OFFwind Highlights No. 9 – MARCH 2025

CASE STUDY – NORTH NORWAY NORDAVIND D FLOATING WIND FARM

The potential for development of significant Ocean Wind Power in Norway and outside North Norway is large.

In 2010, 2012 and 2023 the Norwegian Water Resources and Energy Directorate (NVE) issued their analysis for identification of potential areas for development of Ocean Wind Power. Most of the fields in the later 2023 report are in areas with deeper water promoting floating wind power farms not "bottom fixed" as the feasible development alternative.

One has selected 1 of these areas located on the North Norwegian Continental Shelf for a case study.

The case study is focusing on the development of the wind farm and the economic feasibility.

A conceptual development of the farm is described, with floating wind turbines and substructures (SPAR type), inter-farm AC - Array Cables, Offshore AC-DC Converter station, HVDC transmission cable to shore and the onshore Station with HVDC to HVAC conversion and GRID connection.

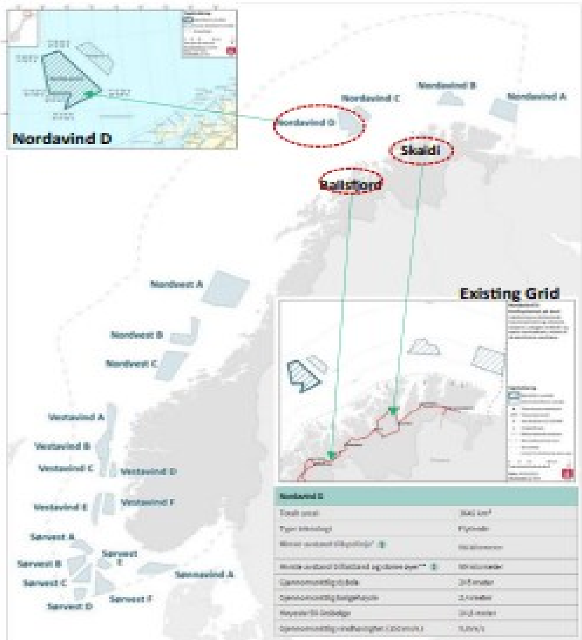
Furthermore, overall CAPEX and OPEX estimates have been generated, and a NPV analysis performed indicating the Net Present Value of such a development with indications on which Levelized Cost of Energy this project will give.

Nordavind D – Area location and introduction

The 2023 NVE-study identifies 20 areas relevant for offshore wind, where 7 are in the Norwegian Continental Shelf outside Nordland, Troms and Finmark. These are Nordavind A, B, C and D and Nordvest A, B and C. All these areas are located more than 50 km from shore, with water dept 200-300 meters. Nordavind A outside Finnmark, Nordavind D outside Troms and Nordvest A outside Nordland were studied. One selected Nordavind D (figure 1) for the case study.

Nordavind D key characteristics are: Total Area 3 642 km2, average water depth 245-meter, distance to shore 89 km, average wave height 2,4 meter, highest 50-year wave 14,6 meter and average wind speed 9,8 m/s (150 meter above sea surface). The area is viewed to have little conflict with other activities as fishing, maritime defense activity, maritime transport corridors, existing infrastructure such as power cables & oil and gas.

The Nordavind D area average water depth of 245-meter implies that the wind farm will have to be developed as an offshore floating wind farm. The distance from shore and grid connection (see figure 1) would introduce a need for AC to HVDC-conversion and HVDC power transmission cable to the land station.



Picture 1. Nordavind D location map (www.nve.no)

Existing grids in Troms and Finnmark have limited capacity. Potential areas for use of the wind power from Nordavind D could be the Tromsø or Hammerfest regions. Skaidi (Finnmark), is a potential grid connection point (assuming a new 420 KV transmission line from Skaidi to Hammerfest (supporting power to the Melkøya LNG plant). Alternatively, is Balsfjord (outside Tromsø) as a grid connection point (assuming a new 420 KV transmission line from Ballsfjord to Skaidi). Then the power can be both used in the Tromsø region and in the Hammerfest region

