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Industrial Electrical Engineering and Automation

# Floating wind power in Norway

## Analysis of future opportunities and challenges

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# Abstract

In the wake of alarming reports from IPCC, policy makers all over the world have recognized offshore wind power to become an essential contributor in the future renewable energy system and battling of climate change.  However, many countries including Norway lack extensive areas of shallow water suitable for conventional offshore wind, hence an interest for deep offshore solutions has arisen. One of them was the first floating offshore wind turbine Hywind, installed outside the Norwegian coast in 2009.

This master thesis was commissioned by DNV GL and was conducted at the division of Industrial Electrical Engineering and Automation at Lund Institute of Technology. The purpose of the thesis is to highlight the potential benefits and challenges for Norway with an increased commitment in offshore wind. This has been done by developing a case around a first potential test park for floating offshore wind in Norway and by conducting an interview study with involved Norwegian stakeholders.

Today, no offshore wind projects are being developed in Norway due to the lack of economic incentives. Furthermore, the Nordic power system is heading towards an oversupply and with an almost $CO_2$ – free power production in Norway, the motivation is limited. However, by engaging in offshore wind, Norway could use its extensive offshore expertise and address the worries and concerns connected to the expected reduced oil revenues. The company survey and case study carried out in this thesis show that the possibility of doing so is tremendous and could position Norway as a world leader within offshore renewables and at the same time diversify the economy by export of the offshore wind supply chain.

Offshore wind in Norway will need the implementation of a strong subsidy scheme and a clear long-term national plan for offshore wind development in order to reduce the financial risks and attract investors.

**Keywords**: Norway, *Floating, Wind power, oil & gas, water injection, renewable energy, Spar, TLP, Semi-submersible, offshore*

# Executive Summery


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 competiveness 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 average wind speeds of 10 m/s at the hub height of 100 m.
- 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 are estimated to have a significant increased demand of power. Mainly due to Hydro's planned test facility for highly energy-efficient aluminium 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 the table below together with the LCOE for three different floating foundation concepts.

*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 nods.

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 levelised 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 power. 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 which will have a 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 if there are insufficient support schemes available. Future prognosis of the Nordic electricity price levels 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 and 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.

# Acknowledgements

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# Nomenclature and Abbreviations

| | |
|---|---|
| **AHTS** | "Anchor Handling Tug and Supply", special designed multi-purpose vessels for handling anchors, towing offshore platforms and operating as supply and assistance vessel |
| **AC** | "Alternating Current" |
| **Ballast** | A heavy substance positioned near the keel of the floating structure to improve stability by overcoming turning moments caused by forces due to e.g. wind. Typically consists of either water or substances denser than water, e.g. sand, concrete or rocks |
| **Capacity factor** | The ratio between actual power production over a period of time and the nominal theoretical production (provided full capacity production at all times) |
| **CAPEX** | "Capital Expenditures", expenses or investments used to upgrade or obtain physical assets in order to create a future benefit |
| **Catenary mooring** | Mooring system which provides restoring forces through the suspended weight of the heavy mooring lines along the seabed, resulting in virtually one-dimensional anchor loads and dampening of construction motions |
| **Crane barge** | Vessel with an integrated crane able to perform heavy lifting operations in calm and protected waters |
| **Crane vessel** | Vessel with an integrated crane able to perform heavy lifting operations at sea |
| **DC** | "Direct Current" |
| **DEA** | "Drag embedment anchor", the commonly used anchor for the catenary mooring system, loaded in a horizontal direction. |
| **DECEX** | "Decommissioning Expenditures", expenses associated with disengagement of the wind park |
| **Decommissioning** | The last phase of a wind power project with disassembly, removal and recirculation of a wind turbine. |
| **Deep water** | Set to depths exceeding 50 m for this thesis |
| **Deoxygenation** | Oxygen deprived zones at bottom of the oceans as a consequence of anthropogenic emissions of carbon dioxide |
| **DNV GL** | "Det Norske Veritas Germanischer Lloyd" |
| **DOE** | "Departement of Energy" |
| **Draft** | The depth below the surface of e.g. a floating foundation. |
| **Dutch Disease** | Economic term referring to the relationship between the increase in exploitation of natural resources, appreciation of exchange rate and decrease in the manufacturing sector |
| **EIA** | "Environmental Impact Assessment", evaluation of environmental, social and economic impacts associated with a project |
| **Export cable** | A cable exporting the power from the wind power plants offshore substation to the onshore connection point (commonly done with high voltage) |
| **Fibre rope** | Ropes produced from synthetic fibres, commonly used as mooring lines |
| **Foundation** | Substructure for land-based or bottom-fixed offshore wind turbines |
| **FTE** | "Full Time Equivalent" |
| **GDP** | "Gross Domestic Product" |
| **GHG** | "Greenhouse Gases" |

| | |
|---|---|
| **Hywind** | Floating wind turbine concept developed by Statoil, with a substructure consisting of a ballast-stabilised spar buoy with large draft |
| **Inter-array cable** | A cable used to collect the power from the individual wind turbine generator step up transformers |
| **IPCC** | "Intergovernmental Panel on Climate Change" |
| **LCOE** | "Levelised Cost of Energy", all discounted life cycle costs relative to discounted life time power production, with all values evaluated at equal terms with respect to the time value of money |
| **Life time / Life cycle** | The time spanning from the initial to the final phases of a product or project |
| **LNG** | "Liquefied Natural Gas" |
| **Monopile** | A steel pipe which is driven into the seabed in order to act as foundation for bottom-fixed wind turbines |
| **Mooring system** | Complete system for mooring of a floating offshore structure, ranging from the attachment point on the floater to the seabed, including mooring lines, anchor and all transitional structures between the elements in question |
| **N/A** | "Not Available" |
| **Nacelle** | Housing for the wind turbine's gearbox, drive train, generator, brake etc. |
| **NCS** | "Norwegian Continental Shelf" |
| **NORWEA** | Norwegian Wind Energy Association |
| **NPV** | "Net Present Value", the present value of a future monetary amount or cash flow |
| **NVE** | "Norwegian Water Resources and Energy Directorate" |
| **O&G** | "Oil and gas" |
| **O&M** | "Operation and Maintenance", activities associated with keeping a wind power plant in adequate operational conditions |
| **OPEX** | "Operating Expenses", expenses coming from performing normal business operations, in this thesis expenses coming from operating and maintaining a wind turbine or wind power plant |
| **Pitch** | Rotation around the Y axis, see Figure 2 |
| **Produced water** | Produced water is formation water from the oil-bearing substrata brought to the surface with the oil and gas |
| **Project bidding** | Also called "Tendering" is the process or type of subsidy where the regulators suggest a project and developers are invited to bid on required electricity price to build and operate the project – Lowest bid gets the project |
| **R&D** | "Research and Development" |
| **Roll** | Rotation around the X axis, see Figure 2 |
| **Rotor** | Collective term for the assembly of rotor blades and rotor hub |
| **Semi-submersible** | Stable construction specially developed to cope with harsh weather conditions by being able to lower itself into the water |
| **Significant wave-height** | The average wave height of the highest one-third of waves within a 20 minute period |
| **SINTEF** | The foundation for industrial and technological research at Norway's technical university in Trondheim, NTNU. SINTEF is a broadly based, multidisciplinary research concern that possesses international top-level expertise in technology, medicine and the social sciences. |

| | |
|---|---|
| **Spar buoy** | Large-draft floater concept where stability is achieved through ballast |
| **Substructure** | Bottom part of wind turbines, attached to tower. Either floater for floating concepts or foundation for bottom-fixed or land-based concepts |
| **Surge** | Translation parallel to the X axis, commonly understood as forwards/backwards motion parallel to the water level, see Figure 2 |
| **Sway** | Translation parallel to the Y axis, commonly understood as side-to-side-motion parallel to water level |
| **SWOT** | A method used to evaluate the strengths, weaknesses, opportunities, and threats for e.g. a project or different concepts. |
| **TLP** | "Tension Leg Platform", a stabilisation technology for floating offshore installations for which excess buoyancy causes tension in anchoring cables |
| **TRL** | "Technology readiness level", a measure commonly used to assess the maturity of evolving technologies |
| **WindFloat** | Wind turbine concept currently developed by Principle Power Inc. Floater consists of three-legged, semi-submersible platform, actively compensating for heave motions |
| **Yaw** | Rotation around the Z axis, see Figure 2 |

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# 1 Introduction

## 1.1 Background

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 additional 3 GW under construction. By 2020, 40 GW is projected, covering approximately 4% of the European electricity demand. According to EWEA, the total installed offshore wind capacity by 2030 could be as high as 150 GW, covering 14% of the EU's entire electricity consumption [1]. These numbers do however represent a very uncertain future and according to Johan Sandberg, global leader for offshore renewable energy at DNV GL, a more realistic projection would rather be around 75 GW [2], which still represent a significant growth from today's capacity.

As the sector is growing, offshore wind power plants are increasing in size and are built further from the coast in deeper waters. Since the easy accessible shallow waters with suitable soil conditions are limited, bottom fixed offshore wind are facing issues in finding economically viable areas for deployment to meet the increasing electricity demand. With the increasing depths, the technological and economic feasibility of bottom fixed wind turbines are decreasing. In fact, depths of 40-50 meters seem to be the breaking point of what is possible with today's technological and economic boundaries [1]. Technology developers are therefore rallying for solutions that might enable the development of deep water offshore wind. One of these enablers is the development of floating foundations for offshore wind. With limited constraint to water depths and soil conditions, floating wind power opens a path to exploit the vast wind resources of deep water areas and play a vital role in the energy transition towards a sustainable future. With a majority of the world's wind resources located in deep water areas together with the fact that many countries lack large areas of shallow waters, floating wind power has a tremendous potential for energy supply. With a projected rapid growth of a global floating wind power market [1], there is currently a window of opportunity to become a first mover and pioneer as no large scale projects are erected. However, for this new technology to become commercially viable, experienced initiative takers are required to push for cost reductions, technology development and address the several challenges that offshore wind is facing.

## 1.2 Purpose

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?

## 1.3 Method

The work with the thesis started out in Lund, where plans and purpose for the work were determined. One month later, we went to Oslo and DNV GL to carry out the rest of the thesis. The supervisor from Lund institute of technology was Jörgen Svensson and at DNV GL Marte De Picciotto.

DNV GL requested a case study of a floating wind power plant outside the coast of Norway, and an evaluation of possible benefits, challenges and applications for such a park and for an offshore wind industry in Norway in general. We had previously taken a wind power course at LTH, but had limited knowledge of the floating wind power development and the Norwegian position. Therefore a literature study was the first part carried out in the thesis work, studying the Norwegian power sector, the floating wind power technology and the international market development. Analysis of these results were partly conducted through several SWOT-analyses.

When more knowledge had been received, contacts were made to companies that we and our supervisor at DNV GL thought would be helpful to communicate with. Several interviews were made with key stakeholders within the industry. Meanwhile we started setting up the case study, mostly identifying a possible geographical position and a potential layout for a test park. The later part of the thesis work was focused on a survey sent out to a large number of companies and to put all the pieces of the thesis into one coherent report.

#### Literature study

The literature study part of the project mainly comprised research of the current international market and technology of floating wind power and conventional offshore wind in general. Due to the immaturity of the technology most handled reports are published the last years, which have provided us with recent numbers and figures and most likely represent the current situations. The literature study has continued throughout the entire work period of the thesis.

#### Interview study

An interview study was also carried out as a part of the project. Each interview was shaped differently depending on purpose for the interview and the time elapsed since the start of the project. All of the interviewed companies and organizations were by the authors identified as key stakeholders within offshore wind in Norway, but some of them also had a more specific knowledge of challenges that needed clarification.

#### Company survey

In order to get the industry perspective of the Norwegian offshore wind market, a questionnaire was sent out to Norwegian companies involved in offshore wind business. A list with these companies was provided by *Norwegian Energy Partners (INTPOW)*. The full questionnaire and introduction text can be seen in appendix 7. The main purpose of the survey was to highlight the industries point of view for the future of the Norwegian offshore wind sector.

When the answers were received, these were analysed and presented both graphically and in free text in the thesis.

#### Case study

Based on NVE's suggested areas for floating wind power together with various economic, technical and social aspects, the most feasible location for a test park was determined. The yearly power production was calculated using 14 years of wind data. Furthermore, different methods and cost segments for three floating foundation concepts were studied and estimated to determine the total cost and the levelised cost of energy (LCOE) for the test park.

## 1.4 Limitations

Due to limited amount of time several delimitations have been made. The following areas which are all seen as highly relevant for this report have not been investigated and therefore not concluded in the report.

- Environmental impact of floating offshore wind in general. The test park is however placed at a proposed area of NVE where they have made some environmental impact analyses.
- The impact on the Norwegian fishing industry and their attitude regarding offshore wind
- The public attitude towards offshore wind power development
- A thorough economic sensitivity analysis of the test park costs
- A cost comparison with both land based and bottom fixed offshore wind
- A deeper analysis of a suitable long term subsidy scheme for offshore wind in Norway

## 1.5 Outline of the report

### Chapter 2

This chapter aims to give an overview of the current floating wind power technologies, describing the different concepts existing today and comparing them to each other as well as describing the benefits compared to conventional bottom-fixed offshore wind foundations. The chapter also aims to give an overview of the international market of floating wind power and the existing prototypes as well as giving a short introduction to Norway's potential. At last, the chapter aims to describe the various challenges which the offshore industry in Norway is faced with, inhibiting a high penetration of the energy market.

### Chapter 3

This chapter introduces some of the various possible applications that floating wind power has to offer in Norway and around the world, both in short term and in a long term perspective.

### Chapter 4

This chapter presents a case study for where and how to build a test park for floating wind power in Norway as well as calculations of the power production for the wind power plant in the chosen area. Moreover, the chapter displays the total costs and the LCOE with a deployment of either of the three floating foundation concepts described in chapter 2.

### Chapter 5

This chapter presents and discusses several considerable benefits and opportunities of establishing offshore wind power in Norway.

### Chapter 6

This chapter aims to present and highlight the Norwegian industry's perspective of the offshore wind market in both Norway as well as on an international level. This is done by presenting the results of a questionnaire and an interview study carried out in this thesis. The questionnaire comprised 50 answers from different Norwegian organisations involved in offshore wind and the interviews were held with key stakeholders within the same industry.

### Chapter 7

This chapter aims to present a prognosis for the electricity price and green certificate price development over the coming years and a comparison with the development of the LCOE for offshore wind power based on estimated cost reductions over the same period of time. These are used to evaluate the probability of an offshore wind development in Norway with an unchanged subsidy scheme.

### Chapter 8

This chapter presents different pathways that Norway could follow and the suggested political actions required in order to develop an industry around offshore wind.

# 2 Floating wind power – Technology and Markets Overview

This chapter aims to present a brief overview of the current status for floating wind power in the aspects of technological concepts, international markets, existing and planned projects as well as potential challenges with a Norwegian engagement in offshore wind.

## 2.1 Floating wind power substructures and technology

A majority of the world's best wind resources are located in deeper waters. As the conventional offshore wind technology is restricted to shallow areas, there is a need for development of floating substructures that could enable this vast amount of energy. Today, several concepts and prototypes are being tested and the most developed are the Tension Leg Platform (TLP), the Semi-submerged (Semi-sub) and the Spar Buoy (Spar) which is shown in Figure 1. There are four full scale prototypes installed worldwide, one of them a spar type called Hywind located outside Stavanger in Norway. Another prototype is a semi-sub called WindFloat outside the coast of Portugal and recently two prototypes, one spar and one semi-sub, have successfully been deployed in Japanese waters as well. There are today no full scale arrays of floating wind power installed anywhere in the world, but Statoil is planning on executing the next phase for the Hywind concept by deploying a small array of five turbines outside the coast of Scotland [3]. Furthermore, Principle power has plans to develop similar parks with their concept WindFloat outside both Oregon and Portugal.

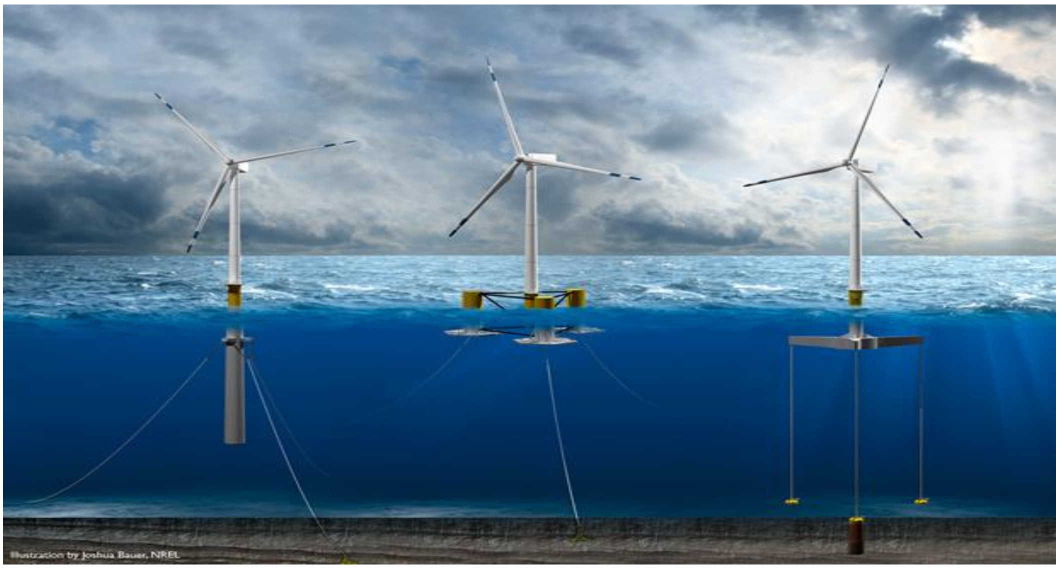

*Figure 1. The three different main concepts for floating wind power [4]*

There are six modes of motions which needs be considered in order to achieve stability for floating wind power turbines units as presented in Table 1 and Figure 2. One of the key challenges when designing floating wind substructures is to minimize the effects of these motions and achieve stability.

Table 1. Motions affecting a floating wind turbine [5]

| | |
|---|---|
| Surge | Translation along the longitudinal axis (main wind direction) |
| Sway | Translation along the lateral axis (transversal to the main wind direction) |
| Heave | Translation along the vertical axis |
| Roll | Rotation about the longitudinal axis |
| Pitch | Rotation about the lateral axis |
| Yaw | Rotation about the vertical axis |

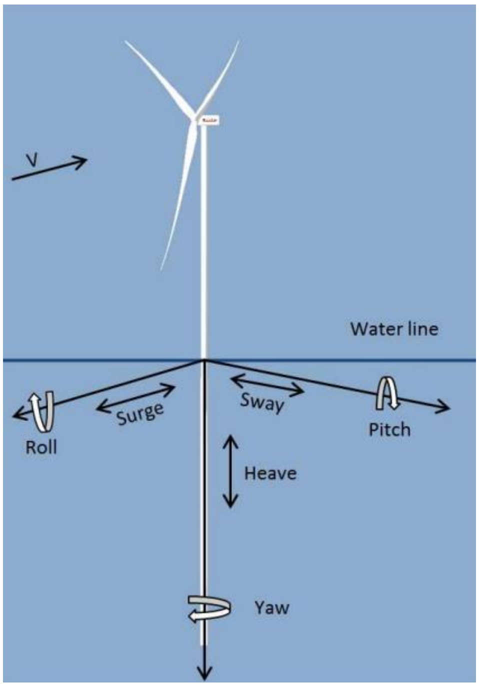


Figure 2. Explanation of the different motions of a floating wind turbine [7]

In order to do this, large floating structures are required. [6] The three ways to achieve stability for a floating platform are illustrated in Figure 3 where each corner of the triangle represent one of the different solutions. All floating structures will be found within this triangle and most structures are a combination of the different stabilizing categories [4].

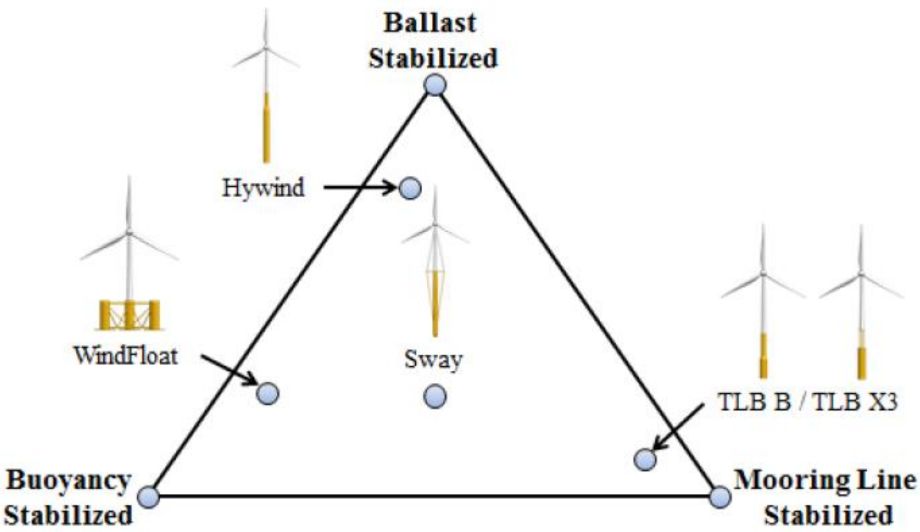


Figure 3. Floating substructure stability triangle [7].

Different loads on the structure arise from the mentioned motions induced on the platform. These are mostly a result from waves, wind and tidal motions. Loads could in some cases also develop from floating ice and debris and marine growth on the structure. [6]

### 2.1.1 Spar Buoy

Statoil's Hywind concept shown in Figure 4 is of the Spar buoy concept where static stability is achieved by using ballast weights situated under a central buoyancy tank lowering the centre of gravity which is considerably lower than the centre of buoyancy. The topside part of the structure is much lighter than the bottom part, which raises the centre of buoyancy [1] . The technology requires a very large substructure, which increases with heavier tower and turbine components. The large and deep substructure results in a large draft, which makes deployment of this type of floating structure difficult in shallow waters where the depths are close to the draft depth.

