wind farms located far from shore, but has been recently criticized, due to local public opinion of the Danish nearshore projects (distance less 8 km from shore. The local residents living close to the nearshore offshore wind farms were dissatisfied with the uncertainty of final layout of the project decided by the winner of the tender.

This has triggered a new and more solid process for environmental assessments of offshore wind projects, designed with two key objectives in mind:

- Minimizing the risks of claims and appeals for the developer after tender award;
- Minimizing environmental and planning risks by carrying out many surveys and studies before tender award, in order to provide the bidders with as much information as possible.

The new approach chosen is based on strategically surveying environmental factors with high risk up front prior to final bids. The purpose of these additional assessments is to provide site data and increase knowledge about the local conditions at the site. All the results and data from the studies and surveys will be made available to all stakeholders.

After tender award, the winner of the project owner carries out the EIA of the offshore wind farm, offshore substation and export cables to the landfall of the specific project, meaning that the EIA is now undertaken after all the specifications for the project have been decided by the winner of the tender. If necessary, Energinet undertakes the EIA of the specific grid project on land from the landfall to the 400 kV transmission grid simultaneously. A graphical illustration of the approaches for the Thor offshore wind project has been provided below.

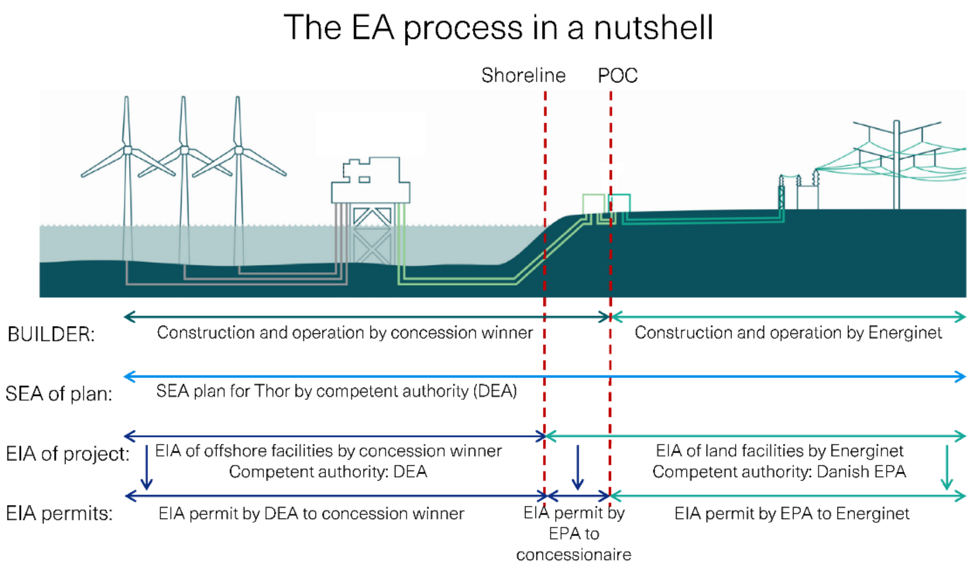


Figure 8: The EA process in a nutshell. Source: Energinet.

This new process is aligned with the front-loaded de-risking approach of the Danish tender model by studying the potential environmental impacts as early as possible in the tender process in order to provide as much as possible information to the potential bidders, while decreasing the environmental risks and risks of future protests from the local residents. This process also allows for flexibility in the design of the future offshore wind farm, so the winner of the tender can decide on the specifications and dimensions within the given frame that will suit best its business model for the project.

Stakeholder management

Over the past decades, the build-out of wind energy in Denmark has transitioned from smaller community driven projects developing small-scale projects, to larger energy companies installing more and larger wind turbines. Economy of scale and efficiency gains has driven the projects into the GW scale. This transition has put focus on public acceptance of wind turbines and the local conflicts that may arise when people become neighbors to large wind turbines.

Over 50 years of wind development has shown that citizens need to be involved as early as possible in the project development process to increase local support to renewable energy projects. Involving stakeholders should therefore start as early as reasonable in the planning process, such as national and local planning authorities, energy regulators, developers, grid operators, NGOs and local communities. Public participation in the decision making process through public consultation procedures and meetings has led to a better public appreciation and higher accept rate.

Fisheries

Developing an offshore wind project will necessarily have an impact on the fisheries in the area, and it is therefore essential to implement a legal framework to facilitate the coexistence of offshore wind farms and fishery activities. In Denmark, the developer has to consult the local fishermen, in some cases represented by the Danish Fishermen Association, and discuss potential mitigation measures or financial compensation to the estimated loss of income. Based on documented data, these estimations are initiated during the environmental impact assessments and finalized once the layout is confirmed. The level of the compensation and the conditions for fishery activities within the wind farm should be settled between the project owner and the fishermen before construction of the project can start.

More details about the environmental assessments can be found in the factsheet: Environmental impacts of offshore wind farms [1].

Preliminary site investigations

Energinet is mandated by the DEA to carry out the preliminary investigations on the offshore wind site during the tender process: metocean (wind, wave, current) studies, along with geophysical and geotechnical surveys.