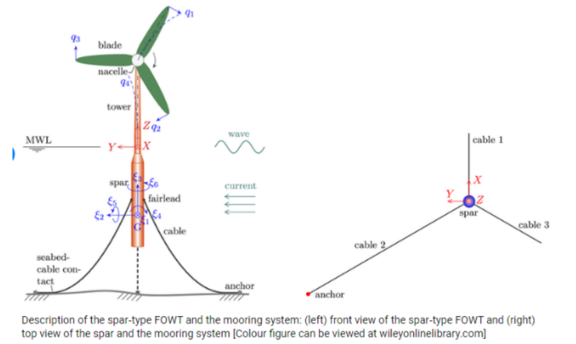
Nordavind D – Floating Wind Farm

- 100 wind turbines (floating)
- 15 MW wind turbines
- 1500 MW in electrical power production
- 700 Km2 Turbine Area
- HVDC converter station (floating)
- 25-35 AC-array cables (to Offshore Converter station)
- 1 DC HV cable to Land station
- 1 Land Station
- Connection to National Power GRID
- Yearly Power Production 6,5 TWh

Power Production Capacity. The plan is to develop the Nordavind D area with large "State of the Art" wind turbines (15 MW) and to install 100 wind turbines, i.e. 1500 MW power generation capacity in total (however there are offshore wind farms today being developed with a production capacity of 2000 MW). The average wind speed in the Nordavind D area is 9,8 m/s approximately 150 meter above sea surface. Area wind analysis (NVE) performed gives a production time of 5200 hours per year, which gives a wind capacity factor of 59%. The yearly power production is estimated to 6,4 TWh, based on 1500 MW in total power generation capacity. This will generate power to 350 000 to 450 000 house units

Wind Farm Area. Wind Farm Area or grid for the 100 Wind Turbines (15 MW turbine size) is estimated to be approximately 600-700 Km2. This is based on that the turbines are located approximately 8-12 times the rotor diameters apart (so that they do not affect each other with turbulence) in the direction of the wind, and 4 times in the direction perpendicular to the wind. An area plot-size as indicated would also give sufficient space for the turbine foundation mooring system.

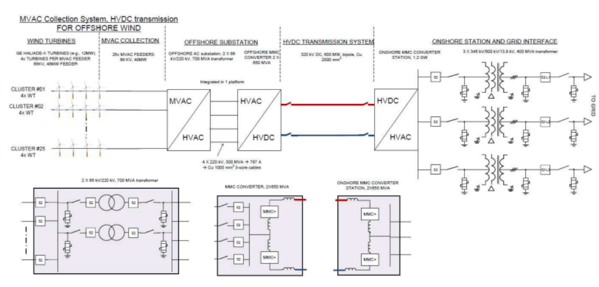
Wind Turbines (15 MW). Such a wind turbine would have a rotor radius of +120 meter or length of turbine blades, a generator, and a steel tube tower of 150m length, and a transition piece of 15 m length all supported by a floating moored substructure which could be the Concrete Spar Concept.



Picture 2. ResearchGate (www.researchdate.net), spar-type FOWT

Electrical Power Transmission, Offshore Wind Farms.

The Nordavind D windfarm will be developed with a (H/M)VAC collection – HVDC transmission system for power generation and transfer to the National Electrical GRID. Typically, the offshore windfarm turbine generates electrical power at 50-60Hz, which is converted to HVAC which then is converted by the offshore substation (AC-DC conversion) to HVDC. The HVDC electrical power is then transmitted through an HVDC transmission system/cable to the onshore station where it is converted to HVAC (DC-AC) and further delivered to the electrical power grid.



Picture 3. Typical MVAC collection and HVDC transmission, Conventional offshore windfarm architecture (source; DC Collection and Transmission for Offshore Wind Farms, Conference paper)

Array Transmission Cables. Electrical Power generated by the wind turbine is AC and Array Cables is necessary for the transfer the AC power generated by the wind turbines to the Offshore Substation. As indicated in the above figure 3, the Array Network is typically linked in strings, ex. 4 turbines or WTG's per array connecting several wind turbines to the offshore substation. This indicates 25-35 Array Cable's for the wind farm.

HVDC Transmission Cable (HW), export cables, a HVDC (high-voltage direct current) subsea cable able to transmit higher energy loads to the onshore (land) station. For example, the German Transmission System Operators TenneT, Amprion and 50Hertz was a pioneering connection of large offshore wind farms to shore by deploying vast programs of 2GW projects, using 525 kV HVDC subsea cables with XLPE insulation for the first time (the technology has been qualified by cable manufacturers a few years ago, and will be deployed by 2030), Nexans (www.nexans.com)

Offshore Converter Station (AC-DC conversion). The Nordavind D area is located more than 90 km from the coast of Troms or the nearest electrical grid connection in Troms County. An AC power transmission from the turbines to shore would have large power losses. Therefor to reduce the electrical transmission losses an offshore conversion station, from AC "turbine generated power" to DC current for transmission to grid, is recommended. An offshore DC converter platform, for HVDC conversion of wind power generated by 100 (15MW – 1500MW in total) wind turbines, would be of considerable size (with a topside weight of appr. 10 000 T) containing HVDC Reactor Halls (HVDC equipment as transformers, converters etc., located in a reactor hall with clean room standard) Utility systems (power supply, ventilation, control system/control room, platform cranes etc.) and Array cable tie-in areas and DC cable tie-in.

