Expert opinion expansion SWE offshore windfarm

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Introduction

In the progress of the Environmental Impact Assessment (EIA) including soil investigation, Saaremaa Wind Energy (SWE) has concluded that within the current planning area of the wind farm, the soil condition (on certain locations) is of such quality that overall there are not enough suitable locations for the application of bottom fixed foundations. Bottom fixed foundations are the most common and cost-effective form of wind turbine foundations which ensures that a wind farm is profitable. SWE has submitted a request to TTJA[1] to change the planning area. With the amended planning area, more locations will become available where bottom fixed foundations are possible to reach the planned 1400 MW offshore wind farm.

Following the application, TTJA does not seem fully convinced of the need to amend the plan area, as reflected in their response on 13.02.2023 (No. 16-7/20-06558-068). In brief, TTJA stated:

1. The survey of fish and bird life supports the expansion of the wind farm area, but at the same time, the studies do not show that the planned activity, the construction of an offshore wind farm, would be hindered in the area of the initial applied building permit. The Ministry of Finance also noted that due to the geology and construction technical conditions, a 1400 MW offshore wind farm cannot be built with the desired technology, and a wind farm with a smaller capacity can be built (Ministry of Finance).
2. Decrease in the number of turbines to be installed can be compensated by installing turbines with a greater capacity (Ministry of Finance);
3. To solve the geological constraints of the seabed for the construction of turbine foundations with wind turbine placement or foundation alternatives, also taking into account, for example, phased construction or innovative solutions in the form of floating foundations (Ministry of Finance and Ministry of Economics and Communication);
4. The analysis of the geological seabed shows that the survey with the floating buoy is not complete and the largest overlapping sand patches could not be mapped in detail. The Ministry of Economics and Communication noted that an indirect assessment has been presented, that there is mud between the so-called blind spots and that not all objects can be identified and that the geological seabed survey provides the most important data on the seabed, but does not conclude that it is not possible to use suitable technology for this area to erect wind turbines (Ministry of Economics and Communication).

SWE has requested Pondera to write an expert opinion on the application for an amendment of the offshore wind farm planning area.

[1] Tarbijakaitse ja Tehnilise Järelevalve Ametile (TTJA), Eng: Consumer Protection and Technical Regulatory Authority

In short, Pondera concludes the following. The success of an offshore wind farm depends on the risk profile of the project, which is influenced by the installation method and foundation type chosen based on local site conditions. In parts of the current planning area of the wind farm, traditional monopiles are not feasible due to the presence of limestone covered by sediment layers in large in-filled channels, leading to high risk for drilling and major environmental and cost consequences for concrete gravity foundations. Thus, only parts of the site with minimal overburden are suitable for wind turbines, reducing the installed capacity and energy production of the wind farm. Floating foundations are still in pilot phases and will have higher LCoE than bottom fixed projects. To make the project economically efficient and minimize negative environmental impacts, Pondera recommends increasing the nominal project size to 1,400 MW with a larger project area, avoiding high-risk locations and reducing grid connection costs per MW. This would increase the chance of realizing the offshore wind farm and ensure high production of renewable energy against reasonable costs as quickly as possible (with a perspective for 2030).

Below Pondera will address the feedback received from TTJA, Ministry of Economics and Communication and Ministry of Finance and will clarify where necessary the intention of SWE.

1. Surveys for fish and bird life and geological seabed

TTJA indicates: the survey of fish and bird life supports the expansion of the wind farm area, but at the same time, the studies do not show that the planned activity, the construction of an offshore wind farm, would be hindered in the area of the initial applied building permit. The Ministry of Finance also noted that the geological seabed survey and the SWE request show that, due to the geology and construction technical conditions, it is assumed that part of the area is not suitable for pile foundations and/or gravity foundations installed by drilling, and from the submitted materials it can be concluded that with the number, placement and power of wind turbines desired by the developer, a 1400 MW offshore wind farm cannot be built with the desired technology, and a wind farm with a smaller capacity can be built (Ministry of Finance).

The surveys of fish and bird life support the finding that expansion of the wind farm area will not lead to a significant increase of environmental impacts. These studies do of course not show that the construction of an offshore wind farm would be hindered in the area of the initial applied building permit due to adverse soil conditions. In case foundations would be constructed at locations with over 4 meters overburden sediment, the environmental impact is much bigger (especially in case of gravity foundation), compared to the situation of constructing foundations in areas where this layer is thinner or missing. There are therefore environmental reasons for not using all of the initial area and expanding the initial area of the wind farm so parts with high environmental impact can be avoided without reducing the number of wind turbines.

Technological considerations to construct foundations on limestone plateau

Van Oord, in its capacity as reputable design and construction company, strongly advise against planning foundations:

- in the case of monopile foundations, if the depth of the limestone is deeper than 40 meters
- in the case of gravity foundations, if the overburden sediment is thicker than 4 meters.

We would like to add the following with respect to the drilled foundations, there is not too much experience with drilled foundations. During the last years, only on the French Saint-Nazaire offshore wind farm monopiles have been drilled and at St. Brieuc offshore wind farm pin-piles for jackets have been drilled.

In case drilled piles (monopiles and/or pin-piles) have to be installed it is recommended to install these piles only at places with (very) limited overburden of soft sediment. If this is not possible the drill has to drill and lowered within a large steel casing which prevents that the walls of the drilled holes collide. These casings can only be removed after the piles are installed and grouted which means that a large amount of casings are needed or an integrated and costly work method needs to be engineered to install the piles directly after the drilling. Alternatively the drill will be placed underneath the piles and pulls the piles down. The latter is a complicated and expensive work method. The soil within the casings needs to be removed which has an additional impact on the environment.

A limited overburden will lead to a less complicated and therefore less expensive installation method which as well avoids unnecessary risks. To install foundations at places with and without overburden would most probably lead to the use of two sets of specific drills which will jeopardize the feasibility of the project.