The metocean study, and especially its wind resource assessment, provides crucial information allowing the bidders to estimate e.g. Annual Energy Production (AEP) of the future wind farm. This data is essential for the potential bidders to assess the future potential revenues generated by the future wind farm. Providing accurate and reliable metocean data often requires on-site investigations, which should last at least one-year to account for the different seasons of the year. Denmark can draw on its extensive experience from development of offshore wind farms having accumulated metocean data for our national waters.

The purpose of the preliminary geological and geotechnical surveys is to generate knowledge about the seabed conditions (geophysical layers, composition, reliefs, presence of reefs, etc.), and the possible presence of unexploded ordnances (i.e. from the World War II) and of other man-made obstructions (such as wrecks or archeologic objects).

The data and outcomes of the investigations are provided to all stakeholders during the tender process well ahead of the bidding date. These in-depth studies of the physical features of the selected area deepen the knowledge of the sites, and provide all necessary data for the potential bidders to start determining the specifications of the project and thus to evaluate the costs of building, operating and decommissioning the wind farm. The potential bidders can better estimate a real-cost based bidding price, while reducing contingencies.

Energinet initially covers the costs of both the environmental assessments and the preliminary investigations. However, they are refunded by the winner of the tender after tender award. The amount of costs are published in the tender material, so the potential bidders can take account of these costs in their business model before submitting their final bidding price.

Market and Technical dialogues

Early in the tendering process, the DEA invites potential bidders and all relevant industry stakeholders to a series of dialogues, called Market and Technical dialogues. These dialogues provide an opportunity for the potential bidders and the wind industry to discuss, question and suggest adjustments to the tender process. On one hand, they ensure optimal sharing of risk between the potential bidders and the authorities by aligning expectations; and on the other hand, they allow for fair competition through transparency and equal treatment of the potential bidders.

The Technical Dialogue focuses on the scope and depth of the planned site-investigations, where interested developers and technical experts are invited to provide feedback on the proposed methodologies and expected deliverables of the metocean studies, geophysical surveys, cable surveys, geotechnical investigations, and SEA/EIA.

The Market Dialogue focuses on the tender conditions: time table, conditions for prequalification, penalties, compliance, process, etc. The DEA asks open questions to the potential bidders in order to get their feedback on the barriers and to potentially make the necessary adjustments to the tender conditions that would ensure the bidders to offer their lowest possible price. These questions can be for example: “Will the subsidy scheme described cause reluctance or concerns with regards to tender participation?” “Are there any unforeseen risks within the subsidy scheme described that could be mitigated by the DEA?”

In addition to this plenary market dialogue meeting, potential tenderers and investors are also invited to provide their views in bilateral meetings of a more confidential nature with the DEA and Energinet offshore wind team. This opportunity is given to companies where commercially sensitive information can be shared with DEA alone and not with their competitors.

The market feedback provided at the plenary Market Dialogue session as well as the bilateral meetings are subsequently published anonymously on the DEA’s website to ensure equal treatment and transparency in the process. The sensitivity around commercial and competitive issues that can cannot be shared broadly is of course respected.

Tender Process

Pre-qualification

In order to ensure that only solid, reliable project developers are invited to submit tenders, the DEA conducts a pre-qualification of the potential bidders by evaluating a number of minimum requirements regarding the financial, economic and technical strengths of the applicants. Pre-qualification criteria should be set high enough to attract only competent bidders but they should not be unreachable in order to allow for competition between bidders.

The DEA usually prequalifies between 4 and 7 applicants. Applicants for pre-qualification may be a single company, a consortium of several companies, a joint venture or a company established specifically for the project – a so-called Special Purpose Vehicle (SPV). In order to meet the minimum requirements for financial and economic capacity and technical capacity, the applicant may rely on other economic operators, e.g. a partner, a parent company, subcontractors, etc. In this case, the applicant must prove that the applicant has at its disposal the necessary experience or resources, and to some extent the supporting entities have to undertake joint and several liability.

Regarding the economic and financial capacity, a minimum annual turnover and a minimum equity ratio are to be met.

Regarding the technical capacity, the potential bidders must prove past experience in developing, procuring and constructing a large-scale offshore wind farm incl. an offshore substation (when relevant). For each project used as a reference the potential bidder is asked to provide information about the contribution to the project within key areas as project planning and management, design, management of construction and quality control of offshore wind farms and finally procurement/contract negotiation.

Tender material

The tendering material includes the complete set of tendering conditions, and provides the draft concession agreement along with the drafts of the three licenses (license for pre-investigations, license to establish the offshore wind farm, and license to produce electricity from wind power). The tender material also includes information on the cost pre-paid by Energinet for the preliminary surveys, the environmental and the site investigations, and that will need to be reimbursed by the winner of the tender. The tender material also highlights the penalties, guarantees and compliance conditions that will be requested from the winner of the tender, e.g. the guarantee for decommissioning.

The tendering material is subject to a dialogue with the prequalified tenderers. Potentially addressed modifications and comments from the consultation process will be incorporated in the relevant documents. This process strengthens the robustness of the tendering material and decreases the risk for later complaints.

One of the core parameters of the Danish tender conditions is that no requirements for local content are imposed on the winner of the tender, which has freedom on the sourcing of the project elements during its procurement process. Local content requirements tend to increase the final cost of the projects by removing flexibility for the winner of the tender to find cheaper options.