The Spar construction is usually a concrete or steel cylinder where the ballast can be either water and/or a solid material. The large draft is resulting in low heave motions and high resistance to pitch and roll motions. The structure is relatively flexible in rotational modes, but stiffer when it comes to surge and sway. [8] In order to keep the structure in position, mooring lines are attached to the seabed with anchors. These mooring lines can be either taut or catenary and be of different types such as anchor chains, steel cables, fibre ropes or a combination of any of these. [8] This is further described in section 2.3.

The large draft of the spar buoy type makes pre-onshore assembly of the entire wind turbine difficult which might lead to high cost actions coupled with turbine assembly offshore. However, ports with suitable depths can enable towing of the structure to its offshore location. Innovative solutions are being researched of how to enable onshore assembly when the depths of the construction ports are insufficient. One of these are the Windflip prototype that enables transportation of the fully assembled wind turbine unit in a horizontal mode, using ballast filling offshore to get the turbine deployed in vertical mode [9].

The Spar is a quite simple structure and therefore relatively easy to produce. However, due to the large structural size, the cost of the Spar foundation is quite high.

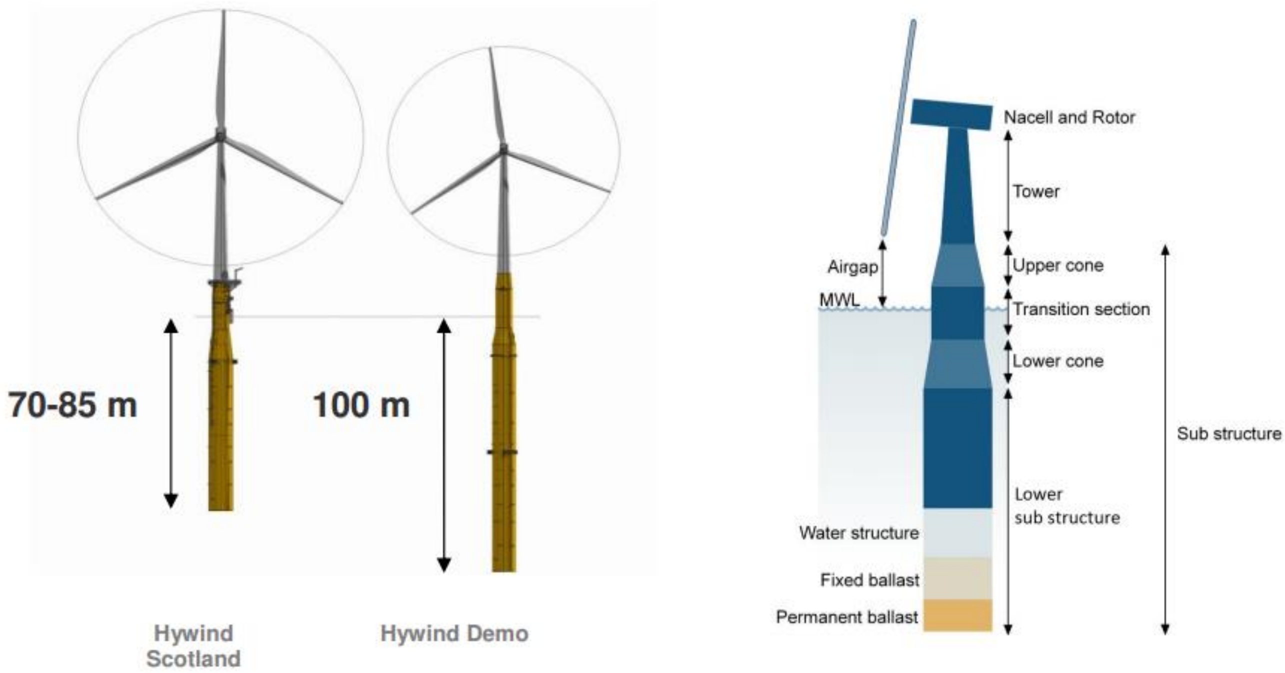


*Figure 4. The Hywind demo and the Hywind Scotland concepts [3]*

### 2.1.2 Semi-submersible

The Semi-submersible structure, like the WindFloat full scale prototype outside the coast of Portugal, is a triangular pontoon-type structure that achieve stability through high buoyancy. Each corner of the platform has vertical tubular columns interconnected by bracings. The columns can hold ballast in order to get the right buoyancy level. The turbine tower is supported and attached to one of the columns as seen in Figure 5.

The structure has a relatively low draft and the mooring system is similar to the Spar type with 3-6 mooring lines. The draft can be as low as 10 meter, which enables full assembly in a dry dock and transport to site by a towing vessel. [8] The low draft also implies that the structure can be used in as shallow waters as 40-50 meters [10]. A negative consequence of having a large part of the structure near the free surface is that it is more affected by ice loading and corrosion. This type of structure will also be more effected by extreme wave conditions. [4] Another advantage with the low draft and thereby easy transportation ability, is the possibility of towing the entire structure to shore in case of a major malfunction where repair might be done at a considerably lower cost compared to major repairs being done offshore. [8]

*Figure 5. The WindFloat concept [11]*

### 2.1.3 Tension leg platform

A Tension Leg Platform (TLP) design uses tensioned mooring lines fixed into the seabed in order to achieve stability. A requirement for this is to have a buoyant submerged structure that will try to pull the structure up above water, at the same time as the mooring lines are pulling it down. The structure has a large main column to which several tension lines are attached. The lines which can be tension cables, tendon pipes or solid rods are connected to the seabed anchors straight under the floating structure. The tension of the mooring lines are critical since a failure here will lead to capsizing of the structure. The anchoring system can be of gravity based, suction or pile driven type and is usually more dependent of the soil conditions compared to the other concepts [8]. Onshore or dry dock assembly can be possible, but will most likely require special purpose vessels during the tow out to offshore location in order to maintain stability.

The most developed prototype so far is the PelaStar shown in Figure 6, although no full scale model is in use today, making TLP the least developed concept of the three announced in this chapter [8]. However, the TLP has several advantages towards the other concepts that could reduce the cost of energy for floating wind turbines. The relatively small structure compared to the spar and the semi-submersible means less expenses for steel and other raw materials. The anchoring system also implies a minimal seabed footprint, enabling easier marine actions concerning anchoring and cabling connected to the turbine. [6]

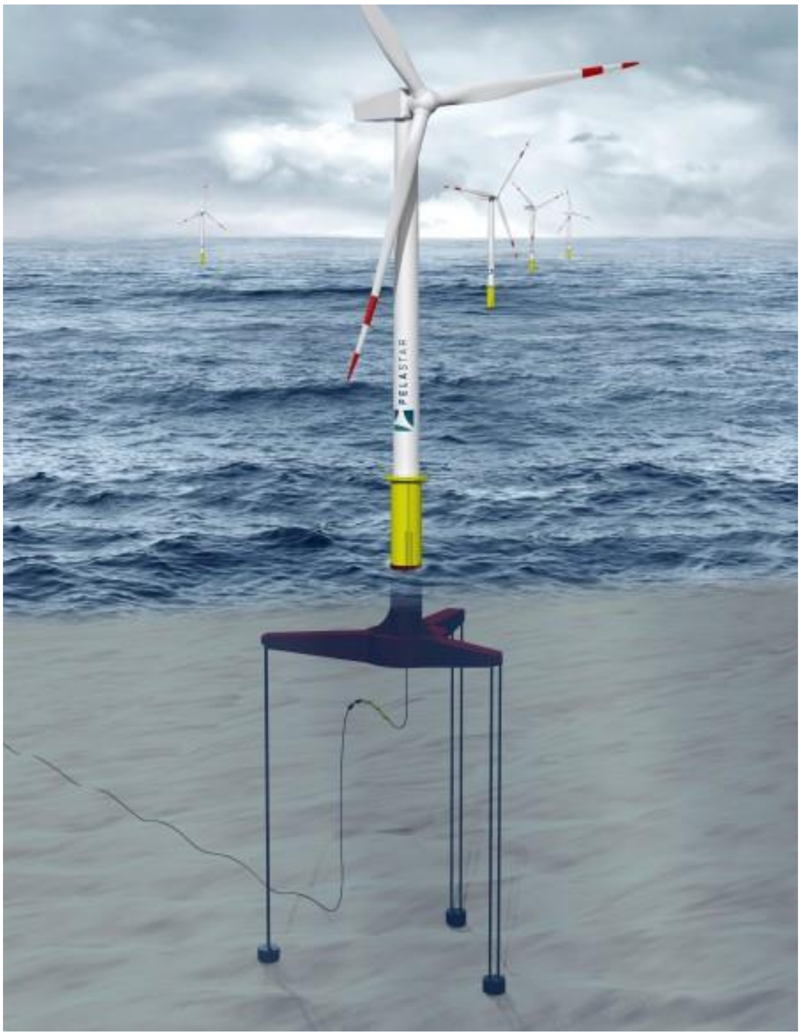


*Figure 6.The Pelastar prototype [12]*

## 2.2 Mooring technologies

### 2.2.1 Mooring lines

The mooring system is used to restrain the floating structure to a specific location, where three main categories of mooring systems are considered in this thesis; catenary mooring systems, vertical mooring systems and taut leg mooring systems displayed in Figure 7.

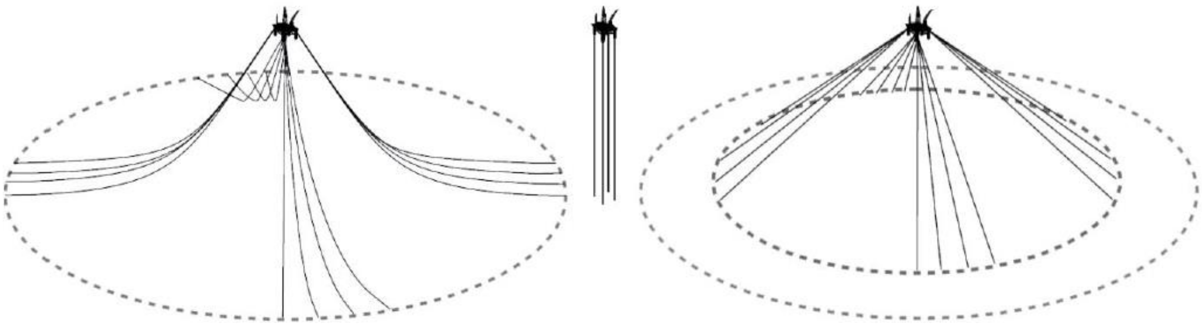

*Figure 7. Catenary system, vertical system and taut leg systems used for mooring.*

The main differences between these systems is that catenary mooring lines arrive at the seabed horizontally, vertical mooring lines arrive at the seabed vertically and taut leg mooring lines arrive at the seabed at an angle as seen in the figure.  Taut leg mooring systems are therefore capable of resisting both horizontal and vertical forces, and restoring forces are generated by elasticity of the mooring lines [7]. The TLP foundation concept commonly use the vertical system with taut mooring lines to the anchors at the bottom, while the semi-submersible and spar concepts commonly use the catenary mooring line method.  This catenary method is by far the most proven technology and works well. [13] This system could however be problematic at lower water depths and would require a dramatically increased line length and some attached clump weights to achieve a preferred catenary shape of the mooring lines [7]. One possibility to reduce costs and improve logistics could be to connect several wind turbines to one high capacity anchor and thus reduce the total amount of anchors.

### 2.2.2 Anchors

There are various anchors used for the different types of mooring technologies mainly depending on the angle of which the mooring lines arrive to the seabed. For foundation concepts using the catenary mooring system, which arrives at the seabed horizontally, a drag embedment anchor (DEA) shown in Figure 8 is commonly used which is also the most popular type of anchoring point available today. This anchor has been designed to penetrate into the seabed, either partly or fully. The holding capacity of the DEA is created by the resistance of the soil in front of the anchor and is very well suited for resisting large horizontal loads but generally not for vertical loads like in the TLP mooring solution. However, there are some DEA on the market today which can resist significant vertical loads as well. [14]

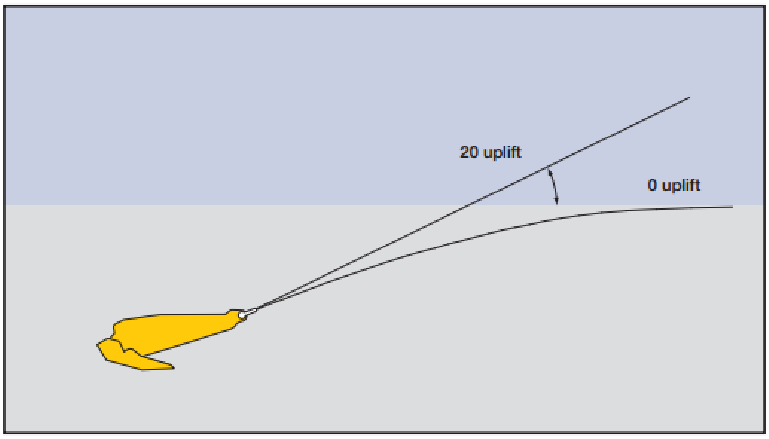


*Figure 8. Illustration of the drag embedment anchor [15].*

When using the vertical mooring system it is common to use a suction pile anchor which is basically a large diameter hollow steel pipe which is installed by creating a pressure difference by a removable pump, forcing the anchor down into the seabed. For the suction pile anchor, shown in Figure 9, the friction of the soil along the pipe and lateral soil resistance generates the holding capacity which makes the anchor capable of withstanding both horizontal and vertical loads [16]. This required friction results in additional necessities for suitable soil conditions compared to the other anchor and mooring alternatives.

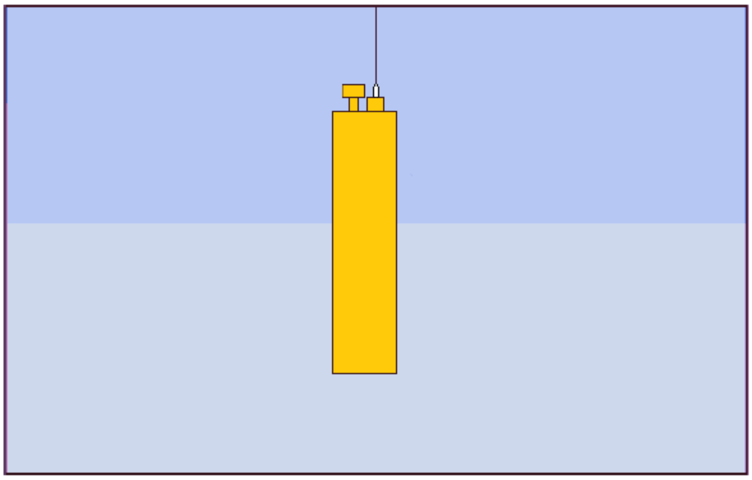

*Figure 9. Illustration of a suction pile anchor [7]*

For the taut leg mooring system the anchor line arrives at an angle of approximately 45˚ at the seabed and the use of an anchor capable of withstanding vertical load is a necessity, such as a vertical load anchor shown in Figure 10. The vertical load anchor is installed a lot deeper than the DEA to withstand the taut leg forces [14].

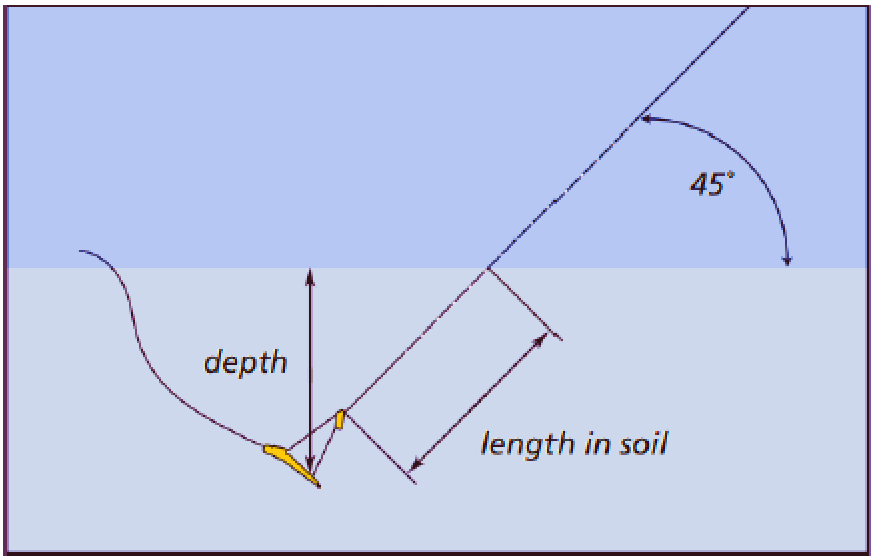


*Figure 10. Illustration of a vertical load anchor [7]*

## 2.3 Installations

### 2.3.1 Turbine and floater installation

Reliant on the floating foundation concept, different installation methods can be used, both proven and experimental techniques. There are several different aspects which are to be considered, such as transport orientation of components such as towers and foundations, the degree of assembly prior to transportation to the installation site and whether components or wind turbines are to be towed or transported on deck of a transportation vessel. [7] Due to this, two different installation methods are described to highlight the differences in methods. The first method is based on a complete installation near-shore before towing the complete wind turbine to the installation site and the other is based on towing the substructure out without the turbine tower attached prior to towing, to offshore sites where the turbine components are installed.

Using the semi-submersible concept with a low draft makes it easier to manage a complete pre-assemble of the foundation in calm waters or in a dry dock prior to tug transportation to the site. Compared to assembling offshore, using this near-shore method removes the need for dangerous, heavy lifts at sea, and should also be associated with lower costs, partly due to a larger operational windows due to milder weather conditions in protected waters. This method requires near- or onshore cranes for assembly and anchor handling tug supply vessels (AHTSs) as well as tug boats for towing and mooring. The installation costs should be lowered further if there is quay facilities adapted to quayside installation of turbines onto the floating foundations, e.g. by having drafts exceeding the foundation drafts at quay. This mean that the installation would not have to rely on crane barges but could instead use only land-based equipment. [7] Thus, this could save sizeable installation costs.

### 2.3.2 Mooring installation

The installation methods for mooring systems can be divided into pre-set and concurrent installation. In the pre-set installation the anchors and mooring lines are pre-laid out and simply hooked up by the supply vessel when the floating foundation is being installed. Using the concurrent method, the anchors are laid out with mooring lines attached to them and connected onto the foundation as this is installed. [17] The pre-set installation has the advantages of allowing a longer weather window and a limited interaction with the installation of the foundation and is therefore less prone to delays and less risky to interfere with installation operations and operators. It will however lead to an extended total installation time of the mooring and anchoring system. In the concurrent installation, almost all activities can be performed simultaneously, reducing the need of additional transfers and transports. It might however end up to being too many vessels at the site operating in a limited area during hook-up [17], making the installation more complex compared to a pre-set.

## 2.4 Cables and substations

An offshore wind power plant generally consist of the turbines, the inter-array cables, the export cables and one or two substations, as shown in Figure 11. The turbine generator is commonly producing power at 690 V and the internal turbine transformers then steps up the voltage to the inter-array cables voltage commonly using 33-36 kV. The inter-array cables then transmits the power from each turbines to the offshore substation, normally with the current standard method using AC submarine cables [18]. The inter-array cables are conventionally connecting two turbines by being drawn along or inside the turbine foundation down to the bottom, along the seabed (usually buried) and then back up to the next turbine. All the turbines are then connected in several tracks to one or several offshore substations increasing the voltage from the 33-36 kV to a higher voltage, generally ranging from 136-

400 kV depending on the rated power, distance to shore, voltage at the connecting grid point etc. The power is then transmitted to the national grid onshore through a subsea HV export cable.

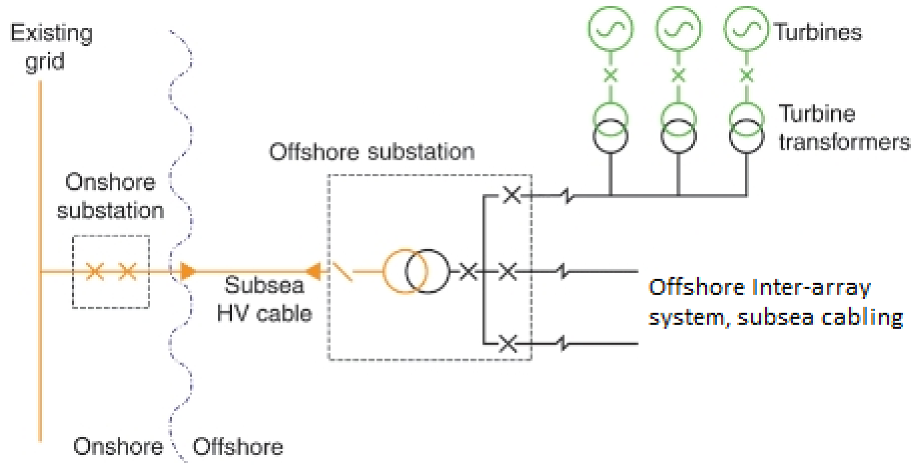


*Figure 11.A simplified Illustration of the grid connection of a offshore wind power park [19] .*

The export cable can be either AC or DC cables. One of the advantages of using AC cables is that no expensive converter is needed, in contrary to a DC system where two converters are needed. One disadvantage on the other hand is that AC cables have a high capacitance which generate considerable reactive current, reducing the overall power rating of the cable. The longer the cable, the larger is the reduction. Moreover, as the capacitance reduces the active current-carrying capacity of the cable, it also requires a scheme to absorb the reactive current. HVDC cable losses over distance are almost negligible but the HVDC converters lead to high electrical losses on both end, up to 5% both ends for the voltage sources converter [18]. Other sources claim that the losses in the converters used today is significant lower. HVDC is generally suitable for significant power transfers or large distances, approximately 100 km [18] depending on the site specifics.

