

Executive Summary

Offshore wind is one of the fastest growing marine sectors, with a global installed capacity of 6.5 GW at the beginning of 2014 and an expected dramatic future growth. The bottom fixed foundations used today are however limited to depths less than 40-50 m due to today's technical and economic boundaries. As the offshore sector is growing, the areas with suitable depth and soil conditions becomes increasingly limited and technology developers are therefore rallying for solutions that might enable the development of deep water offshore wind, where floating wind power opens a path to exploit the vast wind resources of these areas. With less constraints to water depths and soil conditions, this technology could play a vital role in the energy transition towards a sustainable future.

Floating wind power technology is derived from deep water offshore oil & gas structures, where floating foundations have been used in Norway for a long time. Norway therefore has a great opportunity to use the synergies and their extensive expertise within this area to establish an industry around floating wind power.

This master thesis aims to evaluate the possibilities, benefits and challenges for Norway to establish an industry around floating offshore wind power. Furthermore the thesis will investigate possible pathways for cost reduction and for offshore wind development in Norway. The following questions should be answered in the thesis:

- What are the specific costs connected to a potential site for a first test park of floating wind power in Norway?
- To what degree can cost reduction be achieved in the near future?
- What is the Norwegian industry perspective on offshore wind development in Norway?

To answer these questions, a literature study of the floating wind power technology, the international market and the Norwegian power system was carried out. Moreover, the authors have performed a case study to determine the most feasible location for a test park of floating wind power in Norway, where specific costs and power output have been identified and calculated. Finally, the Norwegian industry's perspective of the possibilities and challenges of a potential market for offshore wind in Norway has been analysed by evaluating a questionnaire answered by 50 companies as well as eight conducted interviews with key stakeholders.

Norway's potential

A study of the international market shows a large global potential for floating wind power with over 92% of all the oceans being deeper than 200m. With Norway's extensive experience within the oil & gas industry, the country has a great opportunity to export a large part of the supply chain for floating wind power:

- Norway has a long heritage of working with floating structures and concrete & steelwork fabrication and holds well-developed port structures which makes the manufacturing of foundations especially interesting.
- Given Norway's expertise and trust of shipbuilding, particularly for specialised vessels, this sector has a great potential within the offshore wind industry given the considerable number of installation vessels that will be needed.

- Norwegian capabilities and competence related to offshore substations, inter-array and export cables are also significant with offshore wind leaders within cable designs, manufacturing and installation.

However, without a national market it is hard for Norwegian developers and suppliers to compete on the international market, where especially smaller companies will struggle. To increase the competitiveness of Norwegian suppliers, there is a need to develop offshore wind in Norway in order to establish a base for their technology and prove their competence. An offshore wind test park could serve as a home market enabler.

Case Study – A test park at Utsira Nord

Based on NVE's suggested areas for offshore wind power determined in the Havvind-report, the authors evaluated which location that would be most suitable for a test park based on economic, technical and social aspects. An area called Utsira Nord, located west of Stavanger, was determined to be the most feasible location due to the following aspects:

- Considerable wind resources, with an average wind speed of 10m/s at the hub height of 100m.
- Low impact on other national interests, e.g. fishing, maritime, oil- and gas interest.
- Close to shore and transformer station which reduce the cost of the export cable as well as the time used for O&M and other services connected to the test park.
- Close to Haugesund and Stavanger which have considerable offshore experience and large ports with access to dry docks that could enable mass production of floating foundations and pre-assembly of the entire structure.
- Close to areas which is estimated to have a significant increased demand of power. Mainly due to Hydro's planned test facility for highly energy-efficient aluminum production at Karmøy and the potential subsequent full scale facility with a total increased electricity demand of approximately 4.4 TWh/year. Moreover, the potential electrification of Utsira High would require an additional 2 TWh/year resulting in a total increased electricity demand in the area of approximately 6 TWh.

The test park was designed to comprise 48 turbines á 6 MW with a total capacity of 288 MW. With 14 years of wind data for the specific area supplied by Kjeller Vindteknikk and an assessment of the losses, the power production was estimated to 1222 GWh/year resulting in a capacity factor of 48.4%. The capital cost can be seen in Table 1, as well as the LCOE for three different floating foundation concepts.

Table 1. CAPEX and LCOE using three different floating foundations concepts displayed in NOK.

	Capex [MNOK]		LCOE [NOK/kWh]	
Concept	Low	High	Low	High
Spar	7031	10213	1.03	1.26
Semi-Submersible	8539	12868	1.19	1.53
TLP	6757	8885	1.00	1.13

With a combined average electricity and green certificate price of 0.51 NOK/kWh there is a strong need of an increased support scheme in order to make offshore wind projects profitable. Moreover, future estimates of the electricity price development coupled with the estimated cost reductions for offshore

wind indicates that a long term subsidy scheme is needed. It is however important to remember that it is highly complex to make estimates over such a long time period and that the results will vary greatly based on an immense amount of parameters which are challenging to quantify today. Furthermore, given the immature nature of the technology, most costs in the analyses have been chosen in a very conservative manner. It is therefore possible that when erecting the actual test park costs will be shown considerably lower.