Next steps

Shortly after the winner of the tender is announced, the winner will obtain a license to pre-investigate the offshore wind farm site in order to carry out both detailed site-investigations and the final Environmental Impact Assessment (EIA) for the project. When the winner of the tender completes the EIA process and delivers all other necessary documentation, the DEA issues the construction license.

Furthermore, the winner of the tender will need to obtain the license to produce electricity. The permit is usually issued after construction work has commenced and no later than after grid connection of the first turbine. Compliance with the terms of the construction permit must be documented before the production license is granted.

4. SUPPORTING INFRASTRUCTURE DEVELOPMENT AND JOB CREATION

4.1. Grid Infrastructure and connection

The Danish Transmission System Operator (TSO) Energinet regularly prepares system perspective analyses and scenarios with a view to creating a long-term outlook for the future development of the energy system. It is essential to understand the potential future loads that the energy system should be able to support, as infrastructure solutions developed today often have a lifespan of 50 years or more. The challenge is to ensure a level of flexibility and robustness that enables the energy system to efficiently deal with the future electricity supply systems (see also Energinet – System perspectives for the 70% target and large scale offshore wind [6]).

Nowadays in Denmark, offshore wind represents the backbone of the Danish power system. Today's transmission grids are extended with offshore grid infrastructures to which the offshore wind turbines can be connected. At an early stage, careful planning is needed to keep the overall costs of offshore development as low as possible and to create environmentally friendly, efficient electricity supply systems in the interest of society. A holistic perspective is essential, considering technology developments, while planning and coordinating development – also across borders – is an important prerequisite for integration of a growing share of fluctuating renewables. (see also ENTSO-E Position on Offshore Development [7]).

Since the commissioning of Denmark's first large-scale offshore wind farms (160 MW in 2002), connection to the transmission grid (from 132 kV to up to 400 kV) is required for offshore wind farms, because it is not possible to convey these large power volumes in the low-voltage grids. Historically, the grid connection for large offshore wind farms in Denmark was planned, procured, installed, operated and paid for by the Danish TSO Energinet.

Grid connection – a new approach

In the political Energy Agreement of 2018, it was decided to try a new model for establishing the grid connection. The offshore substation and the grid connection from the wind farm to the onshore point of connection is included in the scope of the Thor tender. The grid connection up to the point of connection on the transmission grid is then exposed to competition as a part of the project. This means that it is the responsibility of the winner of the tender to construct, own and operate the installation. Thereby, the owner of the wind farm concession also owns the offshore substation and the grid connection to the point of connection in the onshore substation (see figure below for more details). The owner of the concession is thus responsible for development of the onshore areas needed for the onshore cables up to the first onshore substation.

The rationale behind the political decision to include the grid connection in the tender is to stimulate critical innovation in design, construction and operation of the grid connection, and ultimately to lower the total cost of the entire offshore wind farm project as much as possible.

The TSO will construct and operate the onshore transmission grid connection on Thor Offshore wind farm from the onshore substation. Energinet is obliged to finalise the construction of the onshore grid connection within a period of 30 months from tender award.

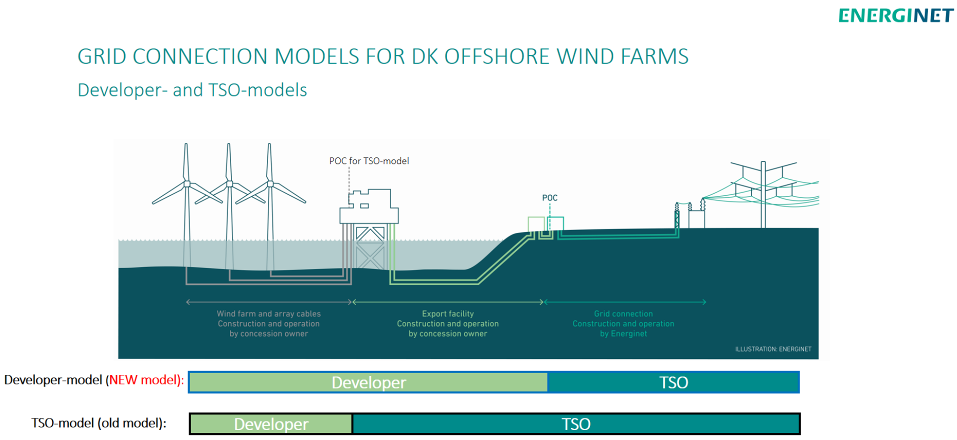


Figure 9: Grid connection models for DK offshore wind farms. Illustration: Energinet.

The wind farm and the export grid connection must be compliant with all grid code requirements at the point of connection in order to ensure a technically sound and efficient operation of the power plant for the society.

4.2. Port facilities

Ports are strategic hubs in the offshore wind farm supply chain, since all components, plant and transport operations must transit through these facilities. Therefore, they must provide suitable infrastructure in order to meet the specific requirements of the offshore wind industry.