With a high installed capacity it will be feasible to use high voltage cables to reduce high line losses (voltage drops) and to avoid the requirement of several cables and the subsequent cable burials. These cables generally have low rates of failure but long repair times and high impact when not available. The export cable to shore will generally be a costly asset together with the cost of installation. Due to the high cost, full redundancy of the export cable is rarely an option. However, installing two cables with less than 100% or three cables instead of two might be worthwhile. As vast majority of the export cable failures are due to some kind of physical damage, it would be ideal to install the cable traces separated by some distance to take full advantage of the redundancy aspect [20]. It could be beneficial to use the same voltage level as at the connection point to the national grid if possible as this would avoid the need of an additional power substation onshore for the HVAC system. This would however require that there are cables available for the corresponding voltage levels.

An offshore industry moving towards deeper waters will require longer inter-array cables to cover the distance to the bottom and back up to the next turbine. Other than the increased cost of cable and the electric losses connected to longer cables, the installation costs and complexity would likely also increase. The increased cost could stimulate the development from submerged and buried cables to semi-floating cables for the inter-array connection as displayed in Figure 12.

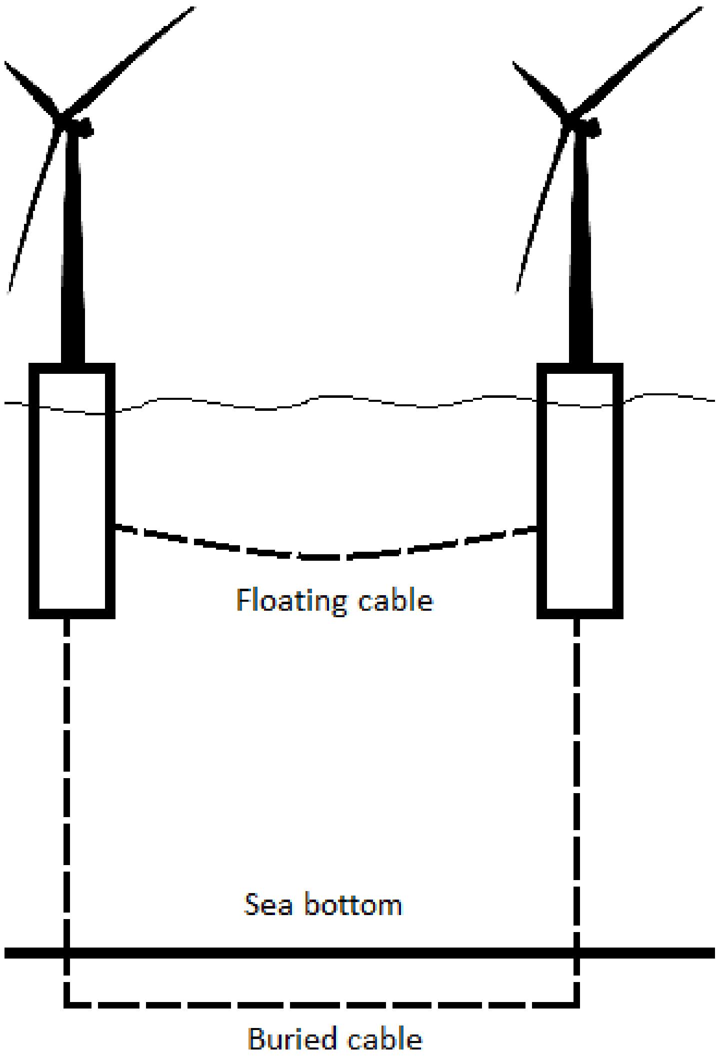


*Figure 12. Illustration of floating cables compared to buried cables for floating wind turbines.*

At what depth this would be considered feasible is difficult to say but the benefits would likely be considerable at deeper depths. If the semi-floating cables are placed too close to the water surface they might create a conflict with shipping and fishing interests as the area might be restricted for passing to avoid collision fishing gear and anchor strikes and fishing if they are at low drafts. At what depth the cables would be located would likely have to be discussed with the authorities to avoid these conflicts.

## 2.5 Benefits compared to bottom fixed offshore wind

In recent years the offshore wind industry has started to look beyond the shallow waters of the Earth and new ways to harvest the vast amount of energy hosted by the deeper oceans. Shallow areas with good wind resources are limited, but deep water areas are abundant. This is one of many reasons why floating wind power recently has started to win attention within the offshore wind industry. In fact a voting lead by GL Garrad Hassan (now a part of DNV GL) at a wind energy trade fair 2012 showed that 62% of the participants believed that floating wind will dominate the market within 20 years [21]. The benefits compared to bottom fixed offshore wind are many and some of them are summarised below.

- **Low day rate for installation vessels**
- **Commissioning in sheltered waters**

- **Potential for lower construction risk**
- **Reduced cost of weather**
- **Cheaper O&M**
- **No piling**
- **Greater scope for modularisation**
- **High learning rates**
- **Location based on energy resource**
- **Easier mass production potential due to less site specific requirements**

Today several prototypes of floating wind power exist, but the technology is still maturing and the costs are therefore still high. The costs are however a key issue for conventional offshore wind and the main driver for the development of floating wind power [21]. The installations of conventional offshore wind often require large and extremely expensively operated vessels and with the harsh conditions connected to many offshore sites, the operating weather window is tight. With the development of floating structures, full assembly could be established onshore or in a dry dock which would significantly reduce the cost associated with offshore wind installations. Major repairs could also be handled more easily since the structure could be towed to shore where maintenance work is more easily carried out assuming cables and mooring systems could easily be disconnected. [6]

Moving into deep waters is all about reducing costs and enable wind power production for areas where shallow waters are limited. Japan is one of these markets, where the shutdown of their nuclear reactors in combination with a shortage of other power alternatives, have made the nation engage with full power towards floating offshore wind [8]. Japan is surrounded by deep water and does not have the luxury provided of sheltered shallow waters as in northern Europe. Japan is however not alone as a nation with limited shallow waters. UK, Portugal, USA and several other nations also have strong interests in developing a sustainable way of harnessing the deep water offshore winds. In fact more than 92 % of the world's oceans are deeper than 200 meters [22], meaning that the potential for floating turbines is far more widely-spread than for bottom fixed ones.

Mass production is a key cost reduction factor [23] and floating wind power offers the possibility of this to a higher degree than conventional offshore wind. The design of the foundations for conventional wind is often site specific and dependent of soil conditions and other variable factors and therefore each element is custom made. Floating foundations however is less dependent of variable factors, and the same element can therefore be used almost anywhere enabling the possibility of a greater mass production and standardisation process. The less location restricted ability also allows floating wind power to be placed where the wind resources are at its best, enabling a higher energy yield. This could lower the LCOE and increase the attractiveness of offshore wind. The cost drivers for bottom fixed and floating foundations are compared in Figure 13. Floating foundations should however be designed for the specific site as well to achieve the best possible performance, but when it comes to bottom fixed each individual foundation needs to be custom built and this is the main difference between the disciplines [24].

As an immature technology the economic and technical risks associated with floating wind power may exceed the corresponding risks for bottom fixed offshore wind power. However as the technology is maturing, the risks are decreasing as well. In fact the floating technology can improve a lot of the insecurities connected to offshore wind. Examples of this are the construction and installation risks.

By minimising the actions needed offshore, the costs can be more predictable and installation complications may not be as severe as if done offshore. [13]

| | Bottom-fixed | | Floating | |
|---|---|---|---|---|
| ← | Commercial WTGs available | **WTG** | Commercial WTGs available | → |
| | Generally lower mass | **Substructure** | Site independent, high potential for mass production | ↗ |
| ↑ | Does not need mooring & anch. | **Mooring & Anchoring** | | |
| | | **Decommissioning** | Easier removal, tug back to shore | ↑ |
| ↑ | Longer track record, more predictable reliability | **Proven technology** | | |
| | | **Installation** | Simple installation vessels – few offshore ops. | ↑ |
| | | **Energy Yield** | Not limited to shallow waters | ↑ |
| | | **Maintenance costs** | Enables major repair inshore (but difficult offshore) | ↗ |

*Figure 13. Comparison of cost drivers for fixed and floating substructures. A horizontal arrow indicate that the aspect does not vary much from the other technology and a vertical arrow indicates that there is a clear advantage. [8]*

Commissioning and assembly being done onshore can lead to safer and better quality of the floating wind turbine [6]. A better quality during the assembly process might lead to fewer offshore maintenance and repair actions which could reduce the O&M costs of the project. The flexible floating structure also enables for that some major repair and maintenance issues can be handled in harbour by towing the structure from its offshore location.

One of the main environmental impacts of offshore wind is the noise disturbance from the installation process of the bottom fixed foundation. The most notable source of this disturbance is the pile-driving process and it may have several effects on marine mammals [25]. Since the installation process of floating foundations doesn't generate the same magnitude of noise disturbance, the deployment will be less harmful for marine mammals.

Comparing with the oil industry it makes perfect sense to go from bottom fixed structures to floating. As the oil rigs went into deeper waters, floating structures were developed significantly reducing the total cost [26].

## 2.6 International Markets

The international market has been studied to provide an overview of the export potential for Norway for floating wind power.

Many of the developing countries have large expected population growths in the coming years where renewable energy is a necessity to mitigate the increasing effects of global warming. Many of these countries e.g. Brazil, India and China lack good wind energy resources onshore to exploit but possess considerable offshore resources in deep water areas as can be seen in Figure 14. The figure displays that the global offshore resources are generally significantly higher than the onshore resources, enabling a considerably increase in energy output. These vast wind resources available in deeper waters have led to an increase in focus and attention towards floating offshore wind technologies in many parts of the world. The global potential for floating wind power is huge with over 92% of all the oceans water being deeper than 200 m [22] which opens up for a large international market.

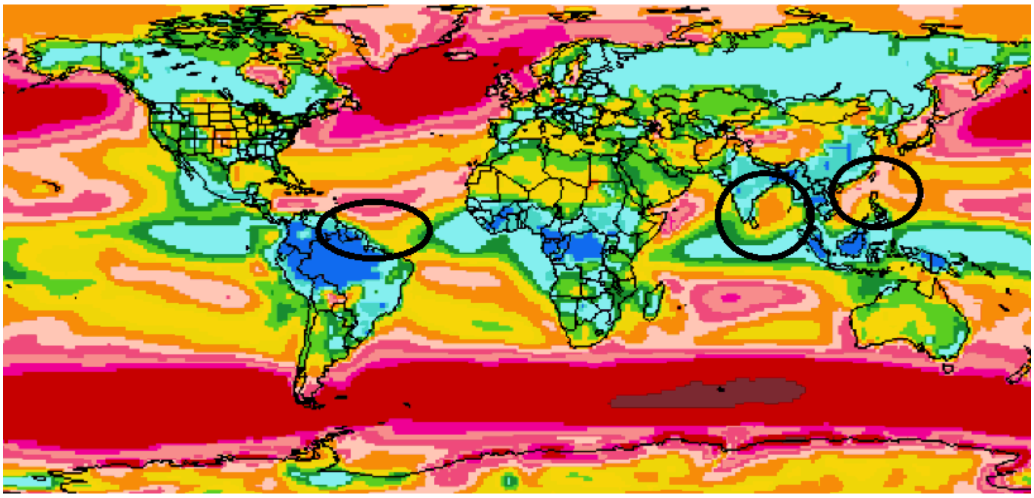

*Figure 14. Global wind resource map ranging from low wind resources (displayed as teal and green) to high wind resources (displayed as yellow and red). [27]*

The development of deep water offshore floating systems has previously primarily been led by Europe but today a large amount of R&D, concept developments and testing of floating solutions are also performed in the US and Japan. [8] With considerable wind resources in their deeper waters, US has a significant potential for deploying floating wind power. In Japan, the Fukushima accident in 2011 has led to a major interest and quick development of offshore floating wind technologies.

### 2.6.1 Europe

Europe has lead the development of offshore wind power and as of July 2013, had 90% of the worlds installed capacity [1]. With the vast wind resources available in the deeper waters, many European countries are interested in developing floating wind power. In the North Sea, 66% of the waters are between 50 m and 220 m deep and the area is therefore a highly suitable location for deep offshore designs. As an example, using 6 MW turbines, this area alone could be used to produce four times today's electricity consumption of EU. [1] According to EWEA, 141 GW of wind power has been identified to be either consented, under construction or already online. As seen in Figure 15, the European waters are generally very suitable for floating foundations.

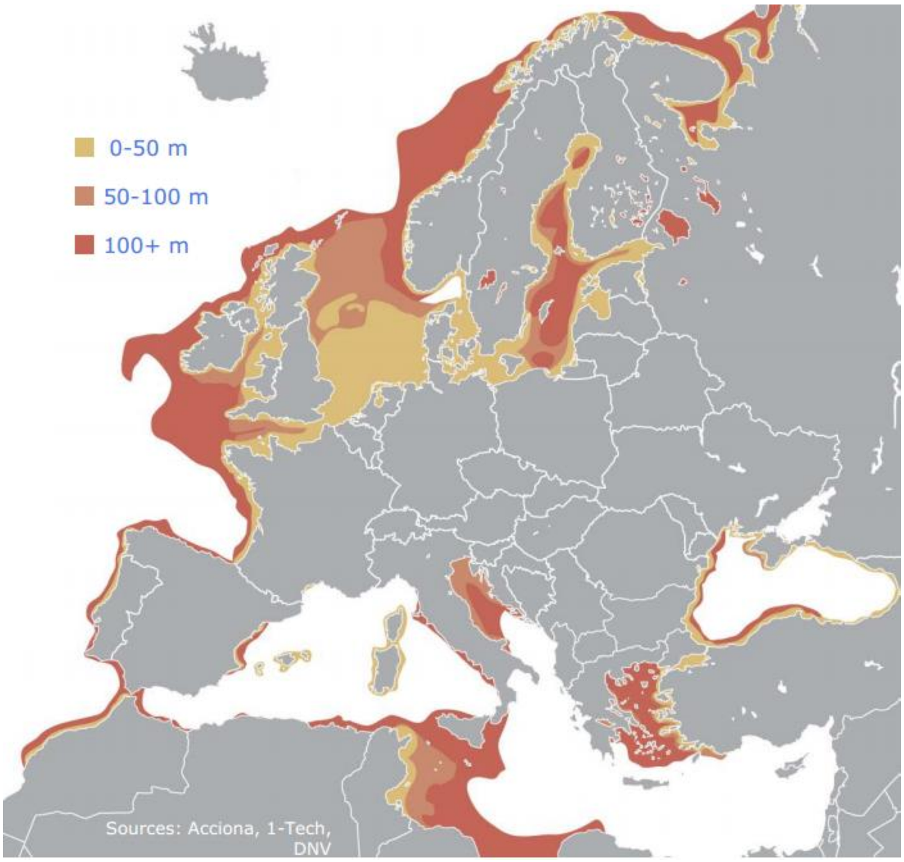


*Figure 15. The water depth in European waters.*

Even though the UK has the far greatest experience of offshore wind in Europe, the technology race is ongoing with several European countries allocating money and feasible sites to deploy wind power plants in deep water using innovative designs. The three countries Portugal, Spain and France are also considering deep water technologies. Portugal has a large maritime area in the Atlantic with great wind resources and both Spain and France have deep water close to shore which enables the potential for floating wind power. Further prototypes are also being developed in Germany, Sweden and the Netherlands. [1]

#### *2.6.1.1 United Kingdom*

Offshore wind is now broadly acknowledged as a central focus in the UK's plans to increase the amount of renewable energy production over the next decade [28]. The UK are currently world leading within offshore wind power, with the highest installed power capacity in the world. Large areas suitable for fixed structures, great wind resources, a long maritime history, an experienced workforce, offshore O&G experience and a stable political framework have created a strong basis for this prosperous offshore wind industry [8]. As UK also has large areas with deep water conditions, the country has a strong interest towards the deep offshore wind development as well.

At this point it is problematic to determine which type of foundations that is likely to be used. The TLP and Semi-Sub could be of interest due to their shallow draft, most suitable for depths of about 50-60 m. However, the deployment of Hywind Test Park outside of Aberdeen in Scotland also indicate that Spar solutions could be used for the deep water deployments [8]. With the fluctuating depths surrounding UK, seen in Figure 16, it is possible that all three floating solutions might be applied complimentary together with bottom fixed wind turbines [8].

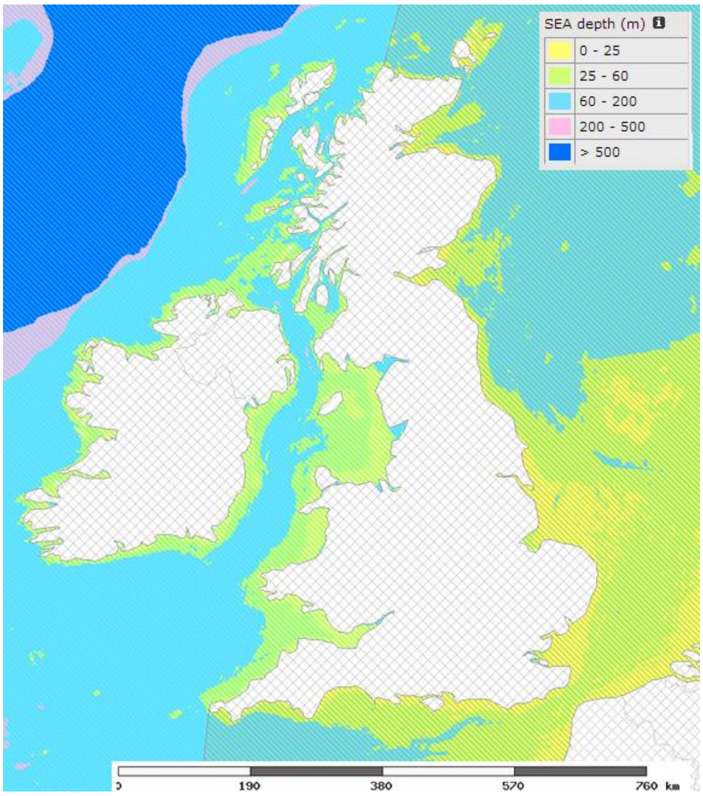


*Figure 16. Water depths around the UK. Source: ORECCA*

### 2.6.1.2 Portugal

Portugal has a European Economic Exclusive zone 15 times larger than its own land area which together with the excessive amount of this being deep water, as seen in Figure 17, makes it suitable for floating wind power development. In 2012, the Portuguese government committed to support the second phase of the successful WindFloat project, which was awarded funding by the European Commission under the NER300 scheme. The second phase will have approximately 27 MW installed capacity using the next generation multi-megawatt offshore turbines. Moreover, a third (commercial) phase is planned to increase the wind capacity to 150 MW [1].

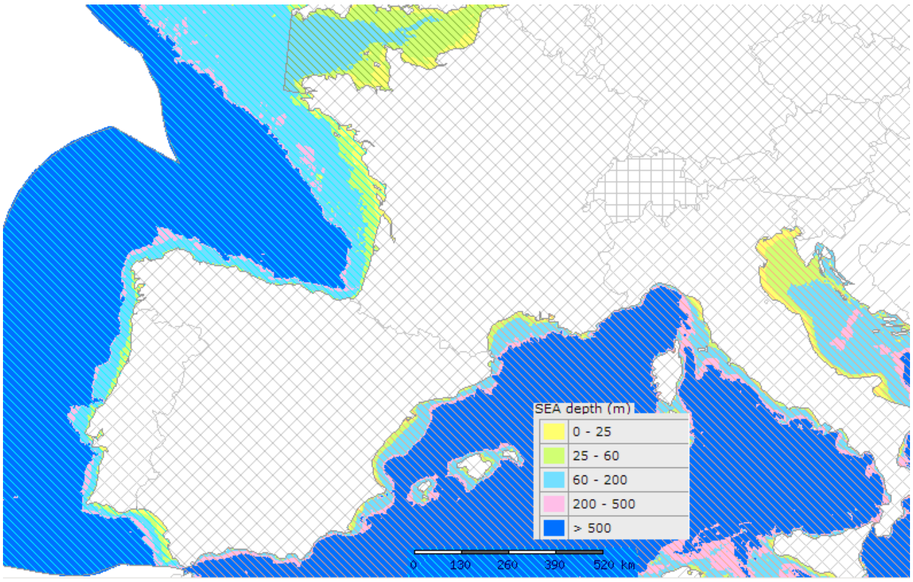


*Figure 17. The sea depths around France, Spain and Portugal. Source: ORECCA*

#### 2.6.1.3 Spain

With the great depths of the Mediterranean and other coastal areas, Spain has great potential for floating offshore wind power with Spanish companies such as Gamesa and Acciona involved in deep offshore projects [1]. Spain is planning several test projects, although the future of them is uncertain due to the need of policy change [29]. The current economic situation of Spain indicates that the market here might occur somewhat later compared to other potential markets.

#### 2.6.1.4 France

France is also considered to be on the forefront of deep offshore wind power development. Currently, there are three demonstrations programs: WINFLO, Vertiwind and IDEOL, where the first two received funding from the 'Grand Emptrunt" investment program. In 2012, the Vertimed project received funding from NER300 to form a 26 MW array to help establishing a deep offshore industry in the country. If these demonstration projects are successful, the government could support the scaling up of the prototypes which could result in the first 100-300 MW floating wind power plants in 2025 [1].

### 2.6.2 The United States

With a large part of the population and consumption located in the cities near the coast, US has great opportunities for offshore wind power as these long coastlines also have vast wind resources, estimated to about 4150 GW, shown in Table 2, where about 60% are in water depths greater than 60 m. This is roughly four times the generating capacity of the entire U.S grid. Even if just a fraction of this would be installed, it could still support a large part of the national consumption.