The Norwegian industry's perspective

The results of the questionnaire and the interviews shows that the Norwegian industry in general believes that Norway holds a great possibility of using the existing petro-maritime expertise to develop a national supply chain within offshore wind. Due to a significant international competition a home market is needed which could be developed by establishing a test park for offshore wind in Norway. The potential for export of the supply chain is great and the development of new offshore wind power production in Norway could be used for electricity export and electrification of oil & gas facilities.

The Norwegian industry stresses that in order for this to happen a clearer policy and national plan for offshore wind is needed. A stimulated offshore wind development could lead to cost reductions and one potential cost driver is the foundation material, where several companies sees concrete as an alternative that could bring down the costs when mass produced. Another important aspect is the development of new international transmission lines that could both increase the electricity price, making new power production more profitable and be the start of a European super grid, with offshore wind power plants as nodes.

The companies and organisations also states that connecting offshore wind to offshore oil & gas production is important in order to reduce the Norwegian greenhouse gas emissions and making the technology commercial.

Floating wind power in Norway - Challenges and benefits

As of today there are no large scale offshore wind power plants in Norway, mainly due to the absence of sufficient economic support. A large scale Norwegian development is in fact faced with several challenges that needs to be overcome in order to succeed.

- A future oversupply of power production in the Nordic region
- A low unemployment rate in Norway
- A low electricity price level and a high leveled cost of energy for offshore wind

Several studies show that Scandinavia is heading towards a large power oversupply towards 2020 due to low demand growth rate and an increase in onshore wind power, CHP and hydro. Wind power is rapidly increasing in Sweden and Norway still has potential for onshore wind and to upgrade its hydro power. If the Swedish nuclear reactors are not being shut down in the time to come, there is a lack of rational for building offshore wind. Norway could however use its excellent wind resources and develop offshore wind, enabling an increased hydro power export to northern Europe. UK, Germany and Denmark are all pursuing in their transition towards a renewable energy system, and Norway could leverage this market chance by selling hydro power at a high price to these countries that will be in great need of balancing power. The expected oversupply may also be limited by further electrification of the transportation and oil & gas sectors as well as an increase in energy intensive industry, attracted by the low electricity prices.

With the current high oil price levels and the low unemployment rate in Norway the incentives for a Norwegian offshore wind engagement are further reduced. As the oversupply is uncertain and since the oil demand is steadily decreasing there are however long term incentives to proceed in this sector, to secure a future continued growth of the Norwegian economy.

The high cost of energy for offshore wind in combination with low electricity prices is one of the major challenges for offshore wind today as the cost of producing energy is significantly higher than the revenues. Future prognosis of the Nordic electricity price level are however highly complex and therefore uncertain, but the possibility for cost reduction is great concerning floating offshore wind. As an immature industry, the learning effects are likely to result in steep cost reductions and in the future floating wind power can be more cost effective than bottom fixed offshore wind. Some potential aspects that could greatly reduce the costs are, onshore assembly, industrialised mass production and the use of different foundation materials as concrete. Even so, it is clear that there will be a need for a support scheme to cover the difference in revenue and the costs.

With the high LCOE, the low electricity price, the immature technology and an uncertain power demand development, it is understandable if policy makers become doubtful of establishing a large scale development of offshore wind in the short term. It is however important to look beyond the short term challenges and look towards the various potential benefits for the long-term perspective. The benefits of a Norwegian offshore wind commitment are many and are likely to directly correspond to the level of Norwegian investment:

- Export of supply chain
- Value and job creation
- Diversifying from an oil and gas driven economy to mitigate future challenges
- Enabling growth within energy intensive industries
- Reduce impact of dry years and enable export of hydro power
- Reduce greenhouse gas emissions

Establishing an offshore wind industry in Norway could help to diversify the economy from the oil & gas industry with a strong national value and job creation and export of the supply chain. It can also increase the possibilities to diversify the power production to reduce the impact of reduced hydro power during dry years as well as significantly reduce the emissions from the oil and gas sector. Additional power production in Norway could be used to enable more balancing hydro power being exported to the continent.

There are several potential pathways depending on the future aims and commitment set by Norwegian policymakers for offshore wind. This will in turn determine how the various benefits turn out. It is therefore, as the Norwegian industry proclaims, important to set up clear goals to avoid missing this great opportunity. The time has come to stop drilling for resources in the depths of the ocean and instead harness the vast resources above it.