Offshore wind power in the Baltic sea

Conditions for profitability

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Content

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Background

Purpose

Many countries in Europe, wind farms are built both onshore and offshore. The development in each country is driven by physical conditions and government-controlled incentives.

The dramatic expansion in Sweden has meant that there is now (mid-2014) more than 10 TWh of annual production capacity from both on- and offshore wind farms. In 2016, capacity is expected to have risen to 15 TWh. In Sweden, almost all production capacity has been built onshore. This may seem surprising given the seemingly very good conditions that Sweden has for offshore installations in the Baltic Sea.

The question is thus the following: Why are not more offshore wind farms in the Baltic Sea being built?

In comparison with the rapid expansion currently underway in British, German and Danish waters, it's hard to understand why not also the Baltic Sea are subject to the same exploitation.

This might be explained by the fact that offshore wind power in the Baltic Sea is generally considered to be much less profitable in comparison to wind farms in the North Sea.

The incentive scheme in Sweden, electricity certificates, provides the same compensation per kWh produced at sea as on land. Incentive schemes in other countries generally provides up to twice the benefit (UK).

The actors who develop and build offshore wind farms in Europe today, has undeniably skills and resources to also build in the Baltic Sea. But due to the fact that economic conditions are better elsewhere, the expansion in the Baltic Sea has not kicked off yet.

This paper begins with an inventory and summarizes the most important and fundamental issues relating to the deployment of offshore wind farms in general. These key points are then analysed from a Baltic Sea perspective.

Finally, profitability of different wind farms is examined. Fictional wind farms in the North Sea, Baltic Sea and onshore are compared from an investor's point of view.

About the author

Henrik Malmberg worked for E.ON 2006 - 2012 and was in charge of the planning of wind power projects in the Nordic market.

Henrik Malmberg left the wind industry in 2012 and is now the CEO of Begoma, a family-owned company in shipping and logistics.

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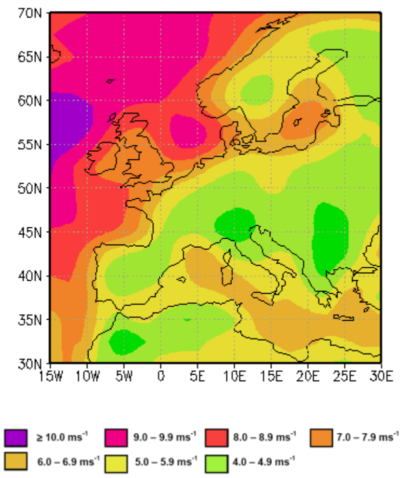
Relevant issues

Wind conditions and energy content

The picture below shows the difference in the average wind speed over Europe during the 1900s the second half. Darker colours indicate a higher wind speed.



Picture 1. Annual long-term means for NCEP/NCAR datasets from 1948-95. (Ag Stephens, Long-Term Variability in offshore wind speeds, 2000)

The annual mean wind speed in the North Sea is slightly higher than in the Baltic Sea. In the North Sea the average wind is about 9 to 10 meters per second, while in the Baltic Sea the annual mean is rather 8-9 meters per second. The annual mean wind speed will of course vary greatly from place to place.

Wind turbines

Wind turbines are divided into different IEC classes according to IEC 61400-2.

Class	IEC I	IEC II	IEC III
Annual mean wind	10 m/s	8.5 m/s	7.5 m/s
50-year max	70 m/s	59.5 m/s	52.5 m/s
Turbulence	A 18% B 16%	A 18% B 16%	A 18% B 16%

Table 1

An IEC1-classed turbine generally has a larger generator than wind turbines in lower classes. A wind turbine which is designed for lower wind speeds often has a larger rotor diameter and a higher tower.

Foundations, ground conditions and water depths

There are a number of different technologies for construction of foundations for offshore wind turbines. The two techniques most commonly in practice are either gravity foundations or monopiles.