*Table 2. Offshore wind potential for areas up to 50 nautical miles from shore with average wind speeds of 7 m/s or greater at 90 m elevation [1]*

| Region | 0-30 m depth | 30-60 m depth | >60 m depth | Total |
|---|---|---|---|---|
| New England | 100.2 | 136.2 | 250.4 | 486.8 |
| Mid-Atlantic | 298.1 | 179.1 | 92.5 | 569.7 |
| South Atlantic Bight | 134.1 | 48.8 | 7.7 | 190.7 |
| California | 4.4 | 10.5 | 573 | 587.8 |
| Pasific Northwest | 15.1 | 21.3 | 305.3 | 341.7 |
| Great Lakes | 176.7 | 106.4 | 459.4 | 742.5 |
| Gulf of Mexico | 340.3 | 120.1 | 133.3 | 593.7 |
| Hawaii | 2.3 | 5.5 | 629.6 | 637.4 |
| Total (GW) | 1.071.2 | 628 | 2,451.1 | 4,150.3 |

However, even with these vast wind resources, US still has no offshore wind park, although a contract has been signed by Siemens and Cape Wind for the first utility-scale offshore wind power plant in the US. The project is situated on the northeast coast with an expected installed power of 468 MW, yet, installation and commissioning is not expected until 2016 [30].

The US has however declared great goals as President Obama's state of the Union Address in 2011 called for 80% of the nation's electricity to be generated from clean energy sources by the year of 2035 [1]. Moreover, the state of Maine are encouraging deep water substructure development with a goal of 5 GW of floating wind capacity by 2030 with already three test parks designated and $8.5 million funding from the department of energy (DOE) to the university of Maine to develop the next generation of offshore wind platforms. In 2012, additional $168 million funding from DOE was announced to be used over six years for seven offshore wind demonstrations [1]. The projects receiving funding was announced in May 2014, one of them being Principle Power's project using 6 MW turbines on their WindFloat foundation. The turbines are planned to be installed 18 miles off the coast of Coos bay in Oregon at a depth of more than 1000 m and will aim to demonstrating an innovative solution for deep water wind turbine projects and reducing costs by simplifying installation the need for highly specialised ships. [31]

Though the national goal might appear challenging to accomplish at this point, a lot can happen during this time and even if US only partly reaches this goal, it is a step towards the right path. In time, even small steps could benefit the technology development and cost reductions for the floating wind industry. Based on the lessons learned in Europe, the considerable experience from the O&G industry, ongoing research and active technology developers, US has the ability to start to scale up in the industry. The US market will likely respond swiftly – once the technology turns more cost-competitive [8].

### 2.6.3 Japan

With the already limited domestic fossil fuel resources, the Fukushima accident had a major impact on the power production in Japan. All the 54 nuclear reactors closed down with 30% of the power production lost as the result. Today, Japan is spending a considerable amount of resources importing liquefied natural gas (LNG) to be able to supply the energy demand [8]. With the record-high price on the Asian LNG markets this has led to major increase in electricity generation costs which can be seen in Figure 18

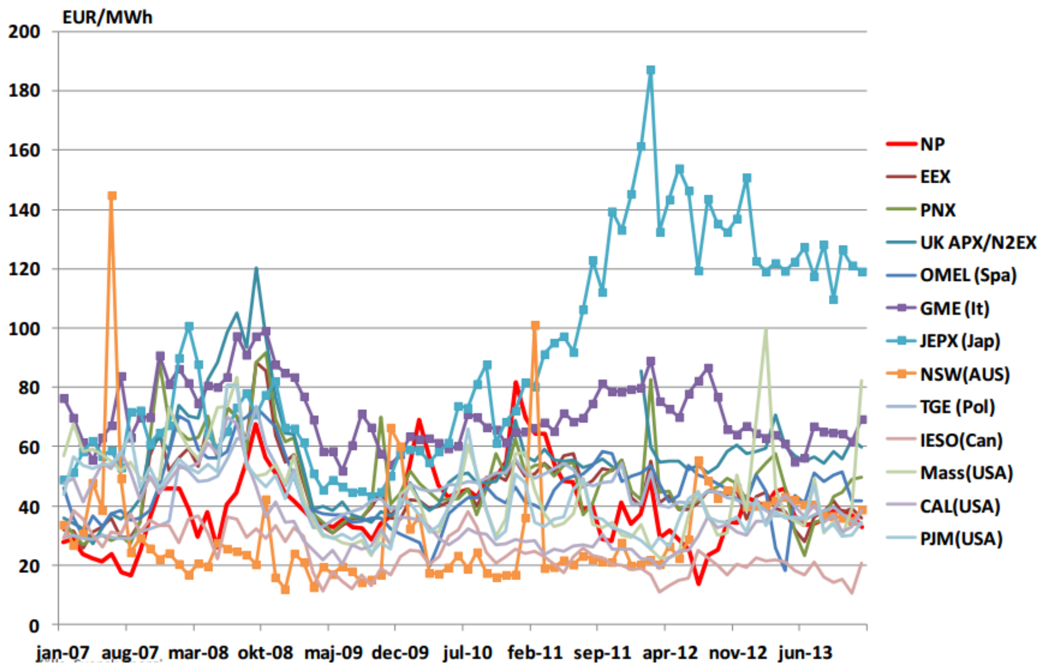


*Figure 18. The development of the monthly average electricity price around the world. [32]*

The Japanese government has lately established a strong interest in developing deep offshore technology and decided to boost renewables with a strong political agenda towards offshore power.

Cumulative, there are many reasons why this country could be considered suitable, partially since Japan has [1] [8]:

- More than 80% of the wind energy resources located in deep water due to a steep seabed and limited land available for onshore wind.
- Long-time experience in floating steel structures, a strong maritime R&D and experience in mass production lean manufacturing enabling cost reductions and commercialization of technologies.
- The world's 6th largest Exclusive Economic Zone (EEZ)
- High electricity prices due to the energy crises
- Over twenty years of public funded research on deep offshore structures
- Strong political agenda towards renewables
- Feed-in-tariff already put in place for wind power and one additional feed-in-tariff for especially offshore wind power has been proposed by a governmental panel suggesting an increase of nearly two third from 22 yen/kWh to 36 yen/kWh. [33]

Together this makes it realistic that floating offshore wind will be a future energy source for Japan and a catalyst to accelerate the developments of new offshore technology solutions [8]. The Japanese wind association estimates that the realistically feasible offshore wind potential is about 608 GW [34].

There is currently no official targets for offshore wind, although it was estimated that around 5-6 GW offshore wind could be installed by 2030. Moreover, the long term energy and climate strategies are assumed likely to be reassessed with the current government in power. The government has to a large extent funded the Fukushima project, which will result in a wind power plant with three different floating concepts by 2015 and commercialization by 2018 which will likely make Japan the global leader with regards to full scale floating projects. [34]

## 2.7 Support schemes

### 2.7.1 Investment support schemes

Investment support schemes are not connected to the actual energy production and performance of the project. They are used to limit the risk and the need for the substantial investment capital in order to engage in offshore wind. Many types of investment support exists e.g. a part of investment being paid by public subsidy, low-interest loans, tax breaks and so on [35].

### 2.7.2 Operating support schemes

Operating support schemes are connected to the actual power production. Within this area of subsidies there are mainly two categories. One of them offers a fixed price for renewable energy production and is therefore a price driven mechanism. This type will have no restraints of the volume of new renewable energy and will favour the most cost effective sites to be built. The other one sets a volume based target of renewable energy and the value of the support will in this case vary. This type is seen as a more market based support scheme and is called a quantity based mechanism. [35]

Green certificates and tendering are two support schemes that are known as quantity based mechanisms and Feed-in-tariffs and Feed-in-premium are examples of price driven mechanisms.

### 2.7.3 European support schemes

#### *2.7.3.1 Investment support*

As mentioned previously many types of investment support schemes exists and are usually custom designed for different electricity systems. In Table 3 various investment support schemes in European countries are displayed.

*Table 3. Examples of European investment support schemes [35]*

| Country | Investment Support Schemes | Comments |
|---|---|---|
| Belgium | » Grid subsidy | Projects with a capacity of 216 MW or more receive a subsidy from the grid operator (EUR 25 M) for construction of the export cable. (Smaller projects received a prorated amount.) |
| Czech Republic | » Cash grant | Up to 40% of investment budget |
| Finland | » Cash grant | Up to 40% of investment budget |
| France | » Accelerated depreciation<br>» Research tax credit | |
| Greece | » Tax break<br>» Cash grant<br>» Leasing subsidies | Total investment incentives up to 40% of investment budget |
| Italy | » Cash grant | Up to 30% of investment budget |
| Luxembourg | » Cash grant | Grant of 20% to 25% of investment budget |
| Netherlands | » Tax break | |
| Poland | » Tax break<br>» Cash grant | Renewable energy is exempt from tax.<br>Grant from EU structural funds |
| Spain | » Accelerated depreciation | Free depreciation of new tangible assets used in economic activity |

#### *2.7.3.2 Feed-in-tariff*

The guaranteed price per kWh Feed-in-tariff is the most used European support scheme and is responsible for most of the renewable energy development on the continent. Many countries have however customized their own arrangement with a limited number of years for the feed-in-tariff [35]. Feed-in-tariff can be problematic for new renewable energy sources experiencing high cost reduction since this might lead to that the tariffs are set unnecessary high. This could have several effects like windfall profits, investment booms and loss of credibility for politicians when they have to cut the tariff prices. This has been seen with the sudden drop in solar power prices and may lead to uncertainty among investors since they are dependent on a certain clear long term policy without unplanned changes. In fact a long term predictable support scheme is what most companies and investors are requiring according to the company survey and interview study carried out in this thesis and presented in chapter 6.

#### *2.7.3.3 Green certificates*

Green certificates or renewable energy certificates are used to stimulate the development of renewable energy providing tradable certificates to qualified renewable energy producers per MWh generated electricity [35]. A demand is created by forcing electricity sellers and users to hold a quota of certificates each year, which they acquire by buying the certificates from the renewable energy producers. Electricity suppliers often pass on the price of the certificates to the end consumers, which means that all the electricity consumers pay for the expansion of renewable energy [36].

The green certificates have however been questioned since they supply more uncertainty when it comes to investment plans. With the certificate market and the electricity market, investors now have two highly fluctuation markets that are directly connected to the profits of renewable projects [35]. Other concerns have also been raised since this system favours the most profitable renewable energy source at time, and therefore doesn't promote diversification of the energy system [35].

#### *2.7.3.4 Tendering*

The tendering support scheme, also called competitive bidding, is a fixed quantity system where regulators appoint specific areas for renewable energy development. Thereafter companies are invited to bid on the project, where the companies that can supply electricity at the lowest cost gets the project [37]

## 2.8 Existing and planned projects for floating wind power

The projects listed in Table 4 are identified as operational or planned for deployment in the near future (2017) and are of either Spar, Semi-Submersible or TLP type. These boundaries have been set according to the scope of the thesis, to investigate the three technologies. Many other projects do however exists.

The probability of realization is likely to differ a lot between the projects but is difficult to estimate. However, as both the Spar and Semi-submersible types have full scale operational plants gives these two technologies a somewhat higher maturity level than the TLP [8].

The table shows that the Semi-submersible type accounts for the largest share of the global market of floating wind power. At present, however, both the Spar and the Semi-sub have two full scale demos in operation. Both concepts also have further plans on realization of a second phase. The future for the TLP is therefore somewhat more uncertain as the larger projects most likely will be put on hold before a full scale prototype has been deployed.

*Table 4. List of projects worldwide, either installed or under development and divided into the different concepts [21, 1].*

| SPAR | **Location** | **Size (MW)** | **Deployment year** |
|---|---|---|---|
| **HYWIND PHASE 1** | Norway | 2.3 | 2009 |
| **HYWIND PHASE 2 SCOTLAND [3]** | Scotland | 30 | 2016 |
| **KABASHIMA ISLAND** | Japan | 2 | 2013 |
| **EOLIA RENOVABLES DE INVERSIONES** | Spain | 5 | N/A |
| **FUKUSHIMA OFFSHORE WIND (2)** | Japan | 7 | 2014-2015 |
| **SWAY** | Norway | 2.6 | N/A |
| **SWAY** | Norway | 10 | N/A |
| **HYWIND PHASE 2 MAINE** | USA | 12 | On hold |
| | | | |
| TOTAL | | **70.9** | |
| | | | |
| SEMI-SUBMERSIBLE | **Location** | **Size(MW)** | **Deployment year** |
| **POSEIDON FLOATING POWER** | Denmark | 6 | 2014 |
| **HIPR WIND** | Europe | 1.5 | N/A |
| **WINDFLO** | France | 2.5 | 2016 |
| **VERTIMED** | France | 25 | 2016 |
| **FUKUSHIMA OFFSHORE WIND (1)** | Japan | 2 | 2013 |
| **FUKUSHIMA OFFSHORE WIND (2)** | Japan | 7 | 2014-2015 |
| **HITACHI ZOSEN** | Japan | 7.5 | 2016 |

| | | | |
|---|---|---|---|
| **TRIFLOATER** | Netherlands | 5 | N/A |
| **WINDFLOAT** | Portugal | 2 | 2011 |
| **WINDFLOAT PHASE 2 PORTUGAL [38]** | Portugal | 25 | 2016 |
| **EOLIA RENOVABLES DE INVERSIONES** | Spain | 5 | N/A |
| **FLOATGEN** | Spain | 5 | 2015 |
| **WINDFLOAT PACIFIC [39]** | USA | 30 | N/A |
| **DEEPCWIND** | USA | 12 | 2016 |
| | | | |
| TOTAL | | **135.5** | |
| | | | |
| TENSION LEG PLATFORM | **Location** | **Size(MW)** | **Deployment year** |
| **BLUE H TLP** | Netherlands | 5 | 2016 |
| **PELASTAR TLP** | USA | 6 | 2016 |
| **FLOTTEK** | Spain | 2 | N/A |
| **EOLIA RENOVABLES DE INVERSIONES** | Spain | 5 | N/A |
| **GICON TLP** | Germany | 2 | 2014 |
| **FLOATING HALIADE** | France | 6 | N/A |
| **MITSUI ZOSEN** | Japan | 5 | N/A |
| | | | |
| TOTAL | | **31** | |

## 2.9 Norway's potential

During the last 5 to 10 years, various Norwegian companies have made themselves known in the international offshore wind power industry [40]. Today, about 300 Norwegian companies have offshore wind activities, or target the offshore wind market with some or all of their products or services [41]. As of 2012, Norwegian companies had been involved in over 30 different technology concepts in the development of 64 wind power projects, in 9 countries. [40] Today there are several large industry clusters and interests groups participating to develop Norwegian expertise in the offshore wind industry. Two of these are ARENA Now in Bergen and Windcluster Mid-Norway in Trondheim. [41]

Norway could, in the short to medium term, attempt to enter the offshore wind business as a manufacturer of components. However, without a major home market, this would in practice be very difficult to achieve for a broad range of components and keeping a focus on specific supply chain areas might offer Norway the best chances for success [18]. According to Douglas-Westwood, an energy business advisory firm, Norway should, based on their heritage and current supply chain position, focus on the "next-generation" technology for deep water and floating wind turbines. For an internal market, Norway should be able to handle most of the supply chain over time with good knowledge within foundations, electrical infrastructure, installation, planning and development [18]. An exception is the wind turbines itself which would likely be imported from foreign suppliers.

### 2.9.1 Foundations

Manufacturing of foundations could be of particular interest to Norway due to its well-developed port structure and technical expertise in offshore concrete and steelwork fabrication. This includes both the constructions of bottom mounted foundations and floating foundations. Although, it might be the potential growth of the floating foundations which offers some of the best opportunities to utilize Norway's expertise in fabrication of offshore structures due to the challenges that will need to be overcome in both design, build and installation. [18] And with Norway's proximity to Denmark, UK and Germany as well as its open sea access would allow it to transport structures to sites. [18] However, in the long term, it will likely be cheaper for each country to build the foundations locally at or close to a port using their own employees. Especially if they have lower labour costs than e.g. Norway.

However, even though Norway has a long heritage and expertise of working with floating structures and concrete, the market for exporting floating foundations might be somewhat limited beyond that. The huge constructions and long distances makes it unlikely that there would be possible to export floating foundations to either US or Japan from both a technical and an economic point of view [13]. The foundations cost being heavily connected to the cost of labour, makes it difficult to compete with various other markets with lower labour expenses. There could also be a difficulty to protect the patent of e.g. foundation technologies in the Japanese market [13]. Although the UK might still remain as a good potential market for exporting floating foundations, the prime focus could instead be on exporting the technical knowledge and expertise on how to build these structures at where they are needed. [13] [42] This in turn could lead to additional cost reductions, making it more attractive for additional developers and markets and thus increase the potential for an export of Norwegian supply chain.

### 2.9.2 Shipbuilding

With the offshore industry, shipbuilding expertise has grown over the years and is seen as a key Norwegian strength [18]. It might, however, be the high specification vessels that will remain as the most competitive and high end vessels should remain more resilient in competing for contracts, partly due to a global oversupply of standard vessels in the near future. [18] Yards within Norway have a great reputation for these specialized vessels and have a long track record of fabricating units capable of working in harsh condition, e.g. in the North Sea. These are seen as one of the most challenging offshore environments which indicate that Norwegian vessels are capable of providing global operations. [18]

The Norwegian shipbuilding industry has been dominated by a handful reputable players, where the four largest actors STX Europe, Kleven Verft AS, Ulstein Verft AS and Havyard produced 80% of the Norwegian vessels over the 10 years up to 2010 [18]. STX Europe and Ulstein are regarded as leading shipbuilders and compete globally given their reputation, track record and built quality. The Norwegian vessels are considered to be of the highest standard by the operator community and the customers are often prepared to pay a higher price for them. Key customers have stated that they have had various problems with vessels from Brazilian and Asian yards. [18]

Given Norway's expertise and trust of shipbuilding, particularly for specialized vessels, this sector has a great potential within the offshore wind industry given the considerable number of turbines, foundations and cable installation vessels that will be required by the industry. There is a substantial potential for the development of new more cost-effective designs [18] e.g. specialized vessel innovations for installation of floating foundations and mooring systems. As these are currently great challenges for the floating concepts they could greatly benefit from solutions to reduce the risks and uncertain cost connected to them. Managing this, the shipbuilding in Norway could have great potential on the global market.

### 2.9.3 Cables

Norwegian capabilities and competence related to offshore substations, inter-array and export cables are also significant. Offshore wind leaders in cable design, manufacturing and installation, e.g. Nexans, Draka and Parker are located in Norway. Based on Norway's track record in delivering subsea cables, interconnectors and electrification of offshore oil and gas (O&G) facilities, experienced engineering companies are now building dedicated offshore wind teams. [41] Due to the insufficient capacity to manufacture required cables for the planned offshore wind parks, these companies should have considerable opportunities in the future.

## 2.10 SWOT- analysis of floating wind concepts

Out of previous analysis of the floating wind technologies, the international market and Norway's potential, a SWOT-analysis has been setup for each of the studied concepts. A SWOT- analysis comprise the Strengths, Weaknesses, Opportunities and Threats identified among the concepts and are those that are specific for each of the different foundations relative to each other. This means that each of the concepts studied may have several strengths and opportunities towards external parameters, for example bottom fixed turbines, but in this analysis only the internal weaknesses and advantages towards each other, are considered.

### 2.10.1 Semi- submersible

The main advantages with the semi-submersible structure are the relatively low site dependency and movability which makes the opportunity great for deployment in most coastal countries around the world. Furthermore most floating wind power projects under development are of semi-sub type which further boosts the concepts market potential. Since some of the most significant technological and economic risks associated with floating offshore wind are the ones connected to the installation phase, one of the key advantages with the semi-submersible type is the relatively easy tow out and installation process which eliminate the need for expensive special purpose vessels.

Some negative aspects with the semi-sub is the high cost due to the large structure. Mass production of the concept could however reduce this cost. The large potential market mentioned for the semi-sub could also be a threat since it will also most likely mean a higher degree of competition.

Deploying the semi-sub in Norwegian waters could have several disadvantages. One of them is the structures relative high wave sensitivity matched with the rather harsh offshore conditions along the Norwegian coast. Another disadvantage is the lack of Norwegian full scale testing of a semi-sub concept.

All these characteristics for the semi-submersible concept are summarised in Figure 19.


*Figure 19. SWOT analysis of the Semi-submersible floating wind turbine concept*

### 2.10.2 Spar

The spar is the only Norwegian full scale tested concept of the three offshore floating wind turbine types which gives it a potential to use the knowledge and lessons learned from the Hywind turbine. The excellent testing and results of the Hywind concept could also make it easier promoted abroad and would therefore give Norway an opportunity to quickly acquire market penetration. Other strengths with the technology is the very simple and stable structure which would make standardised mass production relative easy.

Many of the negative aspects with the Spar concept originates from its large draft, which would greatly reduce possible locations for deployment and make onshore assembly difficult without the development of new types of special purpose vessels. This could also make the spar solution compete with bottom fixed offshore wind for special purpose installations vessels. Since these vessels are limited and very weather dependent, it could result in bottle necks with large scale development.

All these characteristics for the Spar concept are summarised in Figure 20.


*Figure 20. SWOT-analysis of the Spar buoy floating wind turbine concept.*

### 2.10.3 Tension Leg Platform

The main advantage with the TLP design is the low expected cost due to the low material consumption. The concept is also very stable and therefore has a low wave sensitivity when erected. The lack of full scale testing leaves a window of opportunity for the first mover, but also requires a larger risk. Another advantage is the low seabed footprint due to the vertical mooring lines.

One of the main disadvantage with the TLP is the lack of full scale testing, which gives the concept the lowest technology readiness level (TRL) of the three floating designs. The low TRL means that a large scale wind power plant of this type is further away and the risk is therefore more uncertain.