The offshore AC/DC converter station will be supported by a moored floating substructure (for example of Semi-submersible or SPAR concept built in steel or concrete materials with a mooring system which could be of a 3-mooring line concept (spar-type FOWT), Tension leg mooring system or others, and with suction anchors).

On-shore Conversion Plant (DC-AC). The onshore Substation converts the electrical power from HVDC to HVAC and then transfers the power to the electrical GRID in Troms County. The Substation would be technically the same if it is a substation for a floating or bottom-fixed offshore wind farm. The Substation will have 2 main parts, the Wind Park Side of the Substation (HVDC-HVAC convertor equipment/Power Transformers-Busbar system-shunt reactors & Bays, electrical system, air conditioning plant, control room etc.) and the GRID side (**GRID connection**).

The Substation would require a land area of 50 000-100 000 m2.

Picture 4. Onshore Substation (source: www.lamassociates.co.uk - LAM Associates Ltd, UK, Building Services Consulting Engineers)

Potential location of the Nordavind D onshore substation is **Skaidi** (in Finnmark County, south of Hammerfest, see figure 1) which also would provide a good connection point to the national GRID and transmission of the power to Hammerfest. Alternative is a location of the onshore substation in the **Ballsfjord** region (in Troms County, south of Tromsø, see figure 1) and transmission of the power to Tromsø or to Skaidi. Both alternatives would require strengthening of the national GRID in the area to 420 KV transmission lines.

Nordavind D – Economic & Feasibility

Top-down analysis for investment, Capital Expenditures (CAPEX), and Operational Expenditures (OPEX), have been developed for the Nordavind D Offshore Wind Farm. These estimates have been used to calculate the Net Present Value (NPV) and an estimate of the LCOE (Levelized Cost Of Energy) for the project.

CAPEX estimate

The CAPEX estimate is based on,

- Hywind Tampen Cost of 8 Billon Norwegian Kroner (Wikipedia/wiki/Floating_wind_turbine), with a top-down spread (high level model) to generate estimates for Turbines, Foundation (SPAR concept), Mooring System, Installation and Electrical Transmission Cables.
- Then for the generated estimates per turbine (8,5 MW), there is applied a factor x1.5 to establish a cost estimate for 15 MW turbines.
- Estimates for the offshore converter station based on a cost estimate of a comparable oil and gas platform.
- For estimation of Project Planning & Development a factor x5 has been used
- For estimation of Assembly/Installation a factor x5 has been used
- For the Array cables a multifactor x33 has been used. A verification estimate (110.000 GBP*1500MW, array cables & cable accessories), using the "Guide to a Floating Offshore Wind Farm, Wind farm costs" have also been established.

- For HVDC export cable a verification estimate (200.000 GBP*1500MW), using the "Guide to a Floating Offshore Wind Farm, Wind farm costs", have also been established.

This estimate is not a bottom-up generated estimate but a "rough" top-down estimate with a high level of uncertainties. The Nordavind D - cost estimate is appr. 115 billion NOK (CAPEX).

OPEX estimate

The maintenance and operations estimate (OPEX) is based on the Levelized cost breakdown for a Reference Floating Offshore Wind Farm from US National Renewable Energy Laboratory 2021. The OPEX cost is 9.1 USD/MWh for Operation and 26.1 USD/MWh for Maintenence. This estimate is a "rough" top-down estimate with a high level of uncertainties.

The Nordavind D cost estimate for operation and maintenance of the facilities per year is 4,6 billion NOK (OPEX).

Net Present Value (NPV) and LCOE (Levelized Cost Of Energy)

A model for calculating the Net Present Value (NPV) and LCOE (Levelized Cost of Energy) of a Wind Farm project has been developed in WP4 of this OFFwind project.

The base year for the project (Nordavind D) is 2024 with project development planned for 2025 to 2031. The "Contract for Difference"/auction would then be at latest in 2026. A yearly investment plan (distribution of the CAPEX estimate) has been established. This investment plan includes an assumption of a Governmental investment support to the project of 10 BNOK.

The analysis gives an estimated LCOE for the Nordavind D development of around 2,0 NOK/KWh (198 øre/KWh) or 2,1 NOK/KWh (210 øre/KWh) without the Governmental investment support to the project of 10 BNOK.