Ground conditions and water depth determines which type of foundation is best suited. Different countries may have different laws for how foundations may look like and how they may be built on site.

A gravity foundation sits on the seabed and keeps the turbine upright by its own weight. This type of foundation is built from concrete, floated to the site on a barge and lifted into place with a crane. The foundation is then filled with stone. It is essential that the seabed is hard (a sandy bottom is preferred) and smooth.

A monopile is a steel cylinder driven by force into the seabed. On the steel cylinder, a transition piece is fitted onto which the wind turbine is attached. A monopile can be built in deeper water (up to about 40 meters) and in conditions with much silt and mud where a gravity foundation had not been suitable. In contrast, the installation of a monopile involves some risk of complications when driving down the monopile into the seabed.

Weather conditions

Construction

A smooth construction phase is dependent on long periods of calm weather. The construction involves boats, cranes and other equipment that is too expensive to be standing still in bad weather. The special types of vessels are in great demand throughout Europe and can therefore be booked to a following project immediately after the scheduled completion of the current project. If a project is delayed due to bad weather, some ships may simply have to leave the construction site to go on to the next project.

Operation

Under operation, the ability to ferry personnel, equipment and spare parts to a wind farm is naturally affected by the weather conditions on the site. Normal maintenance is generally carried out by boats that can dock at a wind turbine foundation and load or unload staff and equipment.

If an offshore wind farm is located in an environment where the weather and wave height often prohibits transports to the wind turbines; obviously this implies increased maintenance costs and longer stand-stills in comparison with projects located in calmer waters.

Grid connection

An offshore wind turbine does not differ from a land-based ditto, in the sense that in the wind turbine there is a transformer that transforms the primary voltage up to about 30 kV. In an offshore wind farm, there is therefore often a substation where the power from the turbines are transformed to a higher voltage (typically 130 kV), which is more suitable for transmission to the grid onshore.

In large offshore wind farms, located at great distance from shore, a transmission with HVDC (high voltage direct current) may pay off, as the transmission losses decreases significantly. On the other hand, a large and often very expensive substation must be constructed adjacent to the wind farm.

Profitability

A wind power project is a substantial investment and the expectation of return range from 10% to 15% on investment (IRR). Return from an offshore wind farm is generally expected to be higher than from an onshore wind farm, given that the risks involved in offshore wind farms are higher.

In the last chapter, a comparison is made between fictitious investments in offshore wind farms in the North Sea and the Baltic Sea. These are then compared with a typical onshore wind farm in Sweden.

Analysis of conditions for offshore wind farms in the Baltic Sea

Wind conditions and energy content

The annual mean wind in the Baltic Sea is between 8-9 meters per second, where in the North Sea the average wind is 9-10 meters per second. This is a broad generalization; the actual average wind speed for a site depends largely on local conditions. However, one can observe that in the North Sea, there is a higher average wind speed than in the Baltic Sea. Let's figure out what this means in decreased production of a wind turbine with a rotor diameter of 100 meters.

The turbine power is calculated with the following formula:

$$Power = \frac{mass * area * speed^3}{2} * \frac{16}{27} * \alpha$$

Where α is the efficiency of the wind turbine. We assume that the efficiency is 95% and that the weight of a cubic meter of air is 1.25 kg (at sea level).

On a typical site in the North Sea, the annual mean wind is 9 meters per second and 8 meters per second on a typical site in the Baltic Sea

The difference in power (at average wind) then becomes:

North Sea site:

$$\frac{1{,}25 * 50^2 * \pi * 9^3}{2} * \frac{16}{27} * 95\% = ca\ 2\ MW$$

Baltic Sea site:

$$\frac{1{,}25 * 50^2 * \pi * 8^3}{2} * \frac{16}{27} * 95\% = ca\ 1{,}4\ MW$$

The seemingly modest difference in average annual wind between 8 and 9 meters per second, results in the North Sea project produces over 40% more energy!