Another disadvantage with the concept is the complex anchoring system which is also requires a rather complex installation process. Due to the vertically taut mooring lines there is a risk of capsizing if there is a failure in one. The instability without the taut lines also implies that the structure can only be assembled offshore with the need of a special purpose vessel.

All these characteristics for the TLP concept are summarised in Figure 21.


*Figure 21. SWOT-analysis of the TLP floating wind turbine concept*

### 2.10.4 Summary of SWOT for floating concepts

There are many factors influencing the choice of a floating foundation for a Norwegian test park. All the concepts have their corresponding advantages and disadvantages. The Semi-sub is a great choice if a moveable structure is wanted with little installation risk and most potential deployment sites.

The experience drawn from Hywind is great and a large amount of Norwegian funds have already been invested in the project. The Spar type also suits Norway well with its deep fjords that could act as sheltered assembly sites. The already achieved public recognition for Hywind could be further used to penetrate international markets.

The TLP design has great cost potential, but with the lack of full scale testing, both the costs and the risks are still somewhat unknown. However with a suitable installation vessel, the concept holds great potential for the future, but due to the high bottom soil dependency, areas for deployment are limited.

The SWOT analysis should be viewed complementary when studying different potential areas for floating offshore wind in Norway to choose the most suitable concept for each location. One alternative is to deploy all the different designs in one Norwegian test park to be able to match all the concepts and their performance against each other under the same environmental conditions.

## 2.11 Challenges to overcome

The offshore wind industry in Norway are faced with some great challenges in its way towards a high penetration of the energy market, shown in Figure 22. However, some of these challenges do not only apply for Norway but the entire offshore wind industry in general.


*Figure 22. Offshore wind challenges [43]*

### 2.11.1 Low incentives for a new Norwegian industry

Scandinavia is heading towards a large power oversupply towards 2020 due to low demand growth rate and increase in wind power, CHP and hydro. [44, 45] 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. [44] The expected oversupply may also be limited by further electrification of the transportation and O&G sectors as well as an increase in energy intensive industry, attracted by low electricity prices [44].

With the current high oil prices and low unemployment rate in Norway the incentives are for the time being low to invest in offshore wind [44]. This in combination with the mentioned oversupply is providing a reasonable argument to not develop offshore wind in Norway. As the oversupply is uncertain and since the oil demand is steadily decreasing there are however long term incentives to engage in this sector, to secure a future continued growth of the Norwegian economy.

### 2.11.2 Costs of energy

The high cost of energy is the main challenge for the offshore wind industry especially for the floating concepts. As energy sources are competing on a somewhat free market, there is an urgent need for the cost of energy to be decreased in order to enhance the ability to attract capital from investors. The high cost of energy also results in a need for a strong subsidy system. As these subsidies are decided by politicians, the offshore wind energy is also experiencing a political risk that may make it harder to raise necessary capital. [46]

In floating wind power the cost of the foundation is a key element for the total investment. Very large structures are needed in order to minimize motion induced by winds and waves. While growing turbines in one way is reducing the cost per MW it requires even larger foundation structures due to the increased size and weight of the turbines. This leaves an opportunity for cost reduction for the structure. If larger motions could be tolerated, the size of the structure could be reduced leading to lower investment costs [47].

Another cost driver for conventional offshore wind has been the installation process. Studies show that as much as 20 percent of the total investment is linked to the installation of the turbines. These costs are predicted to be lower for floating offshore wind, but still accounts for a considerable part of the total investment. [8]

The electricity price in Norway is an important factor when evaluating the profitability of a wind power project, and the price level has not been this low in 7 years [48]. Since the electricity price is directly linked to the revenues of an offshore wind power project, this contribute to a major investment risk. The current low price is also a direct obstacle preventing projects to be realized as feasibility studies might consider the current electricity price for the total life span of the project. A way to come around this uncertainty and risk could be to offer suitable long term governmental support as is seen in Denmark [18]. This would provide a more predictable financial outcome of the project, and thereby more easily attract investors as the risks are lowered.

### 2.11.3 Intermittent power production

Just as several other renewable energy sources, offshore wind power experience the challenges with an intermittent power production. This means that due to the variability of the wind, the power plant will have a changing power output. With the rapid increase of renewable energy throughout Europe there is a need to establish new ways to maintain a secure power supply, especially when considering larger units such as offshore wind power plants that can account for a major part of the energy supply to local areas. By using transmission technologies as HVDC cables to connect different geographical areas these problems can be minimized, but may however require expensive grid upgrades [49]. Offshore wind power development can trigger the construction of an offshore super grid where the export cables, which are needed for each park, can act as parts of a larger transmission network connecting different countries and electricity markets [46].

Another alternative is using large scale energy storage systems. However, storage solutions for this type of application is today very limited and not cost competitive [49].

The intermittency issues are lower for countries like Norway that has extensive hydro power resources to stabilize the system and Norway therefore has a great potential to large scale offshore wind.

### 2.11.4 Safety and risks

Safe operation and installation is a key issue for the offshore wind industry. The often harsh environment in these areas tend to increase safety risks and financial risks [46]. The offshore remote locations implies that accidents that may happen is harder to fix as help is located further away. This also contributes to a higher economical risk. The economic risk for floating projects is high due to many factors that involves high cost uncertainties. One of them is the installations process of which often large and special purpose vessels are required. These are extremely expensive to lease and due to a very unpredictable weather offshore, the vessels may be leased a considerably longer time than needed for the installation of the actual turbines. The installation process is a major issue for both the floating concepts and the bottom fixed. However, some of the concepts of floating wind, for example the semi-submersible, have focused on reducing the risk of the installation process. By full scale assembly onshore, the complete structure with the assembled turbine can be towed out to its offshore location only requiring a simple tug boat. Even though this would eliminate a lot of the risks, there is still a high complexity and risk with the installation of the mooring system [13].

The safety issues have however been addressed by the offshore O&G industry for a long time [46] and the wind industry should therefore benefit of not being the pioneer of solving these problems. One of the key issues concerning the offshore industry is complacency for experienced service workers. The monotonies actions might cause the workers to take shortcuts to save time and thereby fail to follow the right procedures which can result in accidents. It is likely that this issue will be larger for wind projects than for oil as there might be hundreds of similar machines to serve and maintain [46].

### 2.11.5 Supply chain bottlenecks

Offshore wind industry are subject to several bottlenecks within the supply chain especially since the industry is expected to grow significantly in the coming years. Supply chain concerns involves copper for electrical components, rare earth minerals for permanents magnets, large casting and forging, high powered semiconductors, high modulus carbon fibre. Since these components are needed within other industries as well, the capital cost for offshore wind might increase due to competition. [46] Moreover, a rapid expansion of offshore wind power could require substantial national grid upgrades. Although heavy upgrades and reinvestments are already planned to maintain a sufficient operational reliability [50], the combined expansion of wind power and national grid could be a problem.

The industry will also need a much larger fleet of installation vessels to meet the growing demand of the offshore wind industry. While more of these vessels are being built now, they are not capable of handling the increasing demand of offshore cable installations. This coupled with an insufficient production of submarine cables to serve the planned offshore wind parks as seen in Figure 23, have caused some concerns.

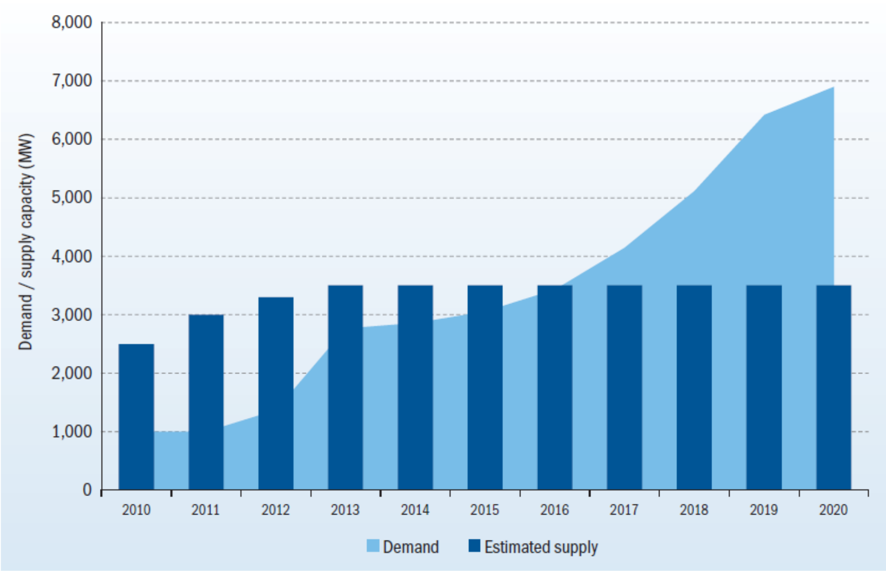


*Figure 23. Analysis of supply and demand for HV subsea cables [46].*

### 2.11.6 Immaturity of technology

Another challenge with this technology, which is a common issue for new concepts, is the immaturity of the technology. Long term simulations and testing are needed in order to achieve an ideal design. The immaturity factor also leads to a higher economic risk of projects, due to an uncertain cost prediction. Bottom fixed offshore wind has been deployed for a considerable time, and the immaturity risks and issues are therefore more likely to be addressed by floating offshore wind developers.

### 2.11.7 Increased weight dependency

As the top weight of the wind turbine is more crucial when it comes to floating wind power, there is an urgent need to reduce the weight by using lightweight materials and minimizing the number of components in the nacelle. This is important as a large part of the CAPEX is connected to the substructure of the floating turbines which is heavily dependent of the weight of the turbine above.

# 3 Possible applications for floating wind power

Floating wind power has various possible applications, both in a short term and in a long term perspective and this chapter aims to describe some of these. The development of floating turbines can in the short term be seen as an opportunity to establish a test park and as a potential way of reducing the emissions of the O&G sector by supplying a proportion of the electricity required to power the facilities. In the long term though, the goal may be for Norway to become a hub of a north European power grid and to supply renewable electricity to the continent.

## 3.1 Test Park in Norway

Developing a home market is a key point for most new industries with an ambition of future export and was seen when Norway found its oil resources on the Norwegian continental shelf in the end of the 1960s. A strong domestic market was developed and today Norwegian companies supply O&G services to industry all over the world. Building a pilot floating wind power plant in Norway could be the starting point of something similar, a new large export industry. Such a park could be the stepping stone of a national market which in turn would showcase Norway as a key player on the international offshore wind market [51]. As a result of the company survey carried out in this thesis it was recognized that 43 % of Norwegian stakeholders stated that they find it hard to enter the international market due to the competition being too great. To be able to better compete on an international market Norwegian suppliers need a home market to develop a base for their technology and prove their competence. To what extent a domestic market would be developed is very uncertain and will partly be influenced by the development of the north European power system.

Many nations are now launching domestic offshore wind markets in order to position themselves to what they recognize as a future global major industry [51]. By building a test park Norway can establish a showcase to prove that Norwegian players can successfully deploy an offshore wind project where Norwegian technology developers get the chance to test and highlight their technologies towards foreign markets. Erecting a test park in Norway is somewhat ideal due to the nations already well developed yards and harbours as well as the available experienced personnel from the oil & gas and maritime industry. This would in turn enable a very high local content of the value creation from such a project [52]. Furthermore Norway has some of the world's best wind resources which would result in high production and capacity factor of the project giving further boost to the reputation of involved Norwegian stakeholders.

A test park in Norway could be the base of other applications for floating wind power, since the turbines used could be moved and tested in different energy systems. The mooring lines could be detached and moving the turbine to an oil rig would be possible in order to evaluate such an application.

The Hywind project has been up and running since 2009 and provided a lot of valuable knowledge for Statoil and other involved stakeholders. This information could be used when planning and developing a test park in Norway. A test park in Norway could however have several different layouts and would not necessary be focused on one specific floating turbine concept.

## 3.2 Electrification of oil & gas activities with floating wind power

Power supply to O&G platforms is conventionally provided by gas turbines positioned on the platforms but alternative solutions are being studied as the gas turbines have low efficiency ratios and are both expensive to operate and emit substantial quantities of $CO_2$ and $NO_x$ [53]. The focus so far has been on the alternative to supply power with a cable from land which have already been implemented for several platforms. However, both bottom mounted and floating wind power in direct connection to the oil platforms, either complementary to the onshore cables or as a stand-alone system might also be a future solution.

### 3.2.1 Wind powered oil & gas platforms

Both bottom mounted and floating wind power could be connected to the oil platforms directly, thus enabling renewable electric power instantly to the platform. The oil platforms are customarily located far out at sea in areas where vast wind resources can be harnessed, enabling the potential of a high power production and capacity factor. The size of the wind power plant and operational strategy needs to be carefully selected for securing technically stable and economic operations as the O&G companies only accept little or no production loss. The intermittent power production from wind power thus cause concerns that wind power alone will not be able to supply the platform at all times. For platforms which already have gas turbines or are connected to a cable from shore there is the possibility to run these parallel to the wind power. One example of this, is the "Beatrice wind farm" project where two 5 MW bottom fixed turbines was built at a depth of 40 m and connected to a nearby oil rig, providing about 30% of its total energy demand. The remaining power was supplied from the national grid. [54] Studies have shown that local wind power production matching the offshore power demand will improve both voltage and frequency stability when in parallel operation with a cable from shore. Moreover, it is indicated that offshore reactive power injections or alternative wind power plant control topologies could improve voltage stability offshore. [53] The study also showed that a system with wind power connected to the system was able to restore to normal operation faster after a short circuit on the main offshore AC bus, which is one of the most severe events the offshore grid can experience [53].

Another study made by SINTEF energy research [55] showed that a wind power plant with bottom mounted wind turbines in operation parallel with gas turbines can be an economic and environmentally sound option for supplying electricity to O&G platforms. In this study, logistic simulations show that the wind turbines result in significant fuel and emission reductions, particularly when allowing for start/stop of gas turbines. [55] One of the greatest challenges is to find a good operation strategy that balances the number of start and stops of the gas turbines against dissipating energy and fuel savings. In time, this should also become an increasingly realistic solution for floating wind turbines when the technology has matured. This could be especially useful for platforms located far from shore or on too deep waters, where bottom mounted wind turbines and mainland electrification might be too expensive or too complex to implement.

To have wind power supplying the platforms with energy by themselves is currently not a feasible solution due to the intermittent power production. This would require a significant higher nominal power capacity than the required power of the oil platform to reduce the risk of energy shortage. How much higher depends on the wind characteristics of the site and the specific requirements of the oil platform. However, a nominal power higher than the need of the platform means that there occasionally will be an overproduction and the power output must be reduced, e.g. by pitching the blades, resulting in dissipated wind energy. This would be necessary unless some form of energy storage is introduced. From a technology aspect, it would be possible to support an oil platform with merely wind power together with an energy storage, although this energy storage would have to be significant to secure the supply of energy to the platforms [56]. Even though a large number of methods for storing energy exists today, few of them are considered economic and technically feasible. Even with an extensive expansion in R&D development lately, batteries are still considered too expensive to use for large scale storage. Many other types of energy storage are under development, where different types of pumped hydro storage might come to play an important role in the years to come. The Subhydro concept seen in Figure 24 is one of the alternatives, using one or several large hollow concrete spheres on the bottom of the ocean as an underwater pumped hydro power plant. This concept uses the excess electricity from e.g. wind power to empty the spheres of water. During an energy demand, the valves are opened, allowing the surrounding water back into the spheres through turbines, using the extreme pressure at the bottom of the ocean they claim to achieve a total energy efficiency of about 80 %. [57] There are several similar concepts, but all would require both large investments and R&D before applicable in the offshore industry.

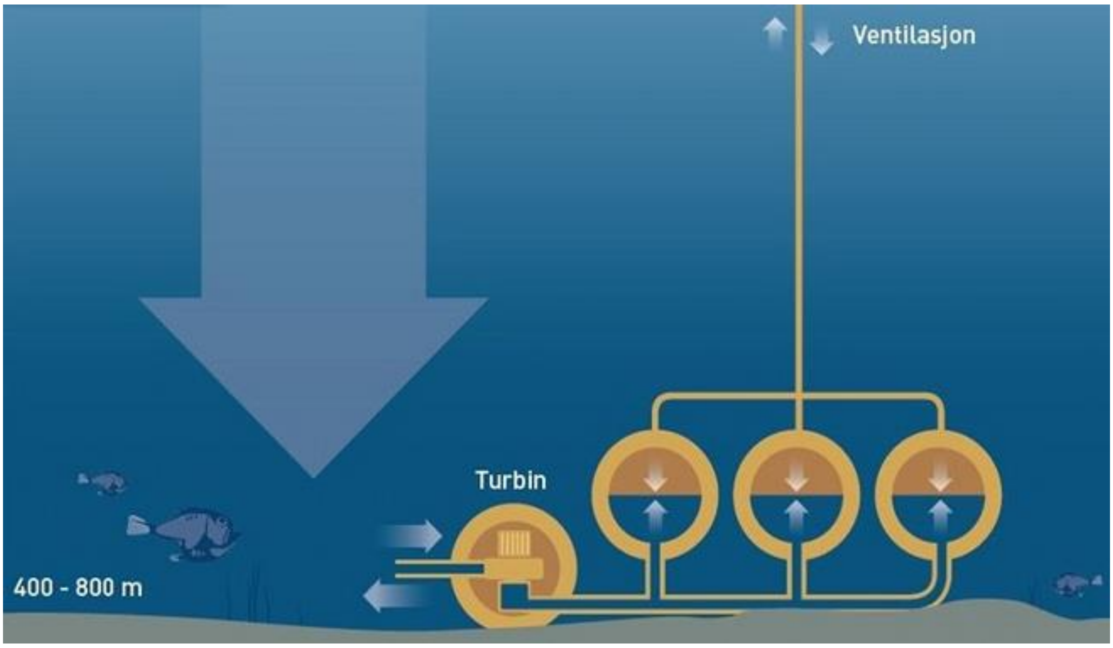


*Figure 24. The Subhydro energy storage concept, where seawater is released through a turbine during energy demand and the water pumped out during excess of energy. [57]*

Another efficient possibility could be to use a combination of the solutions for a cluster of O&G platforms within reasonable distance from each other [56]. The clusters would have a wind power plant connected to them, using the vast wind resources offshore to produce a large part of the power demand. During low demand of energy, the wind turbines could instead deliver the power to the energy storage alternatively to shore via a HV cable when the storage is full. Together with the cable to shore, a backup gas turbine could be installed at one of the platforms to regulate the flow and further secure the power demand of the cluster.

The solution for clusters or stand-alone platforms would have their own optimized solution based on their specific conditions, locations and opportunities. However, even with the benefits of connecting wind power to the O&G platforms shown in the mentioned studies, it might be unlikely to think that the O&G companies will implement this on their own initiative unless the government demands an electrification of the O&G industries. [56]

### 3.2.2 Power for water injection pumps

O&G are commonly brought to the surface by the natural pressure within the field but as additional oil is extracted, the pressure in the reservoirs falls, resulting in a declining production over time. Water injection is a method used in the oil industry to prevent this using pumps to inject water into the reservoirs, increasing the pressure of the field and pushing the remaining oil towards the well to increases the amount of oil which can be extracted, also known as the recovery factor. Moreover, there is today a regulatory demand on the Norwegian continental shelf (NCS) for zero discharges to sea when it comes to both drilling cuts and produced water. The petroleum production facilities therefore have re-injection or injection of this produced water back into the well, thereby solving both issues of storage and enhanced recovery [58]. The conventional method for this has been to use a water injection flow line from the platform to the injection well. The processes for water treatment, seawater lifting, feed pumps, injection pumps and other necessary systems are powered by gas turbines on the platform. The power required for this can be substantial and can in some cases reach up to 39% of the total power consumption of a platform. [59]. The costs connected to this conventional solution is very much governed by the site specific water depth and the distances between the platform and the injection well. [58] These injection wells sometimes lies at several kilometres away from the platforms where they are powered, resulting in several disadvantages [58]:

- A long cable is required which is very expensive to procure, install, maintain and repair.
- The cable is prone to damage by human marine activity leading to loss of production.
- With increased distances between topside and well, the power required to transport the produced and treated water increases. A water-injection flowline is required.
- Depending upon the length of the cable, higher transmission voltage may be used to reduce losses. This would need extra switchgear and transformers at both ends of the cable. The cable would also become more expensive due to higher insulation requirements at higher voltage levels.
- The pumps are fed from variable speed drives located on the platform close to the power source. The operation of the pumps becomes complicated due to the risk of possible resonances in the cable as it is subjected to variable fundamental and harmonic frequencies.

An alternative to the traditional solution is to inject raw-seawater instead of processed water, if the reservoir conditions allow for it. This water is not pumped from the platform but withdrawn directly from the sea by a dedicated seawater injection subsea unit into the oil reservoir. This solution has been successfully implemented both on the NCS as well as internationally during the last years. This method, as shown in the middle of Figure 25, would not require the water flowline from the platform, but would still have to be powered from the platform.