Gravity based foundations can only be placed on locations with sufficient bearing capacity as otherwise the level and stability of the foundation cannot be guaranteed. In most cases a foundation bed needs to be installed underneath the gravity based foundation to level the seabed and to evenly distribute the loads to the subsoil. Placing the gravity based foundations directly on the overburden will not be feasible due to the limited bearing capacity of the overburden; the overburden will be squeezed out between the foundation and the hard soil and this is an unpredictable and risky process which will not lead to a satisfactory result. The overburden can be removed and replaced by a foundation bed but only at places with a limited overburden height. At deeper locations the amount of soil that needs to be removed (dredged) will be enormous, the soft soil can collide easily so long slopes are needed (or sheet piles) and the impact on the environment is very large due to resuspension and dispersal of sediment in the water column. Next to this the gravity based foundation itself has to become very large which will cause serious challenges with respect to the fabrication, transport and installation of the foundation.

Taking the above into account, it is therefore advisable to restrict the installation of the foundations to places where the overburden is limited. At places with a large overburden the risk profile and therefore the costs, will increase dramatically as well as the impact on the environment.

2. Compensation of decrease in the number of turbines to be installed

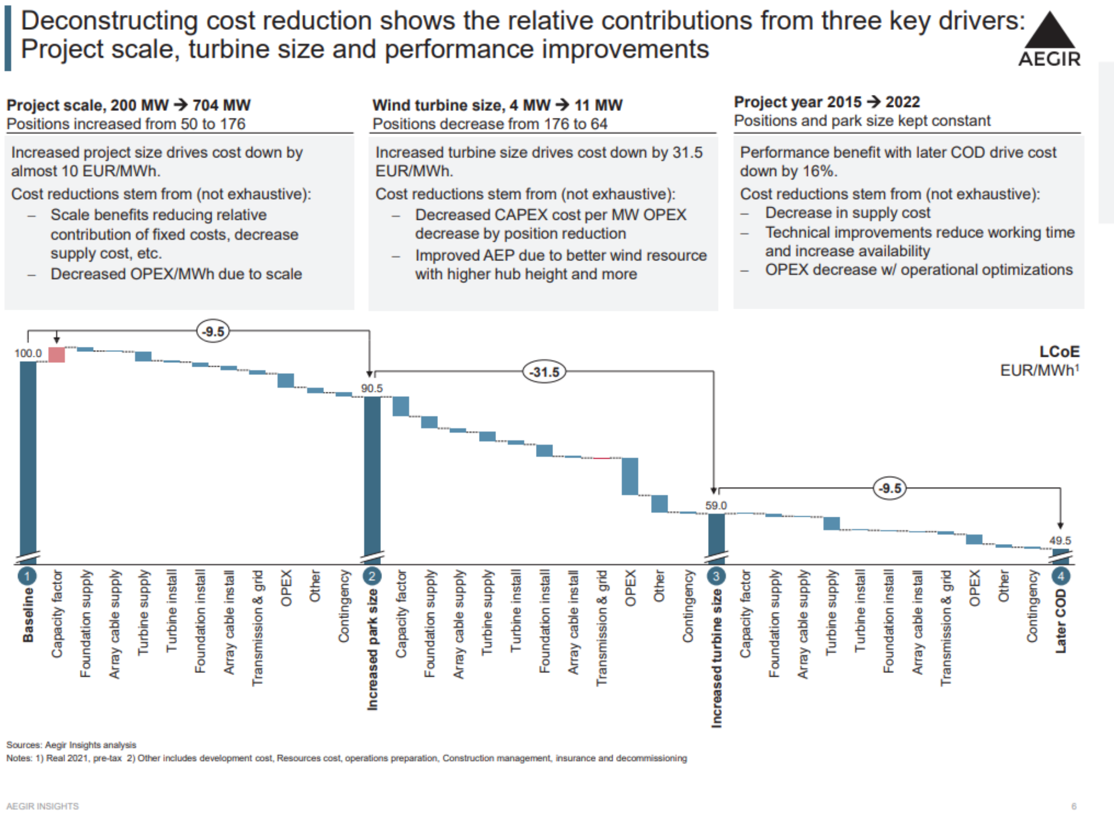
TTJA indicates that the decrease in the number of turbines to be installed can be compensated by installing turbines with a greater capacity.

First of all, if fewer turbines can be placed, then it is theoretically possible to use turbines with a larger capacity in places where turbines are possible, so that the total capacity of the wind farm does not have to be reduced. However, it is not the case that a turbine with a lower capacity can simply be replaced by a wind turbine with a higher capacity. Turbines with a greater capacity have larger turbine blades, are often higher and need to be spaced further apart. As a result, there are also fewer large turbines on the same surface area compared to smaller turbines, which means that the total capacity of the wind farm cannot remain the same in any case.

And about the reaction of TTJA that a wind farm with a smaller capacity can be built, it is wise to look back at history. Nowadays (and in the period 2025-2030) an offshore wind farm has a minimum scale of 1,000

MW (200 km²). The reason for that is the economy of scale: with larger wind farms, the costs per MWh are lower.

A study of Aegir (LCOE, Update of recent trends (Offshore), Morten Kofoed Jensen 30th August 2022) has shown that the main drivers for cost reduction are increasing the project scale and turbine size; see figure below. So, larger turbines and larger project scales are good for the business case.