A sensitivity analysis using 1,8 instead of 1,5 as turbine multiplying factor has been made. This gives an increase of 14,5 BNOK in CAPEX estimate and LCOE of 2,27 NOK/KWh (1,32 NOK/KWh, with 0,58% in technology improvement factor).

Based on a public spredsheet from the Norwegian Water Resource and Energy Directorate (NVE)

The levelized cost of electricity (LCOE) is a measure of the average net present cost of electricity generation for a generator over its lifetime.

	unit	
Fixed monetary value	year	2024
Year 0 =		2030
Currency	NOK	
Lifespan	years	25
Discount rent	percent	6,0 %
Degradation rate	percent	0,1 %
Capacity factor	percent	50 %
Turbine size	MW	15
Number of turbines		100
Production performance	MW	1500
Expected price =	øre/kWh	198
gives a present value =	billion nok	0,0
gives an internal interest rent =	percent	6,0 %

Offshore wind	Unit	
Production performance	MW	1500
Full load hours	hours/year	4 383
Offshore wind farm total investment costs (CAPEX)	NOK/kW	70 735
Sum operating and maintenance costs (OPEX)	NOK/kW/year	3 059
LCOE offshore windfarm incl. internal grid	øre/kWh	**198**
LCOE-share CAPEX	øre/kWh	127
LCOE-share OPEX	øre/kWh	70
Factor for technology improvement 2030-2035		0,58
LCOE YEAR 2035	øre/kWh	**115**
Present values		
Investestment costs	øre	10 610 223 109 249
Firm operating and maintenance costs	øre	5 864 799 271 715
Produced electricity	kWh	83 251 470 184
El. productionon	GWh/year	6 575

Picture 5. Nordavind D – NPV and LCOE estimate (included 10 BNok in Governmental investment support)

Floating wind and latest reference projects/auction (20, www.europower.no)

The Crown Estate Scotland auctioned 8.600 km2 of sea space which could host almost 25 GW of offshore wind energy production. On 3'rd September 2024, the auction was won by the project Green Volt, consortium comprising of Flotation Energy and Vårgrønn). The area is located 80 km off the coast of Northeast Scotland (from Peterhead). The investment is around 2.5 billion GBP, with a power generation capacity up to 560 MW. The LCOE for this latest Scottish auction (floating Wind Farm) is 2,72 NOK/KWh.

Technology development and project execution improvements

There have been several forecasting attempts to estimate technology development and project execution improvement effects on the cost and LCOE for a wind farm development. An analysis by BVG Associates indicates a reduction in LCOE to less than 50% of the 2025 LCOE in 2035. As can be observed in Figure 5, NVE is indicating a "Factor for technology improvement 2030-2035" of 0,58 of the 2030 LCOE (LCOE (2035) = 198 øre/KWh * 0,58 giving 115 øre/KWh).

Examples of Technology and Project Execution improvements,

- Use of Low Carbon Concrete in concrete structures, giving reduced CO_2 emissions (Carbon Tax 10 USD/ton in 2019 to 50 USD/ton in 2022. Furthermore, concrete substructures provide turbines with good stability, good concept scalability, good properties for structural fatigue and systems for cathodic protection etc. providing potentially long design life of the structure.
- Improved Surface Protection Systems, reducing the effect of icing (on rotor blades), reducing friction between ice and concrete structure i.e. reducing ice pressure on concrete substructures – potentially more slender structures – with potential reduction in CAPEX, and reduced maintenance & operations costs (OPEX)
- Effective yard production line for concrete substructures.

- Serial Production of Substructures, assembly of structures and turbines at Quay side, tow-out of entire turbine units, simpler offshore installation at windfarm location. Easy and effective de-installation of entire units (at end of service life)
- Larger Turbines (and serial production of turbines), moving to 15-20 MW turbines, lower cost per MW.
- Development of more effective Mooring Systems (floating wind farms)
- More effective Installation, for floating windfarms – minimize lift campaigns etc.
- HVDC/HVAC substation, floating substation, will provide an easy and effective de-installation of entire units (at end of service life)
- HVDC/HVAC substation standardized design concept, floating substation dynamics and movement optimized to operate in accordance with tolerances for HVDC equipment/HCAC equipment
- Technology development in power transmission cables, better HVDC Cables, increased transmission of power and less transmission losses (moving towards power transmission superconductor technology!!).
- Improved Array Cables, better Array Cables, increased transmission of power and less transmission losses
- Development of solid concepts (to increase operation and service life of the park from today's 25-30 years to 50 years!!