Offshore wind project place more demands on port infrastructures than many other commercial port activities. Ports and commercial shipyards need to be ready to accommodate offshore wind manufacturing and construction activities for all wind farm components such as blades, nacelles, towers, foundations, offshore substations and cables. The port infrastructure necessary to support the installation and service of offshore wind turbines have very specific technical requirements, given the size of the different components. Therefore, the dimensions of the offshore wind components are determining factors for port requirements, as it is critical that port infrastructure can handle both lifting and storage of these components during construction of the wind farm. To avoid making serial upgrades and to optimize improvements of harbor facilities, future technology development of the offshore wind components should also be taken into consideration when determining port requirements.

The installation of offshore wind farm requires a wide variety of vessels, each of them with a specific design and purpose: turbine installation vessels, foundation installation vessels, cable installation vessels, offshore substation installation vessels, etc. The ports involved in the construction of offshore wind farms also need to comply with specific requirements in order to accommodate the necessary vessels.

Operation and maintenance (O&M) port and service facilities act as maintenance base for offshore wind farms and require storage and staff facilities, as well as wharf for berthing of service vessels, including crew transfer vessels and offshore supply vessel. O&M ports can be much smaller than those required for construction. A major requirement for the O&M port is a location in the proximity of the wind farm. This will enable fast access in case of failures or unplanned maintenance activity, thereby reducing fuel, vessel, and personnel costs. Shore-side services are vital to support offshore logistics and all offshore wind farm O&M activity needs access to port facilities such as load-out and work boat mooring.

The visualization below illustrates how various steps towards developing a dedicated O&M port might look – with each step building on the previous to provide compounded benefits. At each stage the shift in focus from project to strategic planning ensures that benefits to the local economy intensifies, as jobs are created and investments are attracted.

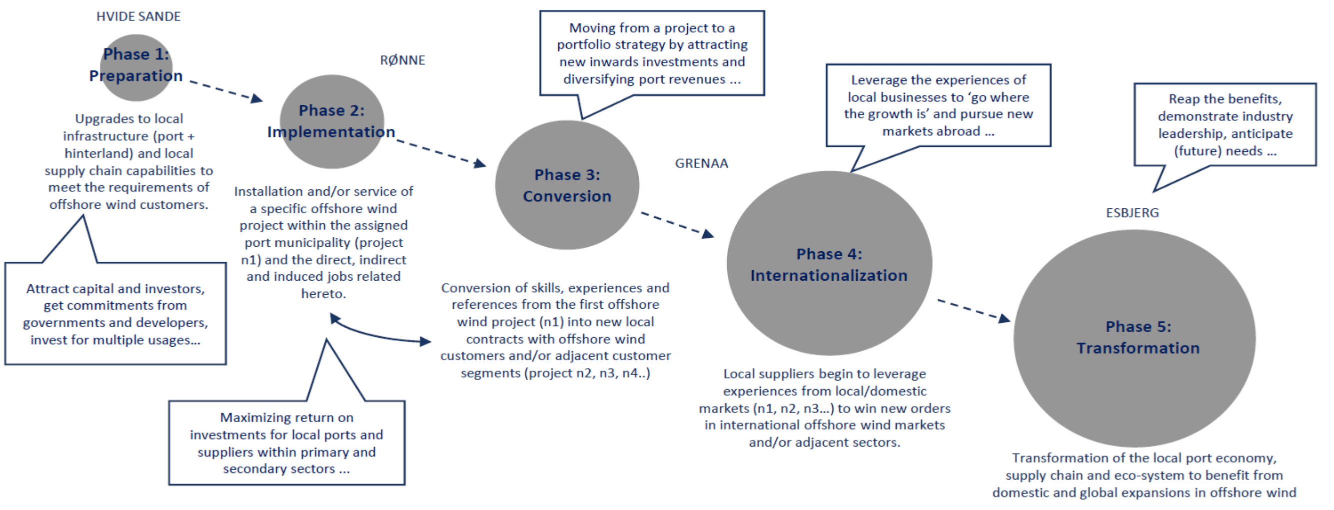


Figure 10: Potential benefits from offshore wind investments within local port installation and O&M port municipalities. Source: QBIS [9].

Port of Esbjerg

The Port of Esbjerg is the leading port in Europe in terms of handling construction of offshore wind power.

The port played a key role in the development of Denmark's offshore wind industry, which took off over a decade ago with the installation of the world's first large-scale offshore wind farm, Horns Rev I. From 2001 to present day, more than 1.8 bn. DKK have been invested in the port, which has been involved in the works of more than 50 wind farms. Over 25% of the ports revenues come from offshore wind

Today, the Port of Esbjerg has evolved from a Danish fishing port over oil and gas hub to a global offshore wind hub with specialized facilities and flexible areas for transporting, pre-assembling, shipping out and servicing offshore wind turbines. The port of Esbjerg now boasts more than 250 local companies that specialize in offshore wind, many of which with links to the oil and gas sector. The companies at the Port of Esbjerg represent the entire supply chain for the wind industry, including several of the world's leading companies specialized in handling and servicing wind installations.

4.3. Supply chain

The national policy has been a catalyst for renewable R&D for decades. And nowhere more than in wind energy where Danish companies and research institutions have been at the technological forefront since the 1970s. For nearly 40 years, companies in the Danish wind industry have developed and built wind turbines, installed them and integrated wind into the energy system. The wind industry is continuously pushing the boundaries for what is technologically feasible in the field.