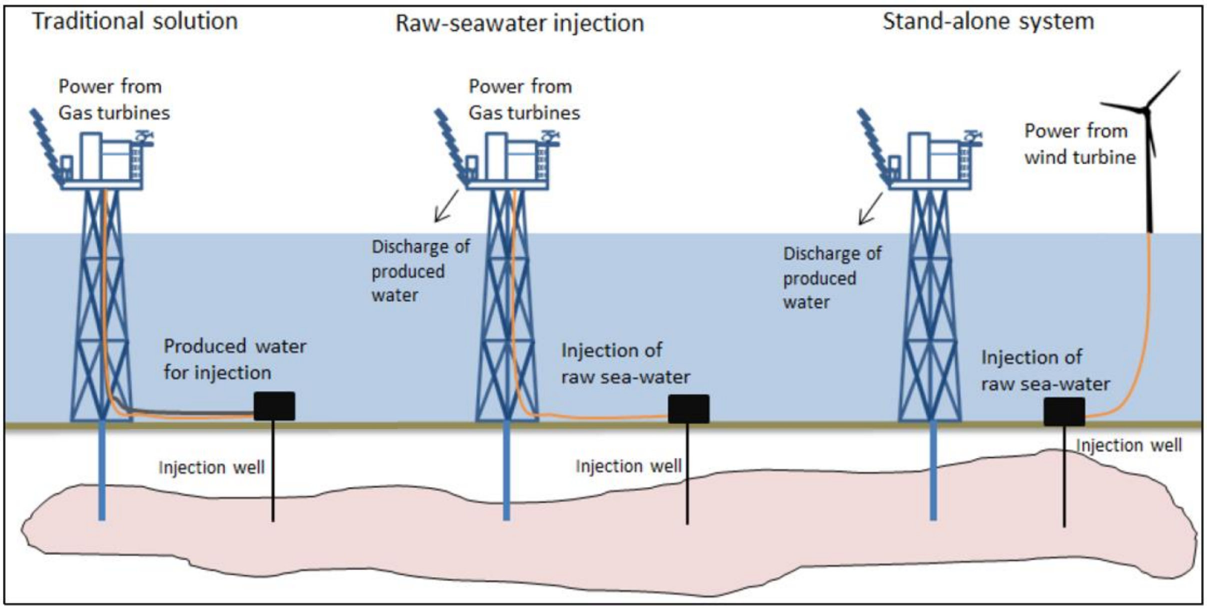


*Figure 25. Characteristics of the three concepts for water injection [58]*

One solution to avoid supplying power with gas turbines from the platform would be to use a floating wind turbine to power the water injection in a standalone system, injecting water when there is wind available. An illustration of DNV GLs vision for this is shown in Figure 26. The intermittent power production would not be an issue, as the pumps aren't required to be active continuously but could simply inject water whenever there is power available. The turbines would however be required to be assisted by a small energy storage device as the intermittent nature of the wind would occasionally cause the wind turbine to be unable to power its own auxiliary systems. [58] These systems are used for e.g. control, instrumentation and communication of the turbine. Moreover, power is required to the pump to keep it in standby position at times without enough power available. [58] But as mentioned, this is not a significant power demand and could use e.g. a battery.

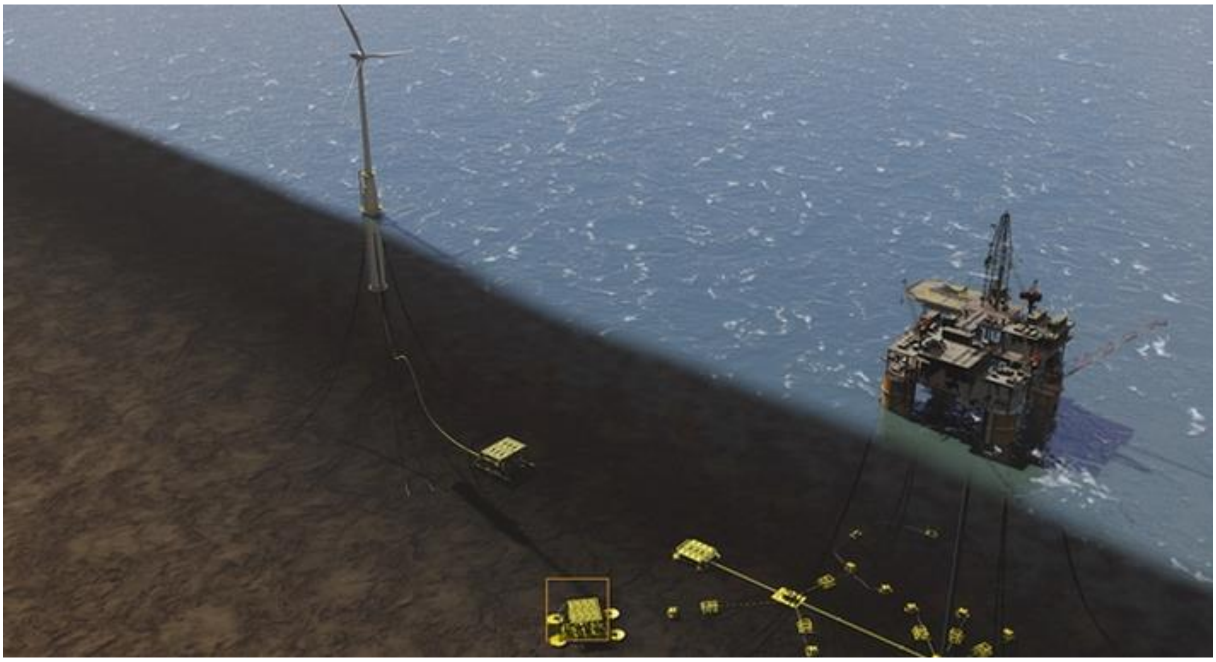

*Figure 26. An illustration of DNV GL's vision of the wind-powered injection system [60]*

This setup is considered to be applicable worldwide, where the feasibility level is dependent on elements such as regulatory aspects, reservoir characteristics, water depths and the distances from the platform to the injection well. It could be developed for both raw water injection and produced water treated on the platform. Analyses have deemed the concept to be technologically feasible and cost efficient under several circumstances where several key parameters has to be taken into account: [58]

- Step-out distance, i.e. the cost implication of the cable
- $CO_2$ tax. Costs for emissions on the NCS
- Fuel costs for running the gas turbines
- Costs for floating wind turbine system, CAPEX and OPEX.

When taking into account the step-out distance from the platform, the fuel costs associated with the operation of gas turbines and emission costs on the NCS, the solution is deemed as highly interesting for further consideration and demonstration. A study done by DNV GL [61] showed that the solution with raw-water injection using a 5MW pump together with a 6MW turbine could be cheaper than the traditional raw-water injection already at a step out distance of 20-30 km. Using the produced water solution, this could become more cost efficient than the current method independent of step out distance, as seen in Table 5. However, the injected water needs to be compatible with the reservoir rock/fluid system which require new subsea water treatment processes together with the water injection. This could include methodologies for particle filtration and sulphur removal before being able to fully replace the traditional solution and would require an additional cost segment. [58] This cost is however not quantified.

*Table 5. A cost comparison of using the wind powered stand-alone system compared to the conventional gas fired solution at different step-out distances. [58]*

| Step-out distance (km) | Total costs gas-fired solution, (MEUR) | Total cost wind-powered solution (MEUR) |
|---|---|---|
| 10 | 117.6 | 50 + Cost for treatment |
| 20 | 138.6 | 50+ Cost for treatment |
| 30 | 159.6 | 50+ Cost for treatment |
| 40 | 180.6 | 50+ Cost for treatment |
| 50 | 201.6 | 50+ Cost for treatment |

DNV GL believes that the implementation of such a system would most likely benefit both the sectors of wind power and O&G. [58] An integration of floating wind turbines with the activities within the O&G sector could demonstrate that the technology is reliable and feasible and could help bringing the technology from concept to a mature and commercially available technology. [58] As a result, this should further spur investments and thereby assist in reducing the costs further for both the floating wind sector and the O&G sector. Analyses by DNV GL have shown that there is no technical obstacles and that the commercial potential looks promising. [58] An implementation of this system for water injection could offer the O&G industry an opportunity to develop more autonomous subsea water injection systems, potentially avoiding a long power cable from the platform, reducing the need for power from e.g. the gas turbines and thereby also reducing the $CO_2$ emissions and fuel costs from the operations. Additionally, with limited space on the platform facilities, installation of conventional technologies for water injection can be constrained. An autonomous wind powered system would not require costly platform conversion. It could instead provide the offshore floating wind industry with new knowledge, bringing forward new system designs and its success would offer a new potential market through the integration with O&G operations [58]. These pumps and turbines could also be designed to be retrofittable to enable repositioning of the turbines and the pumps to another site e.g. if the field is closing down by disconnecting the mooring and pumps from the seabed.

## 3.3 Large scale floating offshore wind power plants

In a more long term perspective when overall costs for floating wind power have been compressed to a competitive level, the technology could act as a large scale power source comprising wind power plants in the GW range. Such an application would in fact be very similar to the large bottom fixed offshore wind arrays planned today, but the floating ability will unlock the utilization of deep offshore areas. Such an industry has extreme potential worldwide since the wind resources at many deep offshore areas are excellent. It also enables to place renewable energy closer to demand, since many of the world's larger cities are situated near deep water areas [61]. On the other hand large scale floating wind power plants can be placed far offshore beyond the land horizon, avoiding local resistance.

In order to deploy large offshore floating wind power plants a solid mass production setup should be used. An example of such an arrangement can be seen in Figure 27, where floating wind turbines ideally can be on-line fully assembled onshore and towed to its offshore location. Moreover, floating turbines are ideally for mass production and standardisation due to its low site dependency.

*Figure 27. Mass production solution onshore. [61]*

For Norway, the possibility of a development of large scale floating offshore wind power is closely connected to an increase in electricity demand. There are several factors that could lead to such an increase in power demand in Norway. Some of the most critical and obvious aspects are stated below. However if there would be a future rationale to develop large scale offshore floating wind power in

Norway, the potential is considerable. NVE has identified four areas for floating offshore wind in Norway with a cumulative capacity of 6 GW [62].

### 3.3.1 Reasons for large scale development in Norway

#### *3.3.1.1 Electrification of the Oil & Gas industry*

The oil companies have been pressured to power the oil fields with mainland electricity via high voltage cables from shore instead of using inefficient gas turbines on the platforms. An electrification of the oil fields could dramatically reduce the $CO_2$ and $NO_x$ emissions and thus provide significant environmental advantages to help battle climate change. For already existing fields this might be complicated from a technology point of view as well as expensive, but for new fields it is likely to be more economically viable. [63]

#### *3.3.1.2 Increased power demand for other industry*

Statoil and its partners have decided on powering the first phase of the Johan Sverdrup field at the Utsira High area, which is expected to start production in late 2019. The cable would ensure a delivery of 80 MW to this first phase. Johan Sverdrup is among the largest fields on the Norwegian shelf, and will at peak contribute with about 25% of the production of the Norwegian continental shelf. Further electrification of other O&G fields on the NCS can result in a significant increase in power demand of around 10 TWh [56].

The power oversupply that the Nordic region is heading towards will most likely cause electricity prices to drop [64]. A reduced electricity price might attract energy intensive industry in Norway [64], causing companies to invest in new production that could result in an increased power demand.

The European targets for increased energy efficiency could lead to a decrease in energy demand for households and industry. However, this process could in fact lead to an increase in electricity demand as fossil based processes are replaced with electricity based systems as heat pumps. [45]Such a scenario also involves a transition from a fossil fuel dependent transportation sector to a one relying on electric vehicles transportation.

#### *3.3.1.3 European super grid*

With renewable energy generation increasing rapidly in the north European countries and base load power as nuclear is being shutdown, the electricity generation is becoming more and more intermittent. In addition, renewable power generation is often situated far from high load centres in contrary to previous conventional power generation. A new challenge arise of how to make such a system stable and ensure energy security at all times. Therefore a so-called European super grid is being investigated, but this calls for further mega investments in addition to the already cost struggling offshore wind business [46]. A potential layout for a European super grid can be seen in Figure 28.

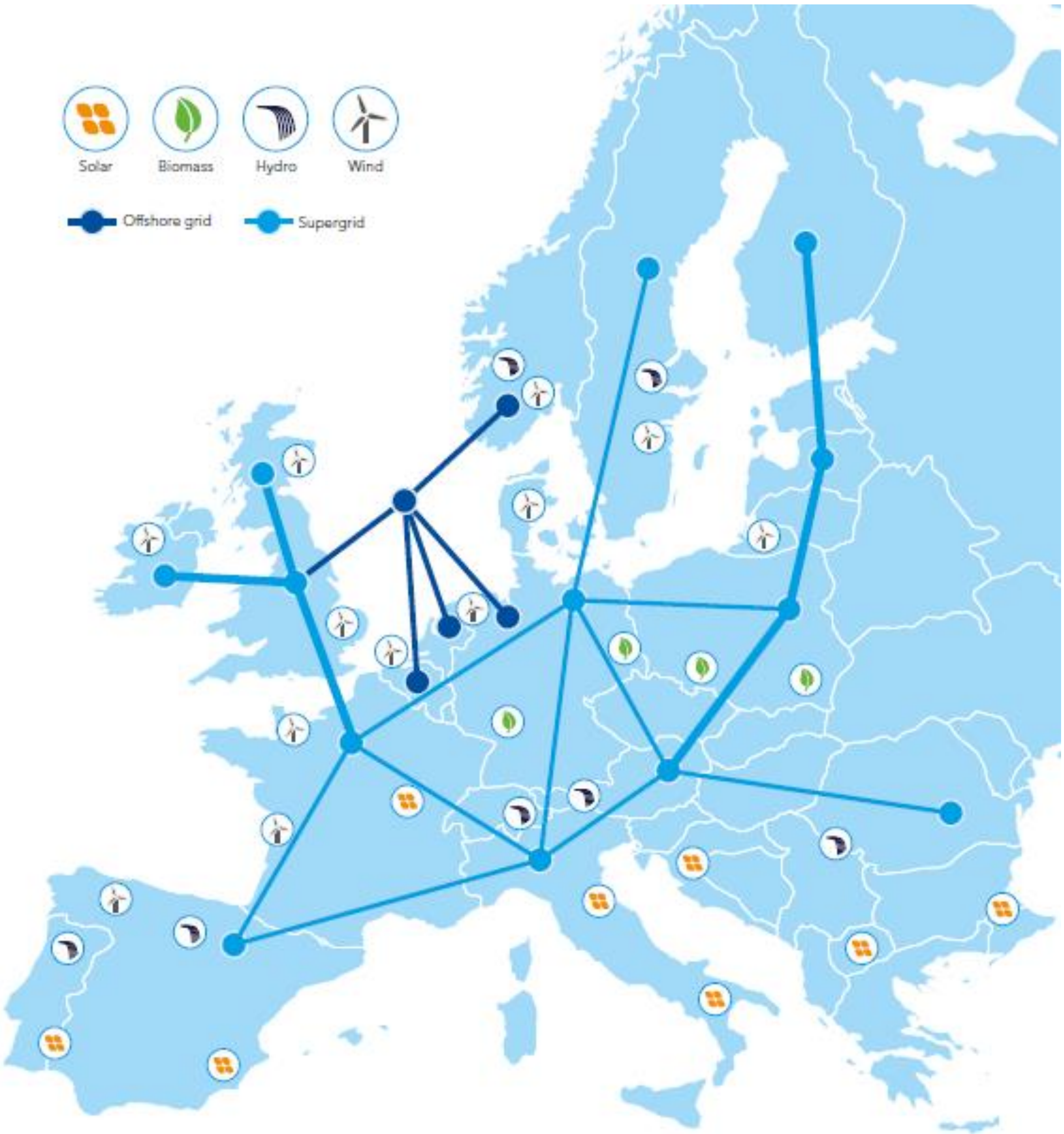


*Figure 28. A potential layout of a European super grid [61]*

The development of such a grid would however have several positive effects on the European energy system. Not only would it help balance the system and enable further development of renewables in European countries, but it could also act as a connection point for offshore wind power plants and electrification of the North Sea oil rigs. As seen in Figure 28, the super grid would connect hydro and wind power in northern Europe with solar power in the south and biomass power in the central part of Europe. This could enable a higher penetration of renewable energy within the European energy system.

For Norway such a grid solution could both benefit the electrification of the oil rigs, but also help the national offshore wind market to kick off. It will also help Norway to deal with seasonal and yearly variation of the hydropower, enabling high export potential of wet years and energy security in dry years [63].

As can be seen in Figure 29 there are currently two consented cables to Germany and the UK of 1400 MW each, planned to be built by 2018 and 2020 respectively. The importance of the realization of these projects for a national offshore wind industry is great. In fact, the company survey carried out in this thesis recognized that 84 % of the Norwegian offshore wind stakeholders believed that these cables are important or very important in order for Norway to establish a home market for offshore wind. One of the interviewed companies claimed that in this market, with the current subsidy scheme in Norway, the only way to establish a home market would be to utilize higher electricity prices and subsidy support in other countries. [56] These two new cables could be the start of a future European super grid, and provide valuable information about its feasibility. Furthermore, analysis carried out by the Norwegian central grid operator Statnett indicate that these planned new cables will by increasing the electricity trade capacity with a great and strong economic benefit as a result [63].

Previous projects as the NorNed cable seen in Figure 29 has proven to generate high revenues. The first two months of operation in 2008 the cable generated approximately 50 million euros in revenues for the owners TenneT and Statnett, covering 8 % of the total cost of the project [65]. This was high above expectations of 64 million euros in yearly revenues.

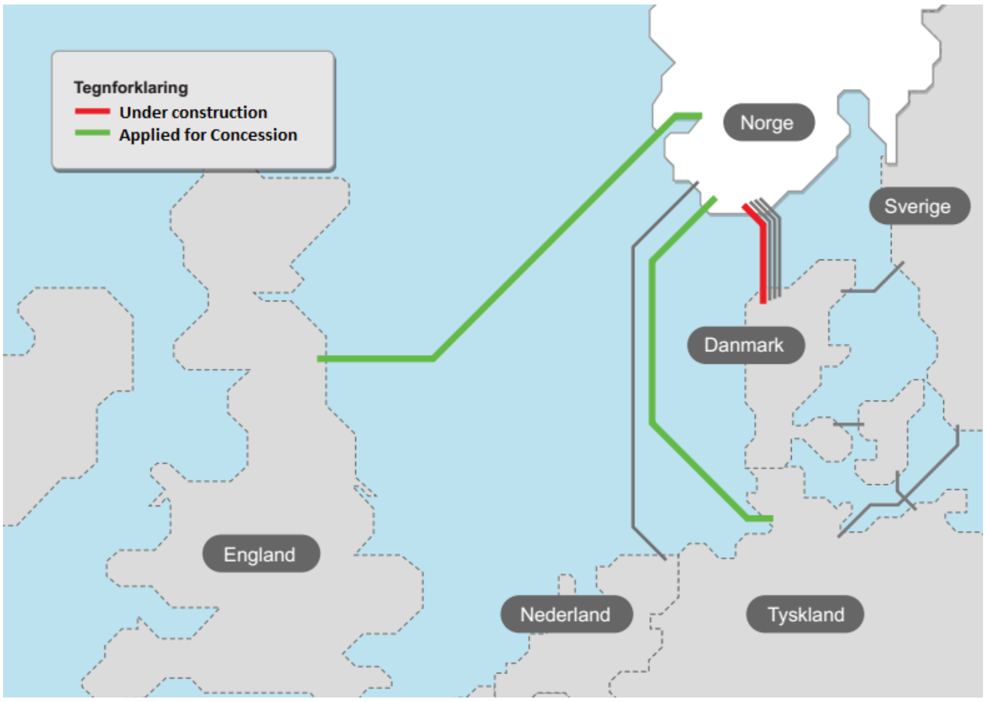


*Figure 29.Exisitng and planned cables in the Nordic region [63]*

The UK cable will have its connection points in Kvilldal at the Norwegian side and Blyth at the British side. The German cable will have its corresponding connection points in Tonstad/Ertsmyra and Wilster. The geographical position of these cables have a great match with several of the NVE offshore wind appointed locations seen in Figure 31. These areas have a very large offshore wind capacity potential with possibly 1500 MW in Utsira Nord, 1500 MW in Sörlig Nordsjö 1 and 2000 MW of Sörlig Nordsjö 2. A total of 5 GW production and in addition the extensive oil fields of Utsira high is located in proximity to the planned UK cable, making it possible to use HVDC HUB connections in order to electrify the oil rigs as well.

Building these offshore wind fields in combination with international transmission lines would enable Norwegian wind power to be sold in European electricity markets with higher prices, when there is shortage of power supply in these areas [66]. If there is high production in northern Europe including production from mentioned wind power plants, the electricity could be used for national electricity supply. Using such power supply could save valuable and easy regulated hydro power in dams of Norway which can be utilized in times of power shortage in northern Europe. Abundant power can also be used for energy storage as pumped hydro, In order to further enhance export potential in times of need [63].

The Norwegian minister of oil and energy claims that new international transmission cables are needed in order to make renewable energy in Norway more profitable [67]. This would bring economic benefit to Norway, and give further help to the EU achieving its renewable energy targets [18].

Considering a further time frame like 2050, another potential outcome is the development of a global super grid [68] where continents are connected with HVDC cables, making it possible to export electricity over several time zones. This would further eliminate the Nordic power oversupply argument as such a power system would be globalized and the Nordic hydro power and excellent wind resources would be a key factor in the arrangement.

## 3.4 Other applications

Floating turbines could be used in niche markets to supply energy for applications which is too far from mainland to connect with a cable from shore. Some of these areas are mentioned here:

### 3.4.1 Supply power to pumps to reduce deoxygenation

Deoxygenation is a global problem in coastal and open regions of the ocean which has led to expanding areas of oxygen minimum zones and coastal hypoxia. The recent expansion of hypoxia in coastal ecosystems has been primarily attributed to global warming and enhanced nutrient input from both land and atmosphere. The largest anthropogenically induced hypoxic area in the world is the Baltic Sea, where the relative importance of physical forcing versus eutrophication is still discussed. [69] Studies show that about 15 % of the bottom is already dead and that 30% suffer from critical low oxygen levels [70]. The extent of hypoxic and anoxic water in the Baltic Sea can be seen in Figure 30.