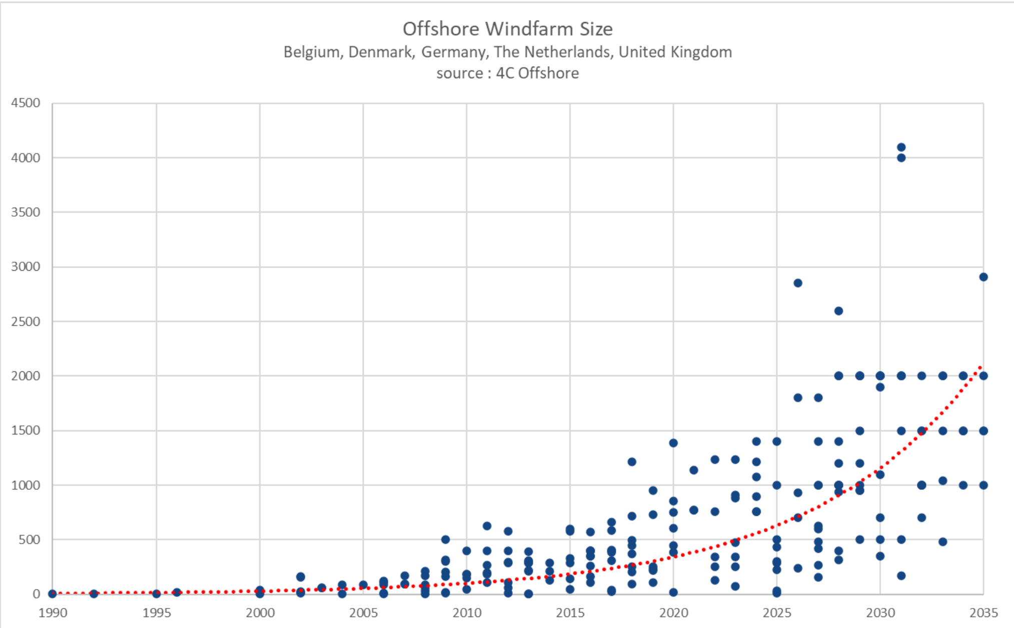


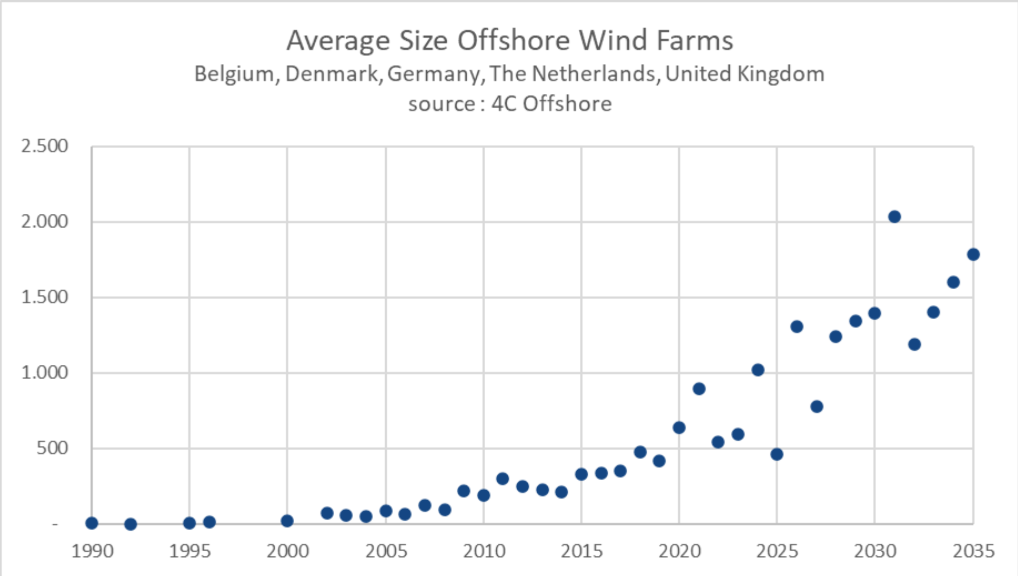
A similar result is shown in the study for TKI Wind op Zee (Pathways to potential cost reductions for offshore wind energy, Authors : TNO: B.H. Bulder, S. Krishna Swamy, P.M.J. Warnaar and BLIX Consultancy: I.D. Maassen van den Brink, M.L. de la Vieter, January 2021), see the next table. The tables shows that the combination of larger wind turbines in combination with larger wind farms lead to substantial lower power costs and therefore to a more economically feasible project.

		2020 (10 MW)	2025 (15 MW)	2030 (20 MW)
# of wind turbines		75	67	100
Pnom of wind farm	[MW]	750	1005	2000
Distance to shore	[km]	70	70	70
Distance to grid	[km]	100	100	100
year		2020	2025	2030
WACC[3]	[%]	3.80	3.88	3.88
Single turbine	[M€]/turbine	7.41	13.05	19.02
Support structure	[M€]/turbine	4.97	8.50	11.38
Electricity total	[M€]	735.97	926.83	1766.74
Project fixed cost	[M€]	45.00	60.30	120.00
Installation total	[M€]	110.31	131.39	205.75
Total Capex	[M€]	1819.8	2563.0	5132.4
Total Opex	[M€]/year	63.90	70.59	107.96
Yield	[TWh]/year	3.5407	4.7775	9.4704
LCoE 2020	[€/MWh]	**55.2**	**48.7**	**42.3**

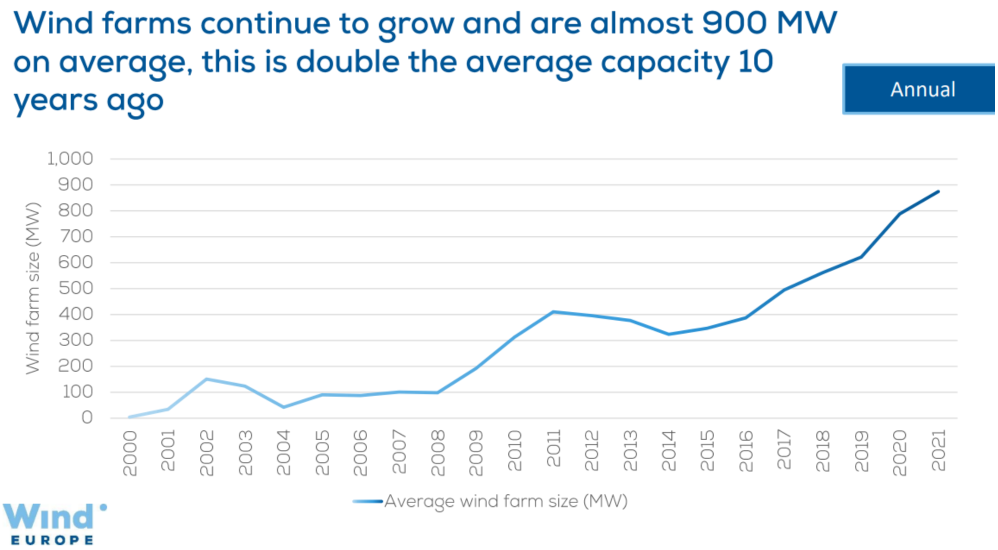
Table 5 The overall characteristics, cost, performance and levelized cost of energy