Today, Denmark is home to some of the world's leading companies in offshore wind energy and a long range of sub-suppliers. A total of more than 500 companies, working in all areas of the wind industry, are located in Denmark. The industry has an unparalleled network of experience, expertise and competencies covering every link in the supply chain. Wind turbine manufacturers, energy companies, components suppliers, services and installation providers as well as consultants and investors form a unique and close-knit supplier hub. According to the Danish Wind Energy Industry, a combination of political focus on renewable energy, a highly educated and specialized labor force and state-of-the art test facilities make it attractive to develop, manufacture, test and promote wind energy technology in Denmark.

The offshore-wind supply chain revolves around three principal phases, supply, construction and management. At the center of the supply chain for offshore wind are the energy companies. The energy companies have a number of suppliers and sub suppliers which provide a range of equipment and services to the offshore operations. The suppliers and the energy companies are also supported by a number of companies which are usually not considered as part of the offshore sector but are important none the less. These companies provide a number of services including includes legal advice, financing, insurance etc. The following 5 major component categories characterizes the full value chain:

- Wind turbines
- Offshore foundations
- Electrical infrastructure
- Installation vessels
- O&M services and equipment

.

4.4. Job creation

The offshore wind industry has expanded heavily in the last ten years. This has resulted in a cumulative increase in employment and economic returns from offshore wind at the same time. Especially the job creation aspect has received increasing focus in recent years, and much work has been done to specify this benefit of wind energy.

While such job creation is difficult to quantify exactly, it is estimated that roughly 75.000 jobs in Europe alone stem directly from offshore wind, containing 31% of global wind production facilities. Furthermore, by 2030 an additional 125.000 more jobs could be added, should national clean climate plans be met.

Naturally, a direct link between installed capacity and jobs (often measured as full-time equivalents (FTEs)) varies from country to country, depending on the maturity of the supply-chain among other things. As mentioned above, the last ten years have seen a strong increase in installed capacity. In 2010, total offshore wind capacity in Europe was less than 1 GW, with a resulting FTEs of roughly 19 per MW installed, or an approximate total of 19.000 FTEs. In 2019, total offshore wind capacity was nearly 23 GW with an assessed 10 FTEs per MW installed (due to economies of scale), and the associated labour input was therefore around 230.000 FTEs. Over the next 20 years, capacity is expected to increase 15-fold. Depending on future efficiency gains, labour can increase up to 3.5 million FTEs if labour input equals 7.5 FTEs per MW as the graph below shows is expected by 2022.

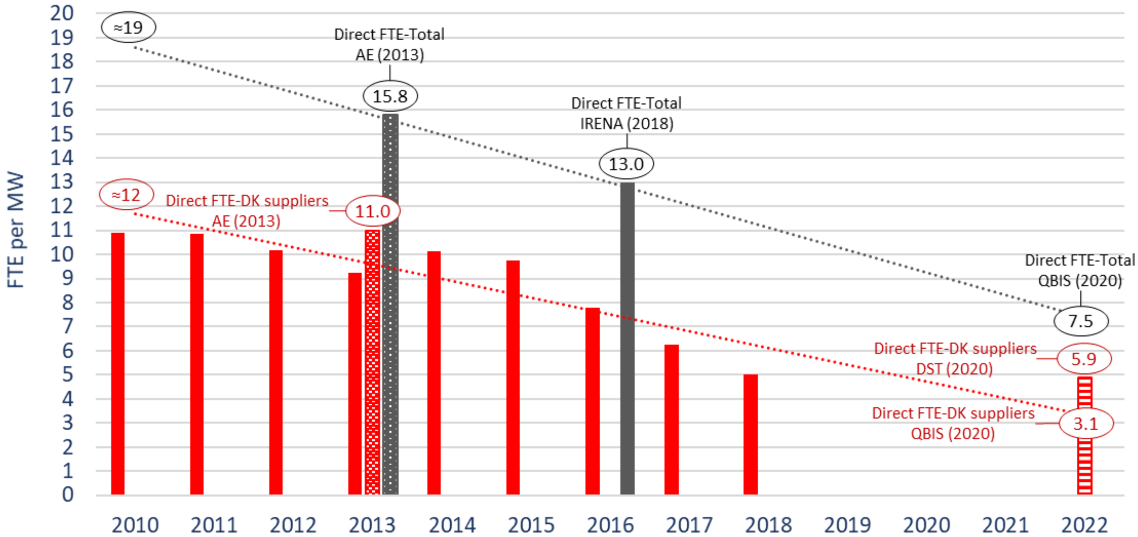


Figure 11: QBIS, based on AE (2013), IRENA (2018b), Statistics Denmark's FTE multipliers, Wind Denmark's member survey, WindEurope (2019 and 2020) and Wind Denmark (2020) [9].

Danish Energy Agency

Offshore wind farms installed and operated bring large FTE benefits. The best example is that the operation & maintenance (O&M) stages of an offshore wind farm creates long term jobs. This is critical from a socio-economic perspective as offshore wind ports are often located within coastal communities removed from the host nation's main economic centres. While ports often employ few people directly, they are an important part of the municipal economy, generating substantial economic activity and local jobs [11].