One possible solution for this is to use floating wind turbines to supply electricity for pumps to mechanically deploy oxygen-rich surface water to the dead seabed. This will help to reduce and mitigate the negative effects of anthropogenic nutrient inputs e.g. to the Baltic Sea, such as cyanobacterial blooms and oxygen depletion in the deep waters with resulting “dead bottoms”. [71] The Baltic Deepwater Oxygenation (BOX) Project, led by Gothenburg University, showed that there is reliable inshore pumping technology that works and that the ecological effects of oxygenation throughout are quite positive. The BOX-WIN project has shown that floating wind-driven pumps, based on modern off-shore technology will work in open sea. [72] The first demonstration pump is currently under development and the technology could be scaled up and down and should also be suitable for fresh water lakes or salt water fjords with similar problems around the world. [73]

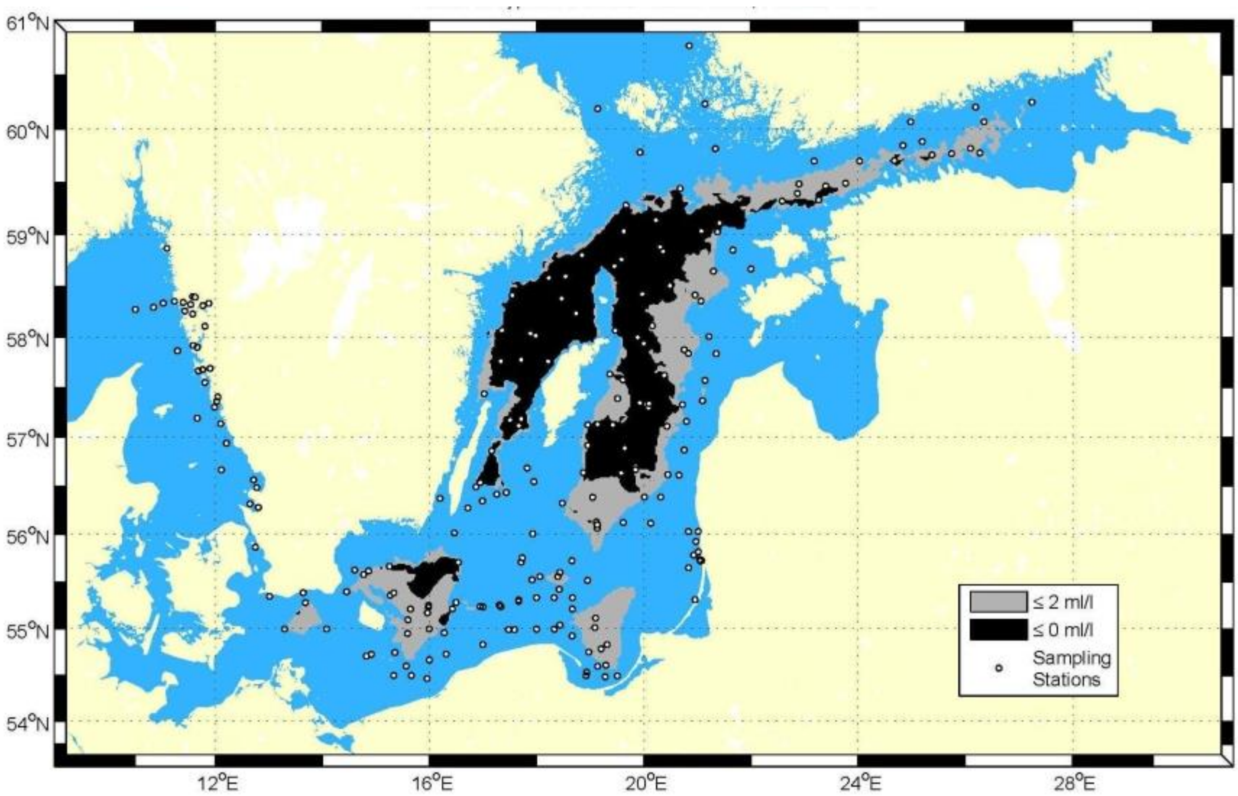


*Figure 30. Extent of hypoxic and anoxic water in the Baltic Sea. Units* given in ml $O_2$ *per litre [70]*

### 3.4.2 Supplying power for remote island societies

Further ahead in time, the floating wind power could become a feasible power supply solution for remote island societies with limited land resources, which in many ways represent an 'extreme' from a power system perspective. Remote islands may often be represented by deep waters, strong winds and high density population centres with large energy demand and low availability of natural resources and space for conventional renewable energy sources. This could make floating wind power the most feasible solution, although it would likely require innovative solutions to handle the intermittent production. Without a physical connection to other electricity grids, the imbalances experienced and the stress on the system will commonly be much more severe than for a system connected to a larger power grid. The most important enablers required are large scale energy storage, small scale fast responding energy storage used for instantaneous power balancing, advanced control of the power system and a heterogeneous generation mix of both solar driven as well as wind powered generation technologies. [58] All together, the island case should be considered not only as an interesting niche application in the future, but also as a small scale application of technologies that might later be needed for larger power systems as well to be able to cope with high renewable penetration levels [58]. What solutions which will actually be applied is however too early to say.

# 4 Case study – Utsira Nord test park

This chapter presents a case study for where and how to build a test park for floating wind power in Norway as well as calculating the estimated power production in the chosen area. Moreover, the chapter displays the associated costs together with the resulting LCOE for building this test park using different floating foundations concepts.

## 4.1 Optimal site selection

The site selection stage is an important stage when developing a wind power park and requires consideration of multiple criteria and evaluation steps to be able to choose an optimal location to both make it profitable and to minimize the obstacles to build the wind park. To truly benefit from the environmental benefits of wind power, the optimal site should have as high power production as possible while having as low impact on the local environment as possible.

To make a wind park profitable it generally requires a big enough area with high wind velocities as the power produced and thereby the profit, (in theory) increases cubically with the wind velocities and thus generally making it the most important criteria for building a wind park. The developers' choices are however restricted to those sites that are geographically available for power production and the developers are also required to follow the national legislation which constrains some areas from being used for wind power. Due to the alteration in technology and the obvious differences in area conditions, the offshore criteria varies greatly to the onshore criteria. To determine whether an area is suitable for wind energy development, all site selection and assessments procedures are bound to address the technical, economic, social and environmental aspects of the project. Such aspects include the distance from shore, grid connection, acceptable water depth, existing cables and pipelines, conflicts with the fishing industry, shipping routes, military areas and the location of O&G structures. Each of these factors place constraints on where a wind power plant can be located and ultimately impact the overall resource potential for each country. [18] Due to limited time, the location for the test park was chosen based on the suggested areas for floating wind power described in the Havvind report by Norwegian Water Resources and Energy Directorate (NVE).

### 4.1.1 Havvind report

At the governmental meeting in 2007 processing the Norwegian climate politics it was decided to establish a national strategy for electricity production from wind power offshore and other marine renewable energy sources. In connection to this, "Havenergilova" was made which would facilitate the exploitation of renewable energy sources offshore in accordance with social objectives and to make sure that facilities would be planned, built and managed with considerations to energy supply, environment, safety and other opposing interests. The ministry of petroleum and energy (OED) gave the task to NVE to establish which locations that should be part of a strategic impact assessment, which resulted in the report "Havvind - forslag til utredningsområder". The report locate 15 areas suitable for offshore wind power, shown in Figure 31, which of four were dedicated to floating wind power. The four locations, Utsira Nord, Stadthavet, Fröyabanken and Træna vest, were chosen by the authors of this report for further analysis to decide which of these locations that would be most suitable for a test facility with floating wind power [74].

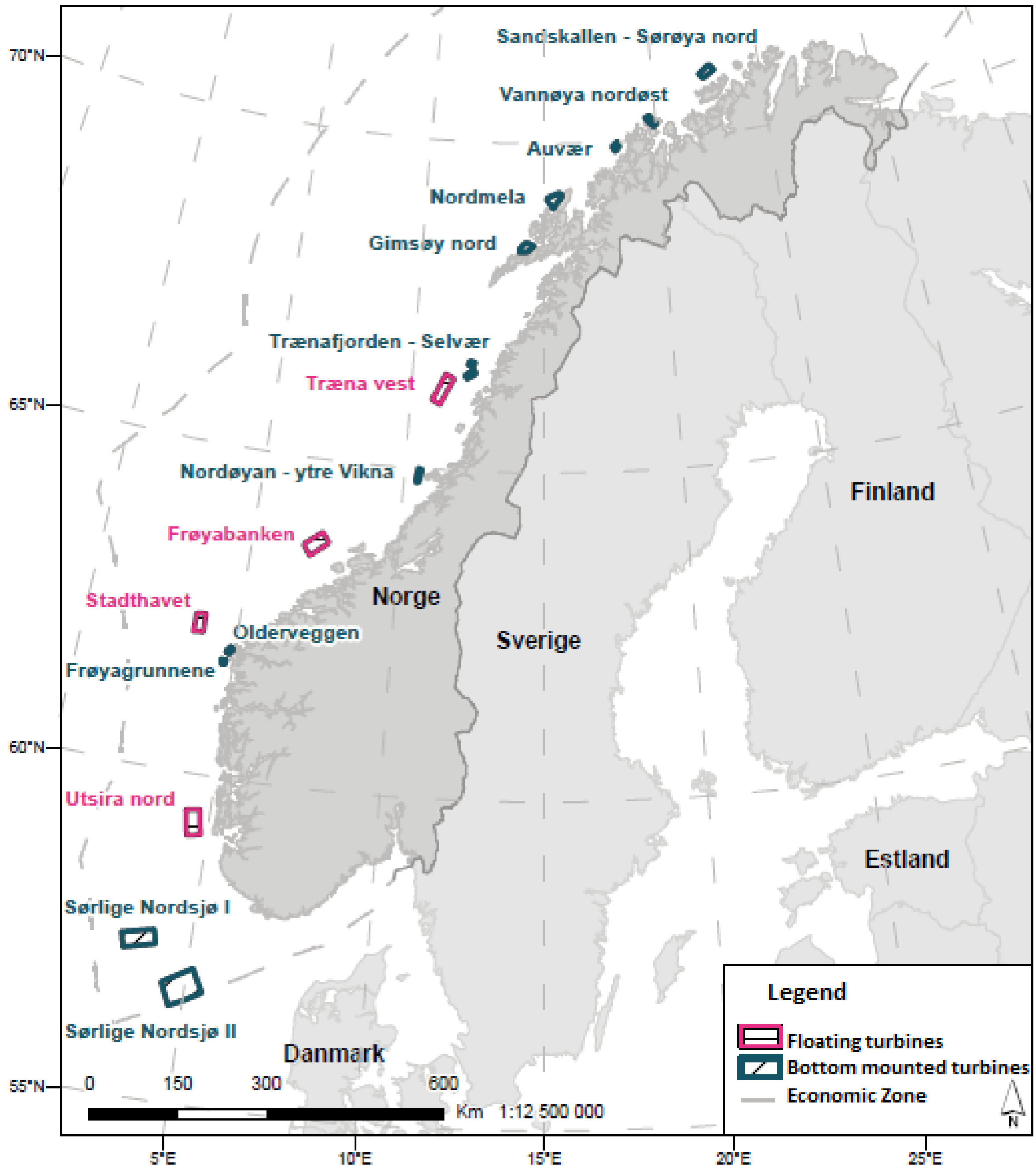


*Figure 31. Locations suitable for offshore wind power suggested by the Norwegian Water Resources and Energy Directorate, NVE.*

These areas were considered as feasible locations as they fulfilled various condition criteria of different aspects:

- Technical and economical properties e.g. depth and distance to grid connection points
- Environmental interests, e.g. protected areas, particular valuable areas for birds and fish etc.
- Other opposing areal interests e.g. maritime, fishing industry and oil interests.

To select the most suitable area for the floating test park, various key attributes, shown in Table 6, was collected which made it possible to analyse the areas separately as well as compare them to each other to make a first phase selection.

*Table 6. Key attribute values for the four locations suggested as suitable for floating wind power by NVE [75].*

| Key attribute values | Utsira Nord | Stadthavet | Frøyabanken | Træna vest |
|---|---|---|---|---|
| **Possible Capacity (MW):** | 500-1500 | 500-1500 | 500-1500 | 500-1500 |
| **Total area (km$^2$):** | 1010 | 520 | 819 | 773 |
| **Depth (m):** | 185-280 | 168-264 | 160-314 | 181-352 |
| **Average depth (m):** | 267 | 208 | 210 | 271 |
| **Average wind speed (m/s):** | 9.8 | 10.5 | 9.2 | 9.5 |
| **Shortest distance to the coast (km):** | 22 | 58 | 34 | 45 |
| **Shortest distance to build site (km):** | 22 | 58 | 30 | 24 |
| **Average significant wave height (m):** | 2.2 | 2.8 | 2.5 | 2.4 |
| **Highest significant 50-year wave height (m):** | 12.8 | 14.7 | 15.1 | 14.9 |
| **Shortest distance to transformer station (km):** | 45 | 115 | 83 | 134 |

### 4.1.2 Utsira Nord

From the key attribute values most aspects pointed towards Utsira Nord to be considered as the most feasible location for a test park. Compared to the other locations, the Utsira site has a significant shorter distance to the coast and transformer station. This would reduce the cost of the cable from the substation to shore as well as reducing the cost and time spent for installation and O&M which should be considered as an advantage for a test park. The wind resources are vast and the wave conditions are the most viable, reducing the forces on the turbines and mooring lines as well as making it easier for both the installation and O&M vessels and personnel to access the turbines.

As the potential impact on third parties and opposing interests are of critical importance, it is essential to include all the affected/involved parties early in the process of choosing location and magnitude of the park. Studies made by NVE showed that Utsira Nord had low impact on opposing interest such as fishing, maritime, O&G interest, birdlife and other aspects compared to Stadthavet, Frøyabanken and Træna vest [75]. Furthermore, the following aspects contributed to the choice of Utsira as the most feasibly site for a test park:

- Statnett has stated that an installation of up to 500 MW at Utsira Nord should be able to be connected to the grid without any significant challenges. Moreover, Statnett concluded that all other locations for floating wind suggested in NVE's report will have major problems connecting to the grid before 2030 and that major investments would be required in order to do this. [76]

- Utsira Nord is located close to areas with a high energy demand as it is close to both Stavanger, Haugesund and Karmøy with a high energy intensive industry where Hydro's aluminium production facility alone consumes 2.6 TWh annually [77]. Hydro also have plans on expanding their production with the world's most energy efficient aluminium plant. The pilot facility could produce 70,000 tonnes of aluminium per year with a demand of approximately 115 MW and could begin its production in 2017 with the possibility to start a new full scale aluminium facility in a reasonable time after this. The total additional power demand (pilot facility included) would be roughly 500 MW. [78] Normally, the production continues all around the year [78], resulting in approximately 4.4 TWh higher power demand each year in the area. The decision whether to on with the plans or not depends on the profitability, power- and grid solutions and support from Enova. [78] In June 2014, it was announced that Hydro would receive financial support from Enova which has decided to contribute 1.5 billion NOK toward Hydro's full scale next-generation electrolysis pilot project. [79] A floating offshore wind power plant outside Karmøy could be directly linked to the aluminium production to somewhat avoid an expensive upgrade of the electrical grid in order to secure the supply of the increased power demand.

  At the same time, there are ongoing plans to electrify the nearby O&G area Utsira High with a cable from shore. The electrification will generate a new power demand of 250 MW, increasing the yearly load in the area by 2.2 TWh. This together with Hydro's plans would double the electricity demand in Sunnhordland and significant grid investments would be required to secure the energy supply. [50] Even if the electrification project wouldn't be built, there is still a high energy use in this area which could benefit from a wind power installation.

  The innovative wind power plant together with the world's most energy efficient aluminium production [80] could be showcased towards the world as a centre for clean tech technology promoting Norwegian industry. The already existing test facility at Utsira for combining wind power and hydrogen electrolysis could also be expanded which would further increase the attractiveness of the area as an innovative clean technology centre.

- As mentioned, the Utsira Nord site is close to both Haugesund and Stavanger and thereby close to their large harbours. The two cities both have strong settlements of O&G expertise and considerable experience in offshore unit production.

- Statnett is planning to build a 1400 MW HVDC cable between Kvilldal and UK [81], showed in Figure 32. This will further increase the need of new power production in the area. The floating wind power facility could be constructed in connection to this HVDC cable, with the possibility to expand the park further.

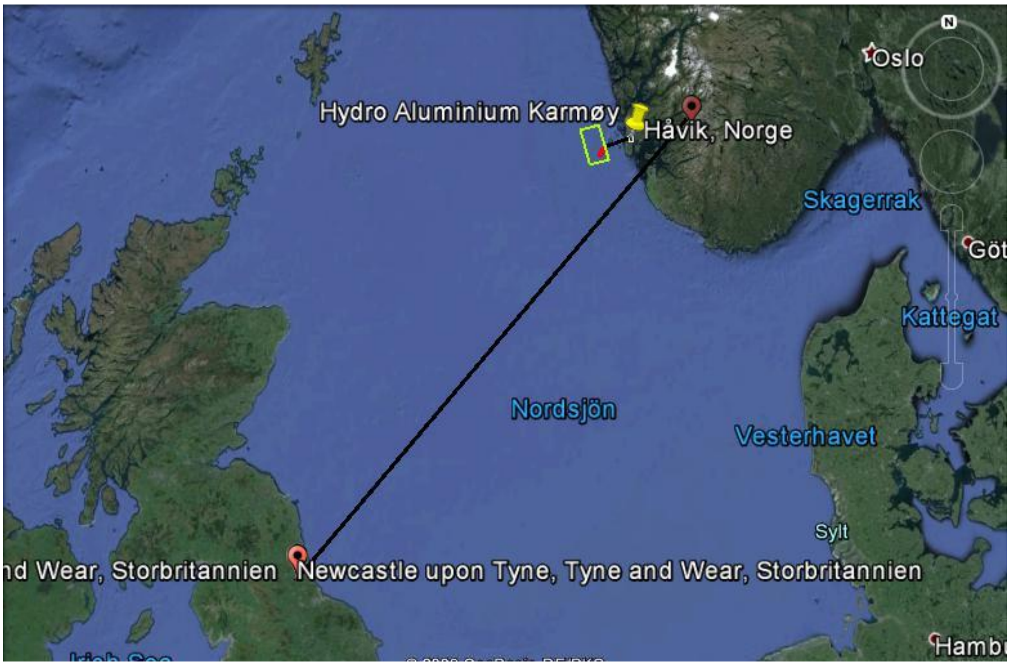


*Figure 32. The planned export cable to Newcastle from Kvilldal as well as the suggested wind power park at Utsira Nord.*

- Utsira Nord is the only location for floating wind which was classified as "grade A" by NVE, meaning it was highly suitable for wind power development. [82]

There are however some opposing interests which need to be considered

- The northern part of the Utsira Nord site seen in Figure 33 overlaps with the area used by the Norwegian Air Force and the Norwegian Navy for practice purposes [83].Wind power could be in direct conflict with today's use of the areas, however, the potential conflict of interest in this area can be easily avoided by not developing in this overlapping area in the north.

- The south part of the Utsira site seen in Figure 34 is overlapped by the Karmøy field, which is considered a valuable area with high biological production with spring-spawning herring and shrimps [75]. Further studies would be required to determine the environmental impacts of the floating wind power in this area. To avoid conflicts, the wind power park could be considered to be situated just north of the Karmøy field area.

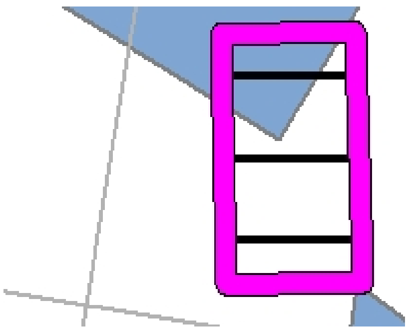

*Figure 33. The overlapping area of the shooting- and practice field in the Utsira area.*

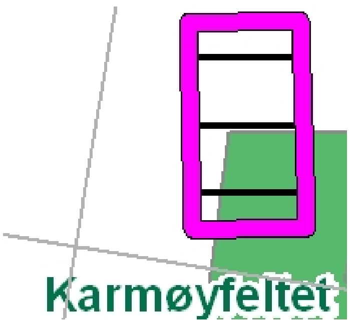


*Figure 34. The overlapping area of the Karmøy field with the Utsira area.*

Based on the key values established by NVE, the low impact on opposing interests and the low distance to Stavanger and Haugesund, Utsira Nord was chosen as the most suitable location for a test facility for floating wind power. The area, however, is quite trafficked which together with its proximity to shore may be associated with a relatively high environmental risk and an development should be done with close co-ordination with the Norwegian Coastal Administration to ensure navigational interests are maintained [82]. Further studies in the form of an EIA would however be necessary to further study the impact on the environment and opposing parties before the test park could be built.

## 4.2 Test park setup

The test park was designed for 288 MW of wind power mainly for three reasons: To be able to show the international market of Norway's expertise to install and operate a floating wind park, to show that Norway have the supply-chain for a large scale park and to be the first country with a floating wind power park of this size.

### 4.2.1 Wind turbines

The choice of turbines should be done at the time of the actual project development, depending on the current technology development and risk acceptance. However, to estimate the costs and power production, the Siemens SWT6.0 turbine was used, with a rotor diameter of 154m and a nacelle height of 100m. A larger turbine enables a higher installed capacity with fewer foundations which result in a high production with reduced cost as the number of foundations currently accounts for a large part of the total cost for a floating wind power park. Moreover, the SWT6.0 has a relatively low tower head mass compared to other turbines of the same size and could thus reduce the required ballast of the foundation, making it cheaper. Moreover, the turbine is designed to withstand a broad range of offshore environmental conditions. This combination of robustness and low weight has the potential to reduce the infrastructure, installation and servicing costs and boosts lifetime power output. Further ahead in time with additional development and testing, even larger turbines e.g. 8MW turbines would likely be even more feasible to increase the power production and reduce the amounts of required foundations.

### 4.2.2 Layout

Several different layouts alternatives were considered, shown in Appendix 3, although ultimately the inter-array structure shown in Figure 35 was chosen. The layout will consist of four rows containing 12 turbines á 6 MW. The power rose, described later in the next chapter, is used to be able to design the park optimal and achieve as low wake effect losses as possible. The distance in between the turbines in the same row will be about 1080 m, corresponding to 7 rotor diameters of the turbines. The distance in between the rows will be approximately 1400 m, corresponding to 9 rotor diameters.