Apparently this is recognized in the market as the project sizes are growing according to 4C Offshore and Wind Europe.





Offshore wind energy 2021 statistics – March 2022. The first graph shows the size in MW per individual wind farm. The second graph shows the average number of MW per wind farm.



Nowadays, if you were to build and operate a relatively small offshore wind farm, the costs would be higher than the sale of the electricity produced could compensate. The economic feasibility of such a wind farm is therefore at stake, while the costs for society will also be high.

3. Phased construction or innovative solutions in the form of floating foundations

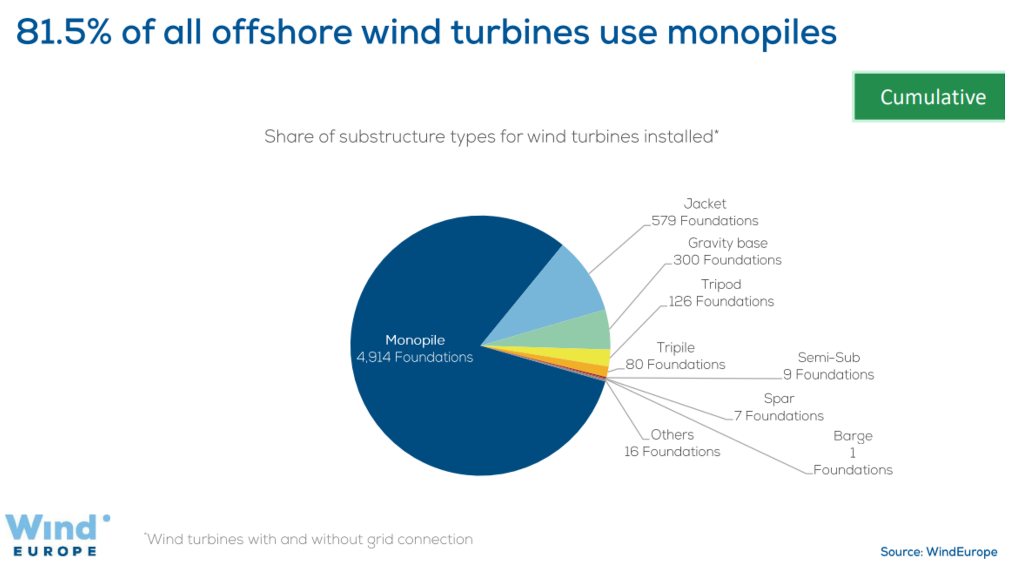
TTJA indicates: to solve the geological constraints of the seabed for the construction of turbine foundations with wind turbine placement or foundation alternatives, also taking into account, for example, phased construction or innovative solutions in the form of floating foundations (Ministry of Finance and Ministry of Economics and Communication).

Phased construction

Phased construction in itself does not solve the difficult soil conditions, this condition obviously does not change over time. Phased construction in itself doesn't take away the need for a larger area of the wind farm. In addition, a phased construction will lead to higher costs because the mobilization of specialized vessels, equipment, manpower, etc. will have to take place several times and the order size of material and wind turbines will be smaller. Maybe even O&M costs will be higher, because the turbines of the first phase might not be available anymore, when the second phase is launched.

Floating foundations

Floating offshore wind turbine foundations are not a proven technology yet. According to the underneath graph, basis 2021, only 17 floating foundations have been installed out of 6.032 foundations. The 4C Offshore floating wind progress update H2 2022 (11/11/2022) mentions that a the end of 2022 in Europe 113 MW offshore wind was installed on floating foundations. All these were pilot projects. Floating foundations are therefore not a realistic option for the wind farm of SWE.



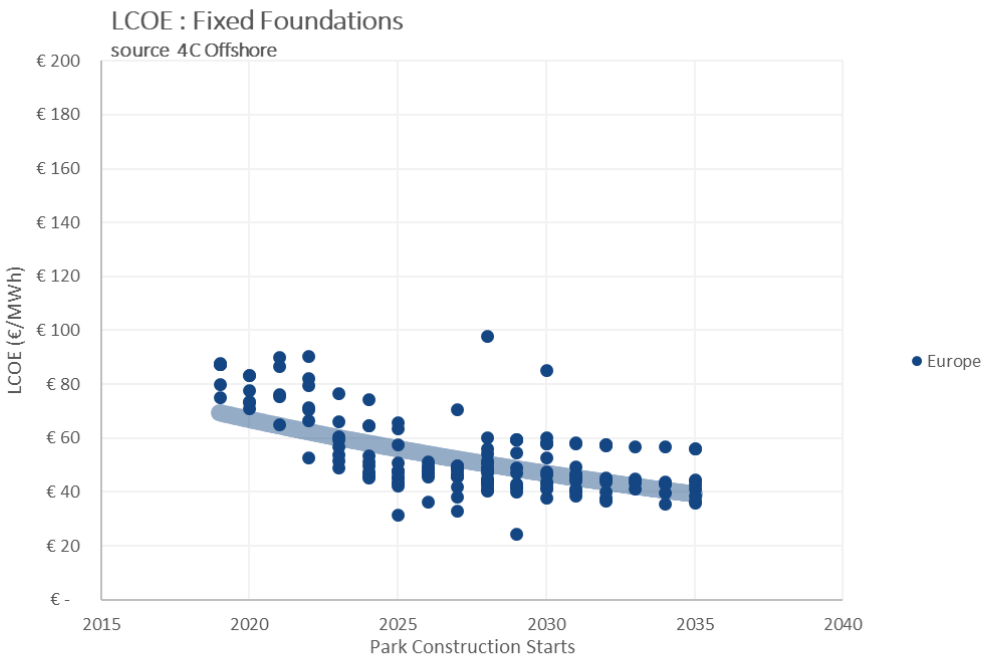
Offshore wind energy 2021 statistics – March 2022