Socio-economic impacts of offshore wind – Thor offshore wind farm

A recent modelling study financed by the Danish Maritime Fund has assessed the socio-economic benefits of existing and new offshore wind farms in Denmark such as the Thor wind farm which is expected to be fully commissioned by 2027. The total direct labour input for the Thor wind farm (800 MW-1000 MW) is estimated to be around 5,234 FTEs in the capex phase, around 1,987 FTEs over the 25-year long opex phase and finally, around 546 FTEs in the depex phase. This result in a total direct labour input of around 7,768 FTEs over the lifetime of the Thor wind farm.

Thor offshore wind farm

800-1,000 MW, +20 km offshore

	CAPEX	OPEX	DEPEX	TOTAL
Offshore wind farm	(0.85)	(1.16)	(0.85)	
- Costs (EUR million)	2,028	1,238	300	3,565
- Costs (EUR million/MW)	2.25[1]	1.38	0.33	3.96
- Labor - direct all (FTE)	5,234	1,987	546	7,768
- Labor - direct DK (FTE)	2,540	1,341	246	4,127
- Labor - indirect + induced DK (FTE)	4,254	3,469	578	8,301

	Installation port: Esbjerg				**O&M port:** Thuboron, Thorsminde or Hvide Sande			
	EUR million		FTE		EUR million		FTE	
	Low	High	Low	High	Low	High	Low	High
Share of contracts	35.0%	57%	35.0%	57%	1.4%	15%	1.4%	15%
Direct	109	178	199	324	0.6	0.6	48	48
Indirect	73	120	250	407	0.4	4.2	1	14
Induced	50	82	217	354	2.4	4.7	12	23
Total	233	379	666	1,084	3.3	9.5	61	84
Total (25 years)	233	379	666	1,084	83	237	1,527	2,109

[1] Expected capex of 2.13 million EUR per MW (DEA 2020) plus development costs.

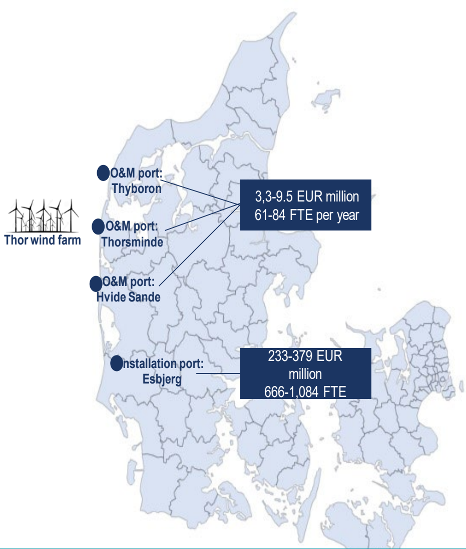


Figure 12: Socioeconomic impact study of offshore wind. QBIS, 2020 [9].

5. OFFSHORE WIND – THE WAY FORWARD

Bolstered by policy targets and falling technology costs, global offshore wind capacity is projected to increase significantly. Offshore wind farms therefore need to be integrated into a regionally planned grid.

Denmark and Germany took the first step in developing such integrated grid planning: the Combined Grid Solution project now connects the Danish region of Zealand with the German state of Mecklenburg-Western Pomerania via two offshore windfarms, the German *Baltic 2* and the Danish *Kriegers Flak*. It is an example of innovation in the context of the energy transition, as it is the world's first project combining grid connections to offshore wind farms with an interconnector between two countries. The interconnector allows electricity to be traded in both directions – from Denmark to Germany and from Germany to Denmark. Construction work began at the turn of the year 2016/17, and the Combined Grid Solution became operational in late 2020. The Kriegers Flak (Denmark) and Baltic 2 (Germany) wind farms are less than 30 kilometers apart and both wind farms are linked by means of two sea cables with a transmission capacity of 400 MW – forming the interconnector.

Denmark is moving even further into the development of an integrated regional planning: the Climate Agreement of June 2020 launched the objectives of building the world's first offshore wind "energy islands", marking a step change in a new era for offshore wind energy in Europe. The energy islands represent a paradigm shift in the approach to offshore wind power in Europe: instead of individual wind farms, energy islands will serve as a hub for electricity generation for the surrounding wind farms, by collecting and distributing the electricity between countries connected by an electricity grid. A number of European countries are currently trading electricity though the day-ahead and intraday markets. The construction of energy islands will help Europe lower its global emissions, by increasing trade of renewable electricity to various neighboring markets. The energy islands hold the key to enable the following advantages:

- Deliver large-scale offshore wind deployment by utilizing some of the large offshore wind potential far from coast;
- Drive efficiencies and cost reduction in transmission utilization as the hub will allow for flexible distribution of the electricity and enable better utilization of the cable capacity;
- Enable effective onshore grid integration across countries with limited need for grid reinforcements on land;
- Apply a modular approach, allowing for future implementation of upcoming technologies such as "Power-to-X" to produce hydrogen, methanol and ammonia. The abundance of offshore wind energy will in the long run be utilized to produce climate friendly fuels for shipping, aviation, heavy industry or heavy-duty vehicles.

The energy islands will be placed in the North Sea and by the Danish Island of Bornholm in the Baltic Sea.