In practice, however, the differences are not so large, because the wind turbines available today do not have generators of more than 5 or 6 MW and thus produce no more than that, no matter the wind speed. Likewise, compensation for lower winds is made by using longer blades of the wind turbine to increase the area, leading to increased production.

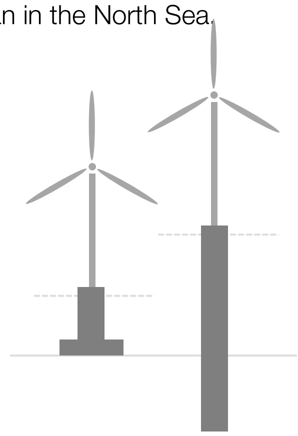
Below, a comparison is made between two different projects that have been built with the same type of turbines (Siemens 2.3 MW). This shows that the difference in annual production is about 10%.

Location	Project	Annual production/ WTG
Baltic Sea	Rödsand	Ca 9 GWh
North Sea	Horns rev 2	Ca 10 GWh

Table 2

Ground conditions and foundation selection

Conditions in the Baltic Sea generally favour gravity foundations, due to suitable water depths (10-25 meters) and a hard seabed. When a gravity foundation is generally cheaper to build than a monopile, foundation costs of a wind power project in the Baltic Sea may be lower than in the North Sea.



Picture 2. Gravity foundation left, monopole right.

The figure shows that a gravity foundation in the Baltic Sea (left) has the potential to be cheaper to build than a monopile in the North Sea, when the water depth is lower in the Baltic Sea and the material is cheaper (concrete over steel).

The actual cost of course depends on how large the project is and how the specific conditions looks like on the actual site.

Weather conditions

Wind turbine choice

The predominant wind direction in the southern Baltic Sea is south - southwest, while in the northern Baltic Sea the dominant wind direction is south.

For any given wind project, there is a combination of rotor diameter, generator power and tower height which is the best suited for that particular site. For example, there are wind turbines built onshore with a rotor of 120 meters in diameter, a tower of 140 m and a generator power of only 3 MW at sites where wind conditions are poor.

In the North Sea there are examples to the contrary, where the wind turbines have a generator capacity of 6 MW in the 120-meter rotors and a tower of only 80 meters.

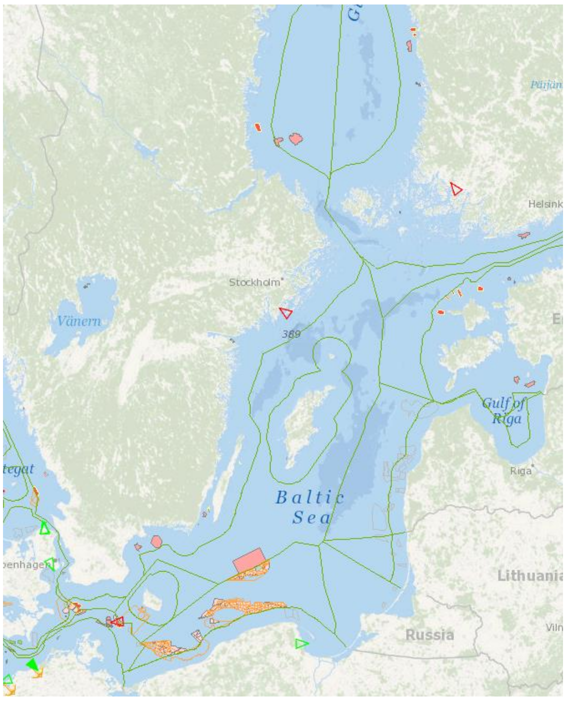
In the Baltic Sea, wind speeds are somewhere in between, which means that range of suitable wind turbine on the market is wide.