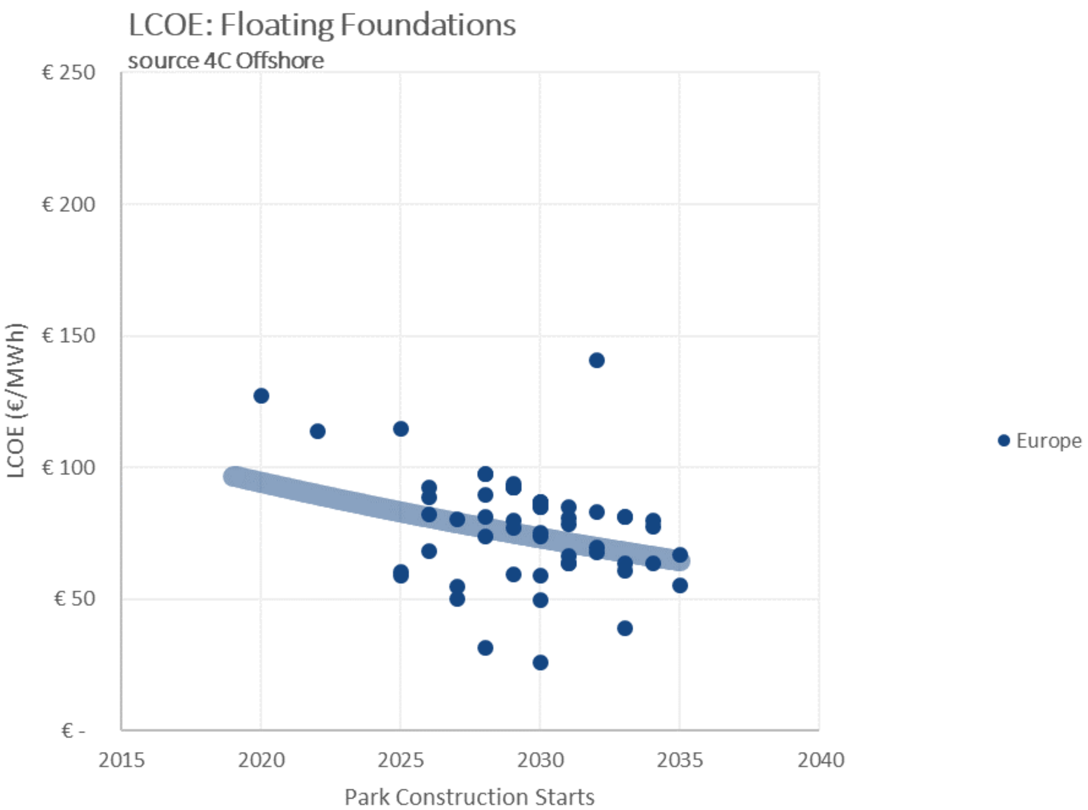
Due to the early stage of the development, floating offshore wind is not competitive with bottom-fixed offshore wind. An analysis made by 4C Offshore shows that the Levelised Cost of Energy (LCoE) based upon bottom fixed can develop from approx. 70 Euro/MWh to approx. 40 Euro/MWh in 2035. A LCoE based upon floating foundations can develop from approx. 100 Euro/MWh to approx. 60 Euro/MWh in 2035. See the following graphs. Floating offshore wind is apparently around 50% more expensive compared to bottom fixed projects.

BVG Associates made an assessment[2] per foundation structure. Essentially floating foundations are significantly more expensive then bottom fixed foundation, especially at less deep locations.

The drilled foundation will be more expensive than the driven monopile, however first assessments show that this will still be at significantly lower costs then the floating foundation.

[2] BVG Associates, Long term outlook on developments in foundation technology, TKI Wind op Zee, August 2022


LCOE : Fixed Foundations
source 4C Offshore
€ 200
€ 180
€ 160
€ 140
€ 120
€ 100
€ 80
€ 60
€ 40
€ 20
€ -
LCOE (€/MWh)
2015
2020
2025
2030
2035
2040
Park Construction Starts
Europe