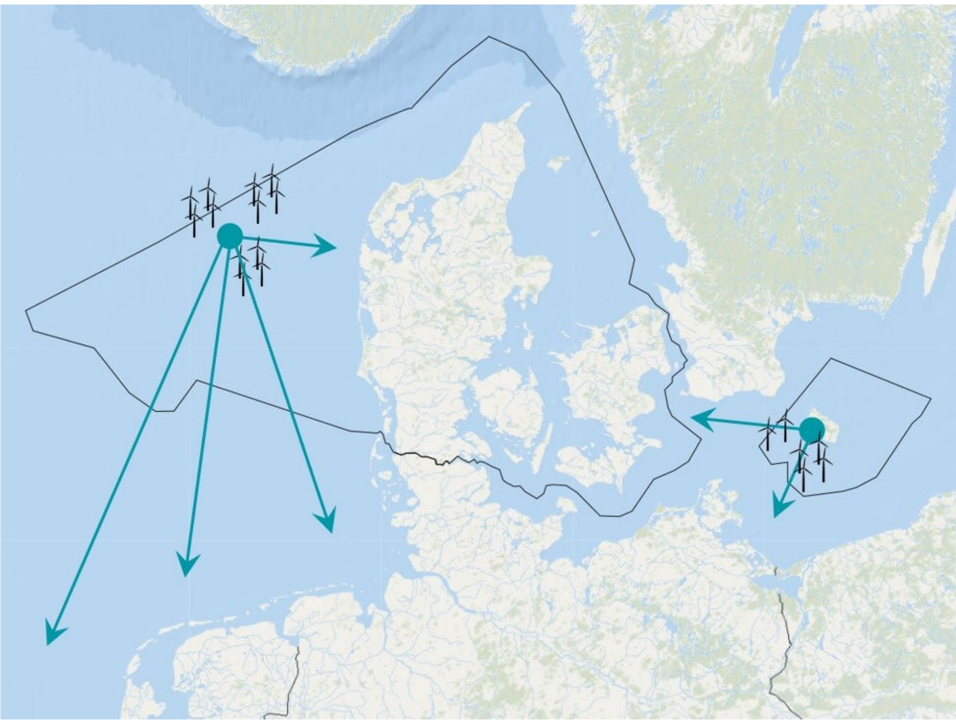
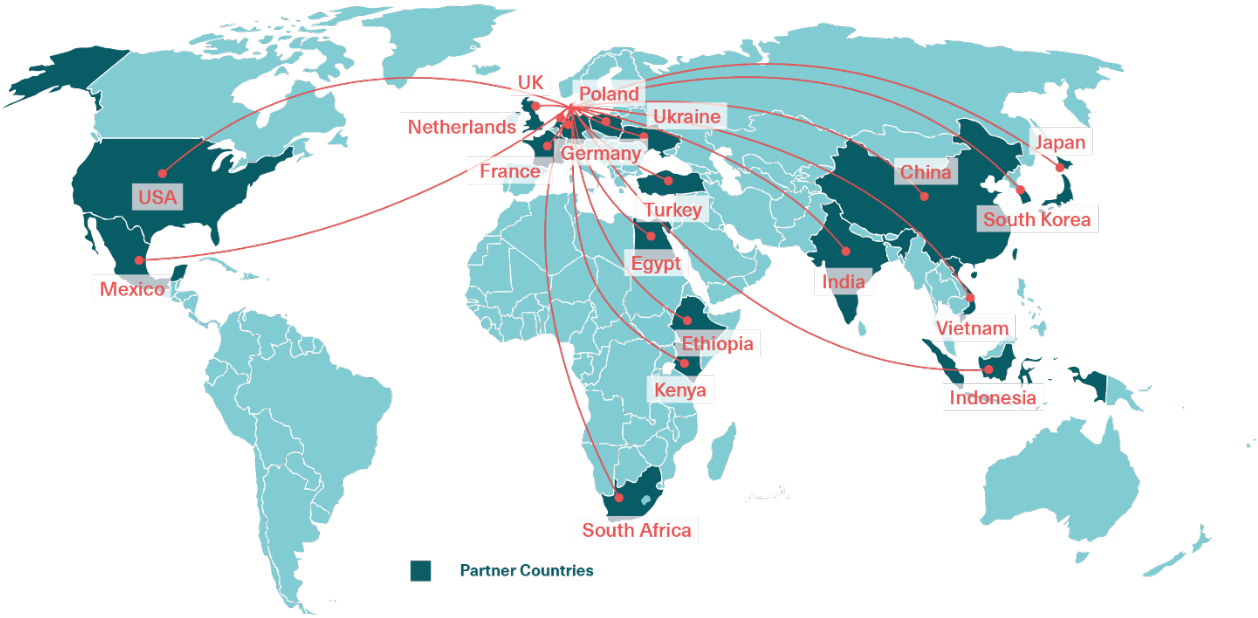


Figure 13: Location of the two energy islands.

