= 1.7 GW in total installed capacity

Offshore wind farms in operation in Denmark as of early 2019 with a total of 1.7 GW in installed capacity.

PERFORMANCE OF OFFSHORE WIND FARMS

Denmark has 14 offshore wind farms in operation with a total installed capacity of 1.7 GW - and considerably more on the way. At least 7.6 GW additional offshore wind is planned by 2030. A recent study carried out by DEA in 2020 reveals that the Danish wind farms were the best performing assets in terms of capacity factors.

The history of offshore wind

The world's first offshore wind farm, Vindeby, was commissioned in 1991 in Denmark. Today Denmark has 14 offshore wind farms in operation - 1.7 GW in total installed capacity - and considerably more on the way, with at least 7.6 GW additional offshore wind planned by 2030.

Denmark has made production data from all wind turbines publicly available[1] and it is therefore possible to track performance and compare against other countries doing the same.

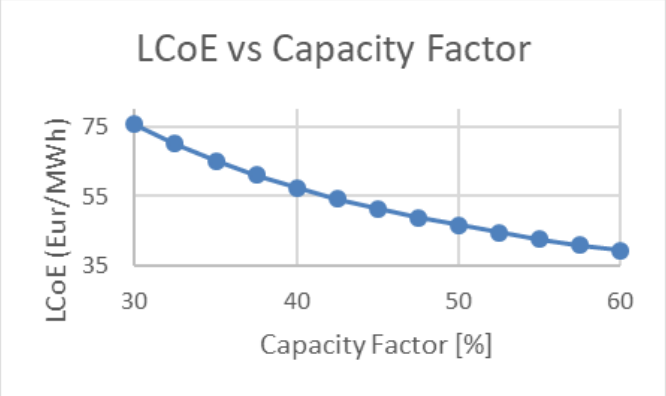
Danish Offshore wind hub

Early on in the development of the wind energy industry in Denmark, emphasis was placed on creating a conducive environment for this new industry. Cooperation between the following three groups has played an essential role in building the Danish hub:

- Research institutions and universities, including public-private partnerships in testing facilities
- Authorities and regulator
- Developers and wider supply chain

Factors affecting performance

Capacity factor is an important metric and is highly correlated to the Levelised Cost of Energy (LCoE), as shown below, taken from the Danish Energy Agency's LCoE calculator for a typical offshore wind farm.



Figur 1: A theoretical example using the Danish Energy Agency's LCoE calculator, for a typical offshore wind farm. Note that the technology data and currency is from 2020, and Weighted Average Cost of Capital is 4%.

A number of technical and regulatory factors impact the performance of an offshore wind farm over the design, construction and operation phases of the wind farm. Decisions made in the design phase cannot be changed

[1] Reference to Danish Wind Turbine Registry, https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/overview-energy-sector

later and poor choices will negatively impact the project over its lifetime. The responsible authorities carry a significant responsibility in **site selection** (considering factors such as wind speeds and seabed conditions), the result of which will largely dictate both LCoE and performance over the lifetime.

In the **Marine Spatial Planning** process, several elements must be considered, such as environmentally sensitive areas and shipping routes, as well as sea depths and seabed conditions. This is mainly the responsibility of the responsible authority (DEA).

The availability of high quality data for design choices is essential to reduce uncertainty for developers, leading to lower costs. Clear division of responsibilities of which stakeholder is responsible for which data is crucial, to ensure a fair balance of risk between the responsible authority and the developer.

For **financial close** of a project, a bankable revenue stabilization is required, similar to a PPA. In Denmark, the agreed CFD is embedded in primary legislation, thus providing the highest possible security and rating to the project owner.

Two of the crucial elements of wind farm design are the **choice of turbine** and the **layout** of the wind farm. The developer optimises the choice of turbine considering mainly the wind resource of the site, and includes hub height, power curve, rotor diameter and generator capacity Micro-siting design aims generally to reduce wake loss in the wind farm. These design choices are made by the developer typically to maximize rate of return on investment.

Manufacturers have been advancing the industry through technology development for decades, designing and **manufacturing** efficient and reliable wind turbines, contributing to the reduced LCoE we see today.

The **electrical system** of the wind farm, up until the Point of Connection, is another important design consideration, and may include inter-array and export cables, voltage levels, AC vs DC, on- and off-shore substations, etc. This requires close collaboration between the developer and the Transmission System Operator (TSO).

After successful commissioning, the **asset management strategy** of the wind farm is important to maximize generation. This includes optimizing operations and maintenance schedule and preventive to maximize availability of the wind farm over its lifetime, and is typically the responsibility of either the developer or the turbine manufacturer.

How do Danish offshore wind farms perform compared with other European countries?

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.

This shows that Denmark has been able to capitalize on its ample wind resource, to ensure that each wind farm is maximizing its generation.

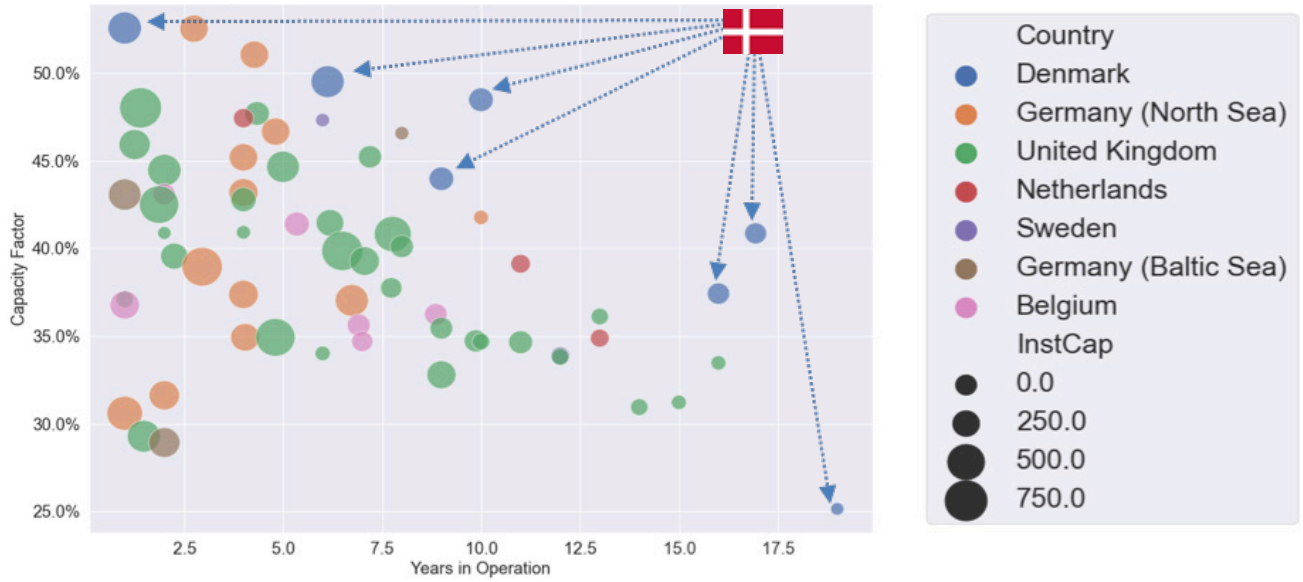


Figure 2: Capacity factor by installed capacity, years of operation and country. Note the size of the circle refers to the installed capacity of the wind farm. Other offshore wind farms were only included if they had more than 1 year of publically available data, and more than 30 MW capacity. Source: Wood Mackenzie & Danish Energy Agency.