LCOE: Floating Foundations
source 4C Offshore
€ 250
€ 200
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€ 100
€ 50
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LCOE (€/MWh)
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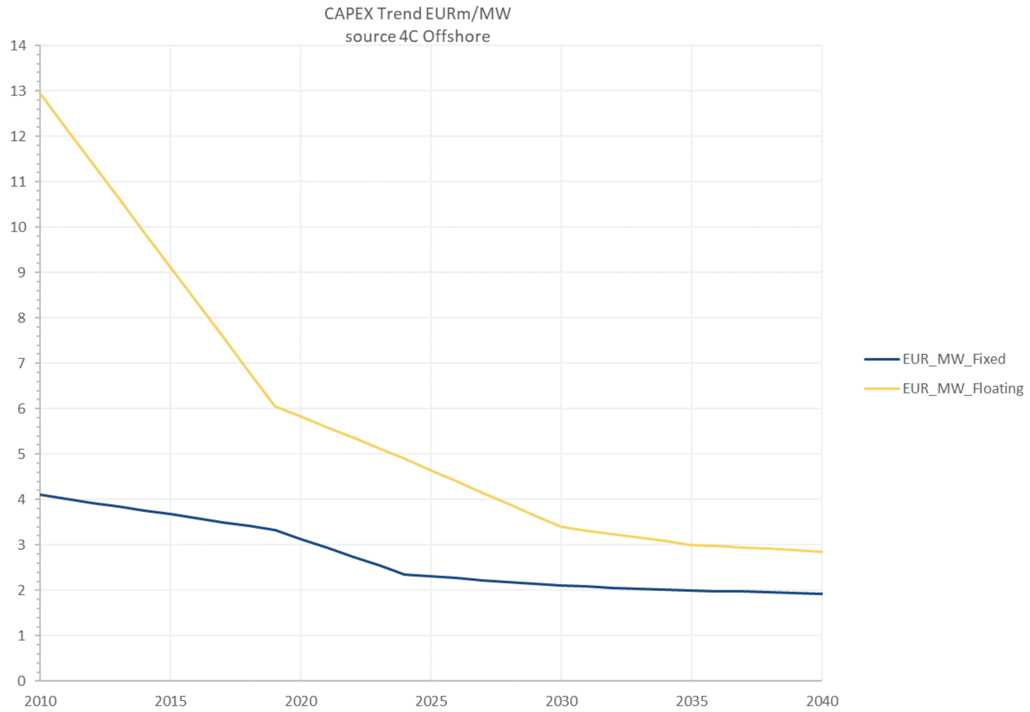
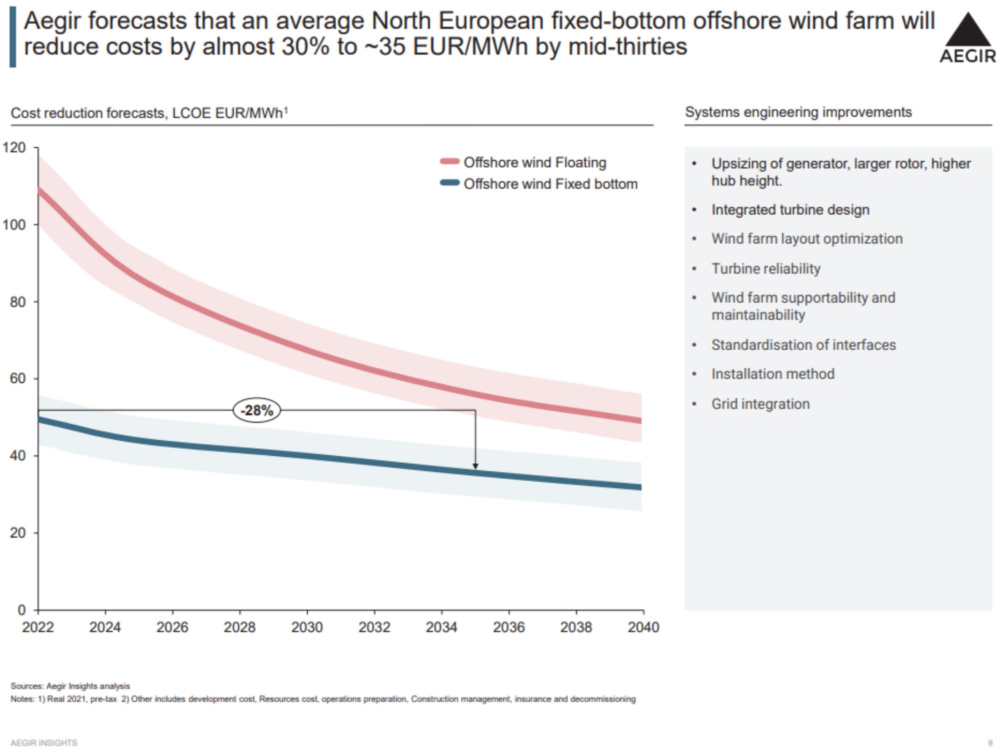
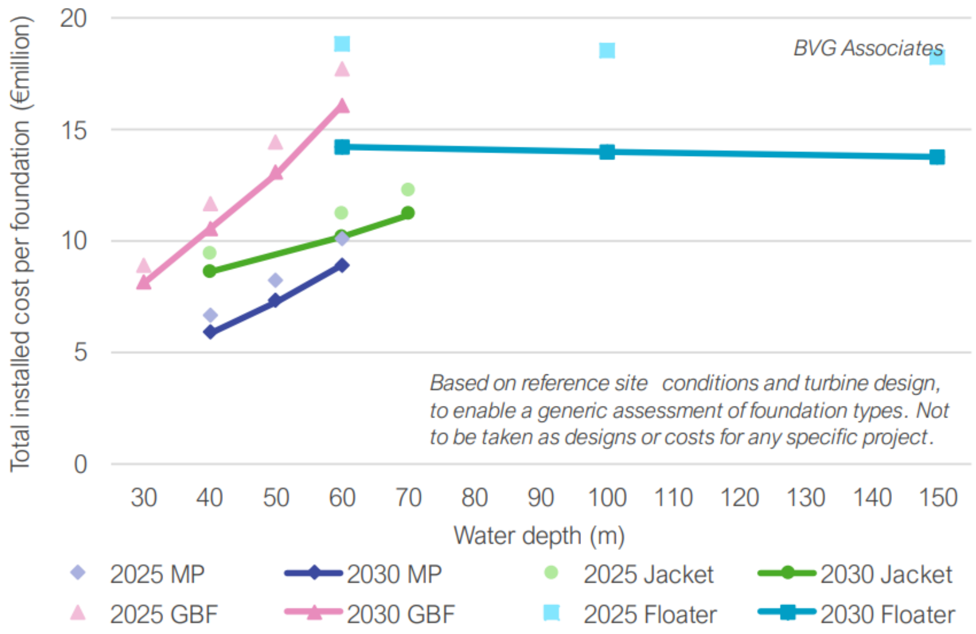
Park Construction Starts
Europe





LCOE, Update of recent trends (Offshore), Morten Kofoed Jensen 30th August 2022



Total installed costs versus depth for different foundation types.
Source : Long term outlook on developments in foundation technology, TKI Wind op Zee, BVG Associates August 2022.