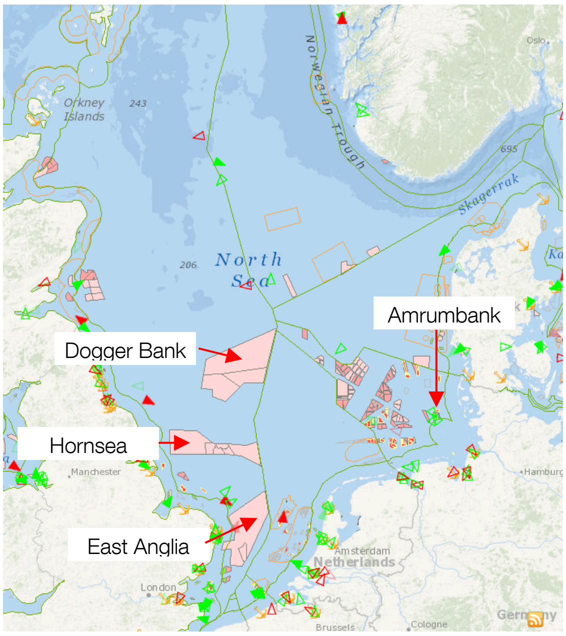
Operation and maintenance

In the Baltic Sea weather conditions are relatively better than in the North Sea, in terms of wave heights and frequency of storms. This leads to that availability of wind farms in the Baltic Sea is probably better than in the North Sea. Naturally, the distance to the coast plays a big part. Also the area's ice conditions affect the ability to maintain the wind farm.

The following two images (same scale) show locations of projects currently under development, construction or operation of the Baltic and North Sea.

In the North Sea there are many projects on the east coast of England and along the North German coastline, which has been under development for a long time. The larger projects now planned are often located far out in the North Sea. Pay special attention to the three major projects in English waters; Dogger Bank, Hornsea and East Anglia who are as far as 200 kilometres from land. Also, the north German projects, such as Amrumbank West, are located approximately 40 km from the island of Helgoland and about 100 km from the coast.





Picture 3 & 4. Planned and existing projects in the Baltic Sea and in the North Sea. www.4coffshore.com/offshorewind

Naturally, having a short distance to land is essential in the operation and maintenance cost of a wind farm. For a project that is close to land, staff and parts will be ferried from a maintenance base on the coast every day that weather permits. A wind farm further offshore requires a platform where staff can spend the night and wait out eventual bad weather, naturally implying building costs.

Distance to shore	Transport time with boat (20 knots)
Rödsand – 9km	Ca 15 min
Horns rev 2 – 32 km	Ca 1h
Amrumbank West – 40 km	Ca 1h 15min

Table 3

Financials

Below is a summary and comparison on the investment and profitability of projects in the North Sea, the Baltic Sea (in Swedish waters) and onshore in Sweden. All investment and maintenance costs in this chapter are the author's estimates based on the three fictitious projects described below.

Assumptions

The following assumptions on each fictional project have been made:

	Baltic Sea	North Sea	Onshore
Nr of WTGs	70	70	70
Total power	210 MW	250 MW	175 MW
Production per WTG and year	11 GWh	14 GWh	7 GWh
Capacity factor	42 %	44 %	32 %
Yearly production	770 GWh	980 GWh	490 GWh
Distance to shore	20 km	40 km	-

Table 4

For the Baltic Sea-project, a 3-MW wind turbine is selected, a 4-MW turbine for the North Sea-project and a 2.5 MW for the onshore project. Turbine selection is made with respect to wind conditions at each site. As discussed above, the lower wind speed in the Baltic Sea and onshore, makes a wind turbine with lower power more suitable.

Investment

It may be appropriate to emphasize that the market for wind turbines is in strong growth and a future reduction in prices can be expected.