6. THE DANISH ENERGY AGENCY

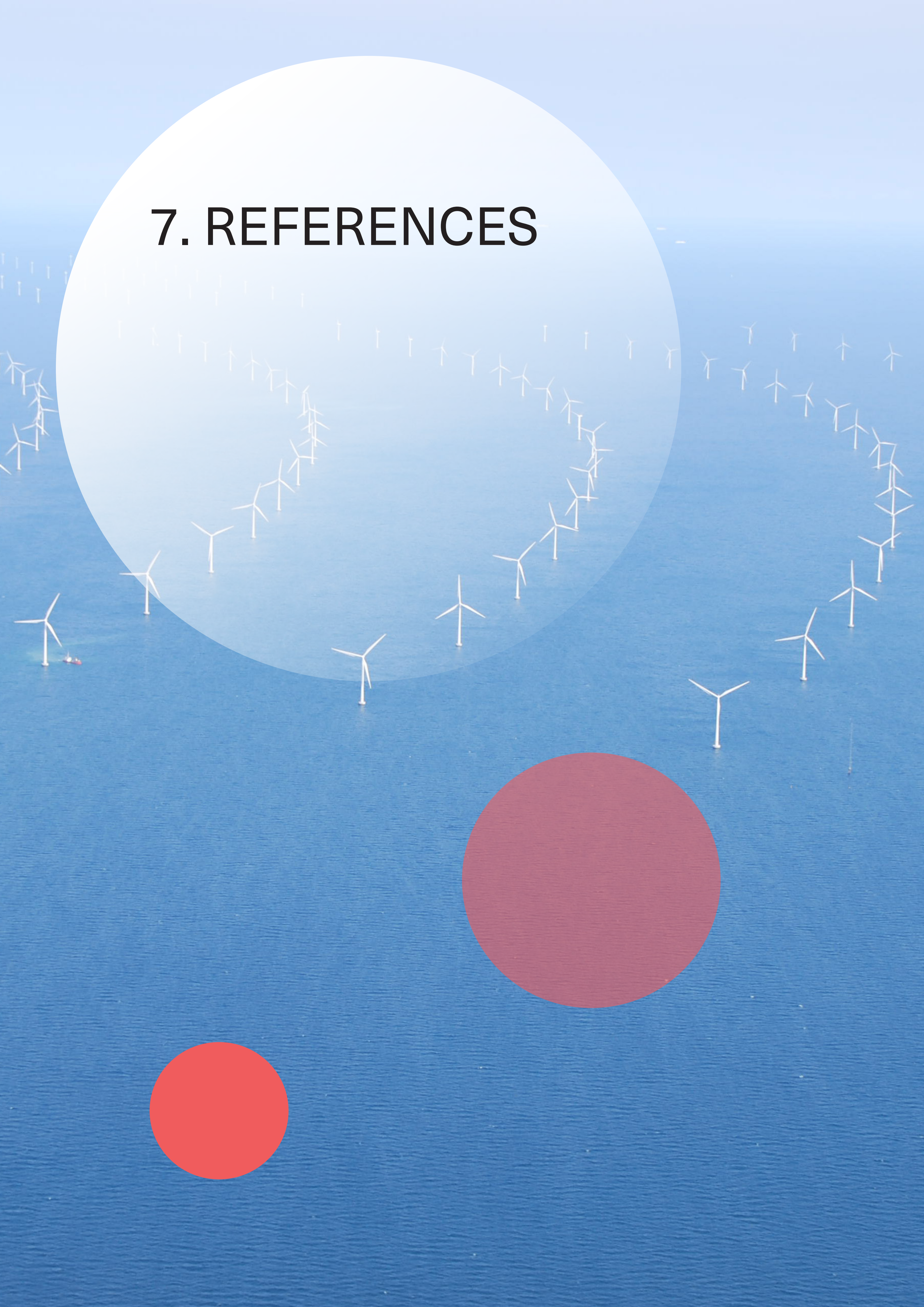


At the Danish Energy Agency (DEA), we monitor and develop energy and supply sectors in Denmark. We focus on being a diverse working environment always strengthening interdisciplinary cooperation. We are responsible for tasks linked to energy production, supply and consumption, as well as Danish efforts to reduce carbon emissions.

Just as climate change knows no borders, neither must our efforts to confront it. At the Centre for Global Cooperation of the DEA, we share Denmark's experience on energy transition with the world. By partnering with some of the world's biggest or fastest-growing economies, we put our expertise to use where it holds the greatest impact. Because our domestic progress owes to decades of active and persistent policy, we are able to assist our partners in deploying the framework for a cost-efficient energy transition. We provide flexible and technical expertise, to leap, together, into a greener future.

The Danish Energy Agency was established in 1976, and is an agency under the Ministry of Climate, Energy & Utilities. DEA has app. 800 employees.

7. REFERENCES



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Disclaimer

This document is intended to serve as an explanation of the rationale behind the Danish model for consenting and commissioning large scale offshore wind. The document is primarily for use within bilateral energy partnerships. The document has been written and proof-read by a group of DEA employees with different backgrounds, perspectives of and experiences within the offshore wind sector. We have in certain places offered opinions and views of best practice that may not necessarily be true in all cases. We have to a limited degree offered views on where the development might be leading, which may not necessarily end up being the case. In spite of that risk we thought it would add value to the narrative. In spite of our best efforts to be correct in all aspects of the narrative, the document may contain errors. This document does not have any legal status and is not an official and legally binding DEA document.

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Credits

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