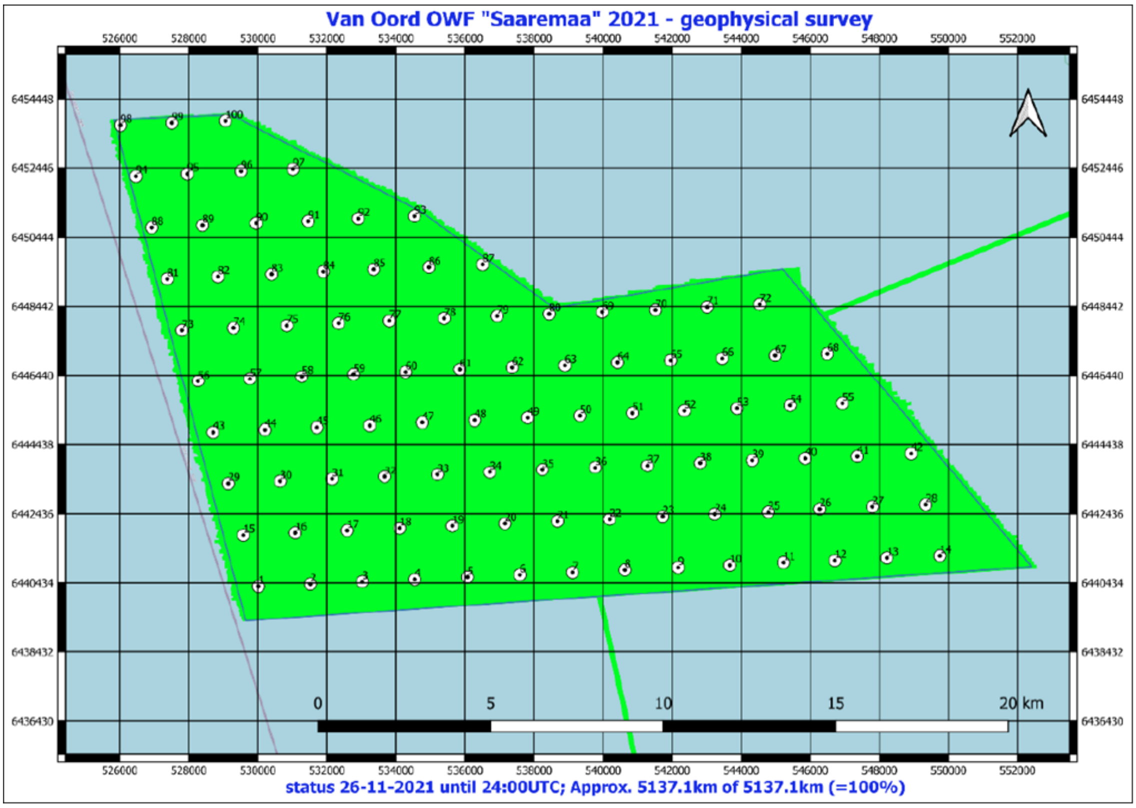
4. Geological seabed survey is not complete and does not conclude that it is not possible to use suitable technology for this area to erect wind turbines

TTJA indicates: the analysis of the geological seabed shows that the survey with the floating buoy is not complete and the largest overlapping sand patches could not be mapped in detail. The Ministry of Economics and Communication noted that an indirect assessment has been presented, that there is mud between the so-called blind spots and that not all objects can be identified and that the geological seabed survey provides the most important data on the seabed, but does not conclude that it is not possible to use suitable technology for this area to erect wind turbines.

On the point of alternative foundation methods such as floating foundations, we refer to the previous section, which shows that these alternatives are not realistic for the wind farm in the period up to 2030.

We can report the following about the other comments (that the survey with the floating buoy is not complete, the largest overlapping sand patches could not be mapped in detail, an indirect assessment has been presented and that there is mud between the so-called blind spots and that not all objects can be identified).

In the course of the surveys, 100% of the seabed was scanned with multiple sensors. There are no so-called “blind spots”. Below picture shows a green line for every trajectory which has been covered by MBES, SSS, magnetometer and shallow seismic.



For the understanding of the subsoil, the seismic surveys are of utmost importance. Two methodologies have been applied, shallow seismic and deep seismic:

- The shallow seismic (or SBP, Sub Bottom Profiling) was performed on the same lines as shown above. Data was recorded continuously together with the MBES, SSS and MAG sensors (Multi Beam Echo Sounder, Side Scan Survey, Magnetometer survey). The shallow seismic surveys were carried out using an SBP2000 compact sub-bottom profiler to obtain information about the subsurface along each survey line. The system was mounted on a moonpool bracket and was in use for the entire duration of the survey. Due to the convenient soil conditions west of Saaremaa, the penetration of the signal into the seabed was excellent in most cases. According to the survey subcontractor, the data quality is "outstanding".
- For the deep seismic measurements, a boomer system was used as an acoustic source and a streamer equipped with hydrophones was used as acoustic receivers. According to the survey contractor, the deep seismic measurements were carried out under mostly good to very good wind and sea conditions. Again, due to the favourable soil conditions, the penetration into the seabed was much deeper than originally expected in most cases. According to the survey contractor, the data quality of the deep seismic survey is also outstanding.

After completion of the measurements, the data was thoroughly analysed and used to create a 3D digital terrain model of the subsoil strata in the investigated area. Because of this, the geologists at Van Oord could develop a pretty good general understanding of the site and the subsoil and their characteristics.

Considering the above, we can not agree with TTJA's comments that the "floating buoy survey of the area is not complete". Also we do not agree with the comment that there are "blind spots, and not all objects could be identified". First of all, there are no "blind spots" in the survey data. Furthermore there were 395,329 objects identified on the seabed bigger than 30 cm. And further 36,387 objects were identified along the export cable routes. So it is unclear why TTJA claimed that not all objects could be identified.