The aim of the above is to reduce both CAPEX and OPEX in order to achieve an improved Levelized Cost of Energy (LCOE). Increased service life of the farm might be a solid contributor to a more competitive LCOE.

However, to achieve a Factor for technology improvement from 2030 to 2035 of 0,58 of the 2030 LCOE seems challenging.

North Norwegian energy market and pricing

In North Norway there is a yearly power production of appr. 22 TWh and an energy consumption of 16-18 TWh giving a surplus of 4-6 TWh (there is a shortage of power in Finnmark County and a large energy surplus in Nordland County). This has provided low energy prices in the range of 0,1-0,5 NOK/KWh. There are also evaluations to increase the north to south Norwegian power transmission lines to "export" more power to South Norway. Finally, it should be mentioned that there are several onshore wind farms planned in Troms and Finnmark County.

There are future industry development plans in North Norway with large energy requirements. Therefor there will be an increase in the yearly North Norwegian energy demand or consumption. The Melkøya LNG plant plan to close their gas power generation plant and instead use green energy (hydropower). This will alone require an additional yearly energy demand of 4 TWh. There are also other industry initiatives that potentially would require significantly more energy.

This picture could indicate the need for the Nordavind D Floating Wind Farm. However, it will deliver costly power (2-3 NOK/KWh).

Nordavind D – Summary/Conclusions

The potential for development of significant Ocean Wind Power in Norway and outside North Norway is large. In 2010, 2012 and 2023 the Norwegian Water Resources and Energy Directorate (NVE) issued their analysis for identification of potential areas for development of Ocean Wind Power. Most of the fields in the later 2023 report are in areas with deeper water promoting floating wind power farms not "bottom fixed" as the feasible development alternative.

One has selected 1 of these areas (Nordavind D outside Troms County) located on the North Norwegian Continental Shelf for a case study. The case study focuses on the development of the wind farm and the economic feasibility. A conceptual development of the farm is described, with floating wind turbines (15 MW) and substructures (of SPAR type), interfarm AC - Array Cables, Offshore AC-DC Converter station (with a moored SPAR substructure concept and with a topside weight of appr. 10 000 Tonnes containing HVDC Reactor Halls with HVDC equipment as transformers/converters etc., located in the reactor hall with clean room standard and Utility systems with power supply, ventilation, control system/control room, platform cranes etc.), HVDC transmission cable to shore and the onshore Station with HVDC to HVAC conversion and GRID connection.

The Nordavind D cost estimate is generated as a top-down estimate, an overall estimate with uncertainties. The estimate is 115 billion NOK (CAPEX). The Nordavind D – OPEX estimate per operation year is appr. 4,5 billion NOK (OPEX). The LCOE for the Nordavind D wind farm is calculated to 2,0 NOK/KWh and with sensitivity evaluation, state support, less sizing factor for turbines etc., would easily bring the LCOE to around 2,5 NOK/KWh. The power generated by a Nordavind D floating wind farm will be expensive (2-3 NOK/KWh). Is this too expensive?

The LCOE of 2,5 NOK/KWh is quite close to the latest UK/Scotland auction for floating wind (area is located 80 km off the coast of Northeast Scotland with an investment of 2.5 billion GBP, with a power generation capacity up to 560 MW giving an LCOE for this latest Scottish auction (floating Wind Farm) of 2,72 NOK/KWh.

The energy consumption for North Norway is 16-18 TWh giving a surplus of 4-6 TWh (22 TWh yearly production). The price of energy in North Norway have been low over the past decades. Equinor plan to use electricity for running their LNG plant at Melkøya (Finnmark). This will alone increase energy consumption with 4 TWh. In addition to this there are also several North Norwegian industry initiatives in the planning and preparation phase that would require future large volumes of electrical power. On top of this there are initiatives to increase the electrical power export line capacity to South Norway. Summing up there would most likely be a shortage of energy in North Norway in a few years. This indicates a future need of at least 5-7 TWh yearly of new renewable energy. The big question is, will there be anyone that is willing (or must) to pay 2-3 NOK/KWh? One is competing with the low-cost hydro-generated power and the several onshore wind farms planned in Troms and Finnmark County, so probably not!

The Nordavind D project would require a huge investment, and the risk exposure would be large. To make such a large development project fly there would have to be a large risk reducing measures, i.e. state subsidies or funding. And in addition, a "safe" roadmap towards technology improvement with an efficient project execution model that might give savings around 33%. Overall, the aim would be to bring the LCOE towards 1,0-1,5 NOK/KWh.

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Co-funded by the European Union

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