The investment for a wind power plant can be split into a couple of items:

	Baltic Sea	North Sea	Onshore
WTG	0,9-1,0	1,2-1,4	0,9-1,1*
Foundations	0,45-0,55	0,55-0,75	Ca 0,1
Grid connection	0,65-0,75	0,75-0,85	Ca 0,15
Transport	0,15-0,25	0,25-0,35	-
Civil works	-	-	Ca 0,15
Misc.	0,15-0,25	0,25-0,30	Ca 0,15
[mEUR/MW]	Ca 2,5	Ca 3,3	Ca 1,6
[EUR/kWh/år]	Ca 0,68	Ca 0,86	Ca 0,59

Table 5

**Onshore turbines are built on taller towers than offshore, driving costs up.*

Operation and maintenance

Maintenance costs for a wind farm can be divided into the following items:

Share of total [%]	Baltic Sea	North Sea	Onshore
Maintenance base in port	15 %	10 %	
Maintenance of turbines	50 %	55 %	60 %
Foundations, grid etc.	25 %	25 %	20 %
Misc.	10 %	10 %	20 %
Cost per MWh [EUR/y]	Ca 22	Ca 27	Ca 16

Table 6

Profitability calculation

Let us assume the following:

	Baltic Sea	North Sea	Onshore
Life	25 y	25 y	25 y
Cost of capital	7 %	8 %	5 %
Inflation	2 %		
Power price*	54 EUR/MWh		
Incentive Scheme*	Certificate system 27 EUR/MWh or feed-in 109 EUR/MWh		

Table 7

** Prices assumed to increase with inflation*

The level of financial risk is higher for an offshore wind project and an even higher risk for a North Sea Project. Therefore, a slightly higher discount rate has been used for the Baltic Sea project and an even slightly higher rate for a North Sea Project.

An investor will evaluate the risks of the underlying project and though the financial risks are higher in an offshore project than in project onshore, this is reflected the interest the project must bear. This will not directly affect the IRR, but well in the calculation of the production cost.

The simulation assumes the same price of electricity in all project alternatives. Historically, electricity prices have been higher in England and in Germany than in Sweden, but in an outlook 25 years ahead, it is not an unreasonable assumption that electricity prices will largely be similar.

Result

IRR [%]	Baltic Sea	North Sea	Onshore
Only power price	3,3 %	0,1 %	6,8 %
Electricity certificates	7,9 % (SE)	4,1 %	12,1 % (SE)
Double cert	12,5 %	8,1 % (UK)	17,6 %
Feed-in*	14,0 %	10,1 %	18,6 %
Grid conn.** + cert	10,0 %	5,7 %	12,1 %
Grid conn.** + cert	15,3 %	10,3 %	17,6 %
Grid conn.** + feed-in	16,5 %	12,0 % (DE, DK)	18,6 %

COE**	97 €/MWh	130 €/MWh	68 €/MWh

Table 8

** During entire period of operation(25 years)*
*** Refers to the cost of connection to the land is paid for by the state (approximately 0,4 mEUR/ MW for Baltic Sea projects and 0,5 mEUR/MW for North Sea projects)*
*** Cost of energy*

Conclusion

With the assumptions made in this report, offshore wind farms in the Baltic Sea generally have better prerequisites in form of simpler and cheaper construction and are less expensive to operate than similar wind farms in the North Sea. However, wind conditions in the North Sea are better, which is reflected in better production than in the Baltic Sea. But given the higher construction and operation costs, a wind project in the Baltic Sea is also more profitable than a similar project in the North Sea.

Also in this report, various incentive schemes have been evaluated from a profitability perspective. This simulation shows that incentive schemes in the UK, Germany and Denmark are more favourable for the investor than the Swedish electricity certificate system. In some schemes the grid connection to shore is paid for by the state.

In table 8, the results which best represent prevailing market conditions, has been marked with grey for each project.

Another aspect is that so far, wind turbines have been designed for offshore installations in North Sea conditions. Wind turbines developed and optimized for the wind conditions in the Baltic Sea, will result in even better profitability.