The Ministry further wrote that "the largest overlapping sand patches could not be mapped in detail". SWE can map all sand patches in detail in the entire area, so we can not agree with this comment.

The Ministry also writes that the survey does not provide evidence to conclude "that it is not possible to erect wind turbines with suitable technology in the given area". Actually, the survey has identified areas, in which the construction of foundations is either impossible or only feasible under intolerable financial investments.

To further clarify this aspect, it is good to consider the following. The survey identified among other things two large-scale palaeochannels, which have incised into the limestone and glacial till. They cannot be seen in the bathymetry, but from the seismic investigations we know that they are up to 20 m deep and filled with very soft, fine-grained sediment. To install GBS or monopiles on top of such soil layers is not feasible for the following reasons:

- The result of any attempt to install a GBS foundation will be similar to placing a candle holder in a pot of soft porridge. Don't expect the candle to remain vertical for 25 years. Having this in mind, SWE proposed in its application not to consider GBS foundations in areas where thick overburden is present.
- Considerations for the design of monopiles in these palaeochannels are different. As the infill material is very soft, it is not expected to contribute considerably to the horizontal stiffness of the monopile; the pile needs to be embedded in the underlaying limestone. For argument's sake, the up to 20 m thick layer of very soft soil could be regarded as additional waterdepth. The weight and size of monopile foundations grow substantially with the waterdepth. Deeper waterdepth lead inevitably to larger monopile diameters, which not only increase the weight but also the complexity of the project. Whenever possible, there are serious logistical reasons to stick to one pile diameter only and to avoid having some few piles which are much larger and heavier. This makes the choice of equipment much more efficient. Last but not least, the environmental impact during installation of larger piles is much higher; underwater noise during the installation of large-diameter monopiles is a serious challenge for the entire industry and may set an end to ever increasing monopile diameters in the North Sea.

For the survey of an area decisions have to be made on the level of detail, any survey can always be executed with a higher or lower resolution. Therefore it is key to choose a level of detail that is appropriate for the purpose of the survey and look for a industry guideline to set-up the study with. In this case the purpose of the survey is to map the soil conditions in a way that insights are gained in the construction possibilities and limitations. The survey has been completed in accordance to best industry practice and applicable standards. There are actually standards prescribing the minimum requirements for surveys in this phase (e.g. the "Standard Ground investigations for offshore wind energy" from German BSH[3]), and the survey was performed in accordance with or exceeding the requirements. Therefore, you could assume that the collected data is sufficient for a good understanding of the seabed.

[3] https://www.bsh.de/DE/PUBLIKATIONEN/_Anlagen/Downloads/Offshore/Standards/Standard-Ground-investigation-for-offshore-wind-energy_en.html

5. Conclusion

The LCoE of an offshore wind farm is strongly dependent on the risk profile of the project. This again is based upon the maturity of the chosen installation method and foundation type. Especially these aspect of the project is of importance and it depends entirely on the local site conditions. At part of the Saaremaa location, due to the presence of limestone covered by thick sediment layers in large in-filled channels, traditionally hammered monopiles are not feasible. Alternatives are gravity based foundations or drilled monopiles. Both solutions are limited proven in the market so far (no large gravity based foundations have been installed in the last years, only a few drilled foundations have been installed). The risk of drilling into the limestone at over 40 m below sea-level, and covered by soft sediments, is considered by Pondera as very high. For concrete gravity foundations, these soft sediments would need to be dredged and removed completely and replaced by a rock bed. This would have major environmental and cost consequences.
Therefor it makes sense to focus on these parts of the site where the risk is acceptable and there's only a limited need for additional precautions. That automatically leads to the part of the site which shows minimal overburden and thus avoid the large in-filled channels. As a result, a large part of the site is not suitable for installing wind turbines, which means that the size of the wind farm in terms of installed capacity and energy production is greatly reduced. In the situation of monopiles: 25.8 km² of the originally applied area and 34.4 km² of the amended area are challenging for monopiles. In the situation of gravity based structures (GBS): 55.9 km² of the originally applied area and 64.7 km² of the amended area are challenging / unsuitable for GBS.
Floating foundations are still in the pilot phases. There's only very limited experience and the expectation is that in the next decade floating foundations may become attractive only at large water depths (beyond 60 meters) which is not the case within the Saaremaa area. Next to this the majority of the studies show that an LCoE based upon floating foundations will be considerably higher compared to the bottom fixed projects. The project would need a significantly higher feed-in tariff or other support mechanism when using floating foundations.

Last but not least several studies show that the size of the project and the size of the turbines determine the LCoE of the project. Size matters, which is recognized in the market as the project sizes are growing. This is also recognized by governments, for example in Germany and the Netherlands as they are scheduling projects with sizes up to 2 GW (and installed within the same time period as Saaremaa).

Assuming 15 MW wind turbines (expected to be "standard" in 2025), it should be possible to realize 600 MW with much less than 100 locations. All high-risk locations in the 'valleys' (the large in-filled channels) with adverse soil conditions could be avoided. However, the relatively small number of ±40 wind turbines left will make the project unattractive to the supply chain for offshore wind. Hence it is strongly recommended to increase the nominal project size to 1,400 MW (about 100 wind turbines). As the valleys shall be avoided due to unacceptable risks, it will be necessary to increase the project area. A larger project will also result in reduced grid connection costs per MW and in the end in lower electricity prices and lower societal costs.

Having analysed the effects of expanding the area, Pondera believes that the extension of the area significantly improves the economic efficiency of the wind farm and contributes to the prevention and mitigation of negative environmental impacts in the construction phase, because of the large amounts of soil have to be removed for drilled monopiles and gravity based foundations. Pondera therefore believes that the expansion of the area will significantly increase the chance of realizing the offshore wind farm and ensure high production of renewable energy against reasonable costs as quickly as possible (with a perspective for 2030).