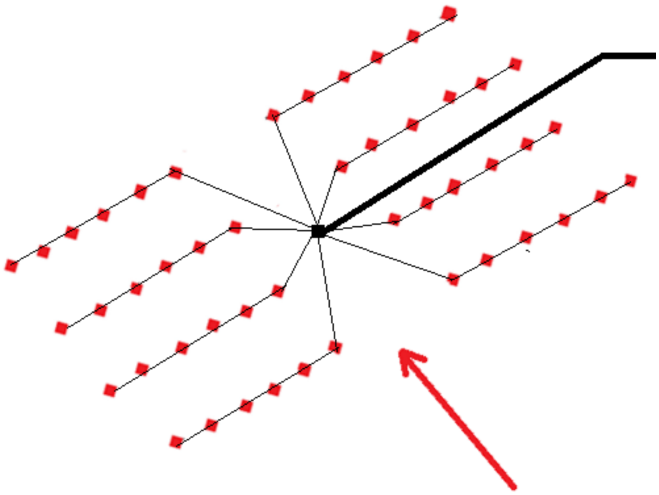

*Figure 35. The inter-array structure used for the test park with the transformer in the middle. The red arrow symbolises the main wind energy direction from southeast.*

### 4.2.3 Foundations

The decision of which foundation to use for a site will depend on the site specific conditions, where soil conditions and water depth etc. plays an important role. For this case study however, all three floating foundation concepts mentioned in chapter 2 have been used to display the differences in total costs and cost distribution for the project stages.

### 4.2.4 Mooring and anchoring

For mooring, the TLP concept will use the vertical mooring lines to the anchors on the bottom, while the semi-submersible and spar concepts will use the catenary mooring line method. This catenary method is the far most proven technology and works well. [13] As the average depth is 275 meters at Utsira Nord there shouldn't be an issue with the catenary mooring system which can experience some problems in shallower waters.

One possibility to reduce costs and improve logistics could be to connect several wind turbines to one high capacity anchor and thus reduce to total amount of anchors. The setup of using a high capacity anchor for several turbines is interesting, but will not be used for this case study due to limited research and data available. This could however be of interest for the test park even if for just a few turbines, to further study the properties of the system and show for the international market. Instead the semisubmersible and the Spar concept will use the DEA while the TLP will use the suction pile anchor. Due to uncertainties of the soil conditions at Utsira Nord, further investigations would be required to determine if this TLP solution would work in practice at this location. However, for simplification purpose it is assumed that the soil conditions will be sufficient the TLP system as well. In reality, the soil conditions could vary within the project area which require different anchoring and mooring solutions.

### 4.2.5 Cables and substation

The semi-floating technology is an interesting aspect with a large potential for the future, but as it isn't yet commercially available and as the average depth is only approximately 275 m, the conventional buried cable technology will be used for this case study.

The inter-array cables will consist of 33kV cables. The total required cable length for the project has therefore been determined by adding up the distances in between all the turbines in the rows and substations together with the vertical distances to the bottom, set as the average depth of 268 m. The calculations for this can be seen in the digital appendix, displaying the total inter-array cable length to be approximately 53.8 km.

As the distance to the connection point in Håvik is only 39.5 km, a HVDC transformer and export cable could be considered as excessive. As future commercial floating wind parks might be located further out than 100 km from shore, it could however be interesting to consider for a test park. Using HVDC will require an expensive and heavy HVDC substation, which in turn will require a considerably larger floating foundation to support it and will together result in a considerable cost increase.

As the connection point in Håvik uses 300 kV, the assumption has been made that it is possible to use a 300 kV cable to this connection point to avoid the need of another substation onshore. An offshore substation will be used to step up the voltage from 33 kV to 300 kV. The HVDC solution will however require an additional substation onshore to convert the HVDC current back to HVAC which is used in the onshore power grid at this location. Due to the high costs and the short distance, the HVDC solution has not been considered further for this case study

### 4.2.6 Logistics, Infrastructure and Installation

As previously mentioned, the site of the suggested test park is close to the large harbours in both Haugesund and Stavanger. The two cities both have strong settlements in the offshore industry and have considerable expertise in the O&G sector as well as offshore unit production. The port of Haugesund is a base for offshore oil production and shipbuilding and also a repair hub with one of the largest dry docks in Scandinavia. Stavanger has been known as the capital of oil in Norway and has relatively deep water just outside the city which could make it possible for towing a pre-assembled turbine from the harbour. The large international airport in Stavanger enables import of components and additional expertise if required and allows the test facility to easier be displayed for international investors willing to invest and import the technologies from Norway. This in combination with the proximity to the test park area could enable easier installation and maintenance procedure.

#### *4.2.6.1 Foundations and turbines*

Due to the uncertainties in what installation method that is most likely, the two different installation methods described in chapter 2.3.1 has been considered to estimate the costs.

The Norwegian coast gives access to numerous bays with calm waters suitable for pre-assembly. Moreover, the nearby shipyards/ports of Haugesund and Stavanger should be able to be accessed for pre-assembling the foundation and turbine at the dry docks as seen in Figure 36 and then towed to the site as was done with the WindFloat turbine, as shown in Figure 37. Whether the ports would be accessible or available for the period it would take to pre-assemble 48 turbines is uncertain and would have to be discussed with the corresponding shipyards. If these ports could not be used for the entire construction period, the use of additional ports, e.g. Bergen or close by sheltered calm water areas would be an option for installing the foundations. The assembling strategy will be to only use two lifts; the nacelle and a preassembled rotor onto the preassembled floater and tower configuration done in the dry docks. This should be associated with the lowest risk, the largest operation window and the lowest costs.

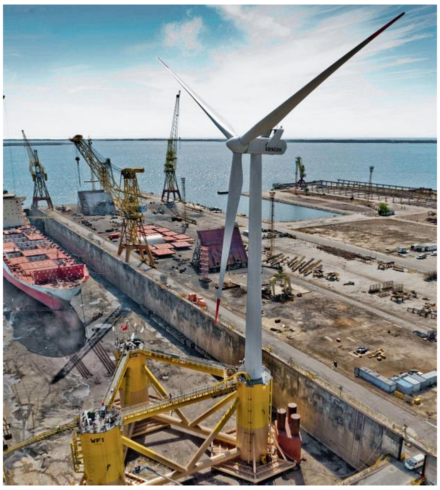

*Figure 36. The pre-assembled WindFloat unit in the dry-dock in Setúbal, Portugal [84]*

*Figure 37. Towing to installation site of the pre-assembled WindFloat turbine. [85]*

#### 4.2.6.2 Mooring and anchoring

The mooring system installation for a large scale wind park of 48 turbines would likely require numerous operations due to the amount of installations which would also require severe logistical operations prior to installation to ensure a proper installation process [7]. A pre-set installation strategy has been assumed, partly due to simplified logistical operations during the wind turbine installation.

### 4.2.7 Operation and maintenance

Maintenance actions comprise of several actions intended to maintain the technical state of the wind farm as close to perfect as possible and could include actions such as removal of damaged parts, exchange of parts, addition of a new part, changes or adjustment of settings, software updates and lubrication or cleaning processes [7]. O&M for a floating wind park will likely to a large extent be similar to the O&M of the conventional wind park with bottom mounted foundations. One exception however, would be that turbines with major failures could be disconnected from the anchors with a AHTS vessel and towed to an existing shore side infrastructure (if the depths allow) or to calmer water where it is possible to do the maintenance operation with a crane barge. This provides an opportunity for considerable cost and risk reduction relative to unscheduled maintenance at times with high demand and cost of crane vessels. [7] The nearby ports of Haugesund and Stavanger both opens for opportunities to use personnel and vessels (which as of today works with the offshore O&G industry) to support the demands of the test park. For future large floating wind power parks, located far offshore, a platform for offshore personnel might be suitable in order to reduce costs. This has however not been applied for this test park.

### 4.2.8 Decommissioning

At the end of the wind turbines lifetime, removal and decommissioning of selected components would take place, including wind turbines, the floating foundation and transition pieces, subsea cables and substations. All which requires environmental monitoring. The practice for decommissioning varies somewhat in between countries, although in most countries a plan for the decommissioning phase are required to be approved before the offshore installation initiates. Decommissioning can be assumed to be a reversed assembly process to installation although it would take less time and require less focus as any damages caused on the components will not matter as they are to be recycled or scrapped. The cables will be cut off at a depth below seabed and most of the cables will not be pulled up. [86]All other infrastructure will be removed and transported back to shore, sorted for recycling and delivered as scrap metal which could be sold.

## 4.3 Wind resources and characteristics

Wind is a complex phenomenon but as mentioned in the beginning of the chapter the wind resources are one of the most important criteria for a wind park as the power production, in theory, increases cubically with the wind speed and thus the profit. This means that twice the wind speed results in an eight times increase in the power production. In reality, this does not always play out accurately as different turbines have different efficiencies and also operates at different wind speeds although the principle remains important for understanding the power production. The theory behind wind power is further explained in Appendix 4.

The wind speeds patterns varies over both seasons and years, consequently, the amount of wind data available is an essential aspect for the accuracy of the power production estimations. For this case study, extensive wind data for the specific area has been supplied by Kjeller Vindteknikk, providing the hourly wind speeds and wind directions at various altitudes over a period of 14 years.  With wind data available for such a long period of time, it is possible to estimate the power production potential with better accuracy. The average wind speed at the SWT6.0 nacelle height of 100m altitude is 9.94 m/s which is considered as excellent for power production. Even more important than the average wind speed however is the wind distribution.

### 4.3.1 Wind speed distribution

To be able to predict a wind turbine's production it is essential to know exactly how often the wind blows with different velocities due to the nature of the cubic relationship in between the wind velocity and the power production. The wind distribution seen in Figure 38 describes the frequency of the various wind speeds over the year and can be compiled by adding up all hourly wind speeds over the year using the frequency command in Excel.

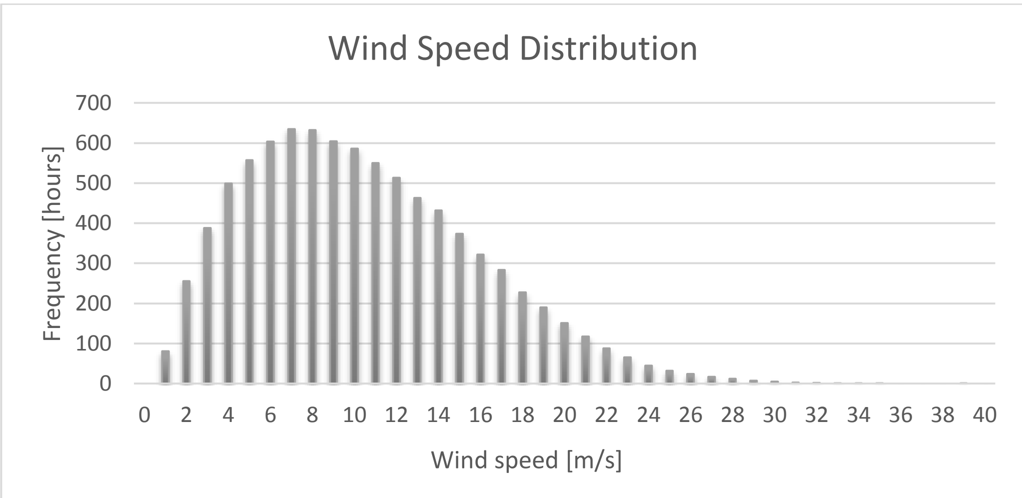


*Figure 38. Average yearly wind speed distribution, 2000-2014.*

### 4.3.2 Power rose

Another crucial element is the wind directions as this is required to optimize the internal placement of the turbines to reduce the internal cable costs and avoid array losses, which is described in the next section. The wind direction distribution is displayed with a power rose made with Matlab by comparing the hourly wind speeds over the year with their corresponding wind directions, see Appendix 5. The results of the power rose calculations can be seen in Figure 39.

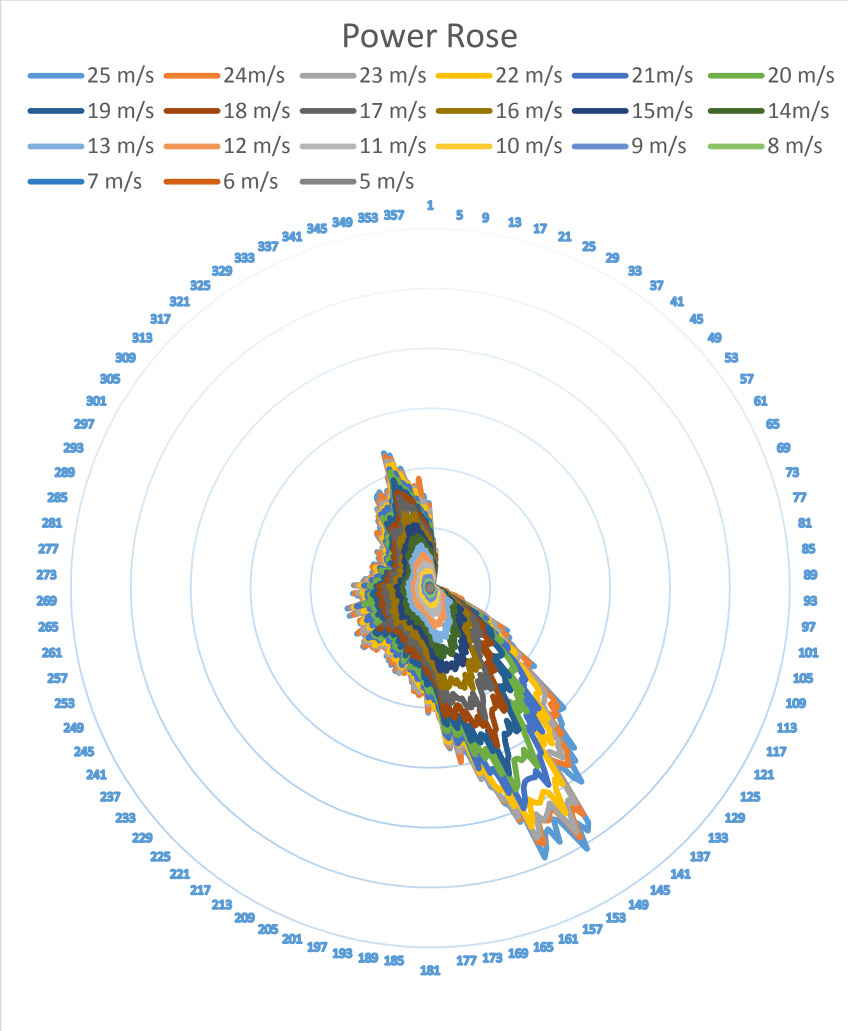


*Figure 39. The power distribution of the wind energy showing how much of the wind energy that comes from the various directions, where 0 degrees represents north and 180 degrees represents south.*

As seen in the figure, the majority of the wind energy comes from the southeast and from the northwest, which was used to determine the layout shown in Figure 35. Even though most of the wind comes from southeast and the northwest, there is still a fair amount of energy coming from the southwest direction which will result in some loss of power production in the form of array losses.

### 4.3.3 Energy losses

Knowing the layout of the park and the wind characteristics, it is necessary to define and estimate the losses to calculate the power production. There are several different losses, e.g. electrical array losses, wind power plant availability, environmental losses and aerodynamic losses which is described below.

#### *4.3.3.1 Array losses*

As a result of the wind turbines extracting energy from the wind, the downstream turbines in an array receive lower wind speeds and therefore less energy to capture than the previous turbine. Although this energy loss in the turbine wake will be replenished over a certain distance by exchanging kinetic energy with the surrounding wind field, some of these array losses generally remain. The array losses can be reduced by optimizing the geometry of the wind power plant based on aspects such as the wind turbine spacing (both downwind and crosswind), wind turbine operating characteristics, the number of turbines and size of the wind power plant, turbulence intensity and frequency distribution [23]. This is generally done with advanced programs such as WindFarmer or WindPro to generate accurate wake effect estimations based on all wind velocities together with their corresponding wind direction. Without access to these, a simplified method was used, where all the wind velocities was divided into four main directions and calculated how large the losses would be for each turbines at the different wind velocities and wind direction seen in the digital appendix. The total array losses for the entire wind power plant was estimated to be about 12.1%. If there are other nearby wind power plants, these could also result in wake effect. As there is no other wind power parks nearby, the external wake effect is set to 0%.

#### *4.3.3.2 Availability*

The availability of the wind power plant corresponds to the percentage of time which it is available to produce power, usually excluding the times without sufficient wind speeds to produce power. Most statistic reports rates availability around 98% for onshore wind which means that energy losses due to maintenance or technical failures generally will be about 2% [87]. However, as these wind turbines are located offshore and thus more difficult to access, e.g. a machinery or component failure will result in the turbines to stand idle for a certain time before they can be repaired. However, generally modern wind turbines are very reliable [87]. As this is a test park, the availability may be somewhat lower. Not necessarily due to breakdown of the turbines but more likely controlled stops due to additional controls and inspections of e.g. the foundations and mooring lines. The average availability over the entire lifetime of the park is therefore set to 95% in this report.

#### *4.3.3.3 Electrical losses*

Electrical losses denote ohmic losses dissipated as heat in the inter-array cables, export cables and substation. The electric losses depend on where the power are being delivered. For example, in Denmark and Germany, the transmission system operators (TSO) are responsible (building and funding) for the connection of the wind power park to the national grid. The wind park developer therefore gets paid for the power submitted to the delivering point, usually the offshore substation and thereby avoids loses in profit due to the electric losses connected to the substation(s) and the export cable. As Norway currently doesn’t use this system, the developer will also have to consider all the electric losses to the power delivery point in Kåvik. The losses vary with power plant layout, voltage levels and cable length and the substation solution. The average combined losses of the inter-array cables, export cable and the HVAC substation has been estimated to 4%.

#### *4.3.3.4 Losses due to turbine pitch angle*

During considerable wave heights, the pitch motions can decrease the relative wind velocity experienced by the turbines blades and thus lead to some energy losses. The average yearly losses however is considered to be insignificant, due to the low frequency of high pitch of the turbine. [88]. The authors have therefore estimated the losses to 0.2%. How much this will affect the yearly production will depend on how stable the floating unit is designed which in turn usually depend on the acceptable pitch angle from the turbine manufactures. One additional parameter is the frequency of high waves and fluctuating wind speeds. As large pitch motions also influence extreme loads and fatigue life, having a good prediction of responses to wind and waves is crucial [88] and should be considered when designing the floating foundations.

#### *4.3.3.5 Icing losses*

Ice on structures could result in significant problems in colder climate. In marine environments, the icing is generally divided into sea-spray icing and atmospheric icing. [89] Sea-spray is common with strong wind in combination with low temperatures, where sub-cooled sea water hits structures and the water can freeze instantly. Atmospheric icing is a complex issue which is due to several different mechanics, where the most important are the following [89]:

- Precipitation Icing, freezing rain, re-freezing of wet snow.
- Icing in cloud or fog
- Rimfrost / Sublimation

Studies by Stormgeo show that the power production of the Utsira location will have a very limited impact due to sea-spray icing. Neither are there any significant problems anticipated due to atmospheric icing. [89] The environmental losses are consequently deemed to have very limited impact and therefore estimated to 0%.

#### *4.3.3.6 Total average losses*

The total average losses are approximately 20% which is displayed in Table 7. Note that the losses should be multiplied and not added.

*Table 7. Estimated total average production losses of the test park.*

| **Loss aspects** | **Production loss [%]** |
|---|---|
| Wake Effect Loss - Internal | 12.13 |
| Wake effect loss - From other parks | 0 |
| Availability | 5 |
| Electrical - Internal and external | 4 |
| Turbine pitch losses | 0.2 |
| Environmental (Ice, dirt) | 0 |
| **Average total losses** | **20.02** |

## 4.4 Power production

The gross power production is generated by combining the yearly average wind distribution with the power curve of the wind turbines which show the equivalent power produced at various wind speeds. As the SWT6.0 turbine has not been fully tested, no official power curve has been released by Siemens. A power curve spreadsheet was therefore used, provided by DNV GL to generate an estimate the power curve. The calculations presented in the digital appendix show a gross power production of 1528 GWh/year. With the average losses of 20%, there is an average annual estimated production of 1222 GWh/year corresponding to 4244 full load hours, and a capacity factor of 48.4%. The electricity would be enough to supply the yearly demand of approximately Norwegian 73640 households. [90]

*Table 8. Key power production values.*

| | |
|---|---|
| **Gross production [GWh/year]** | 1528.3 |
| **Average Losses [%]** | 20.0 |
| **Total net production [GWh/year]** | 1222.3 |
| **Full load hours [hour]** | 4244.2 |
| **Capacity factor [%]** | 48.4 |

## 4.5 Financial estimations

For the financial estimations, the authors have focused on the LCOE for the project. The LCOE can be defined as the price of electricity required for a project to break even, including a return on the capital invested equal to the discount rate. An electricity price above this would thus yield a greater return on capital, while a price below it would yield a lower return on capital, or even a loss. [91] It can be used to either determine the minimal required electricity price or to compare different projects or even different power generation sources. The LCOE is calculated by evaluating the sum of all accumulated costs for building and operating a plant and compare them to the expected annual electricity production. The calculation in this thesis is done on the basis of the net present value (NPV) method, where the expenses for CAPEX and OPEX accumulated during the plant's lifetime are calculated based on the discounting over the lifetime [91] and can be calculated with equation 1.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}} \tag{1}$$

Where:
LCOE = the average lifetime levelised cost of electricity generation
$I_t$ = investment expenditures in the year t
$M_t$ = operations and maintenance expenditures in the year t
$E_t$= electricity generation in the year t
r = discount rate
n = economic life of the system.

Due to the youth of technology and limitations in availability of data for floating wind power, cost estimates is rather uncertain and will only provide an overview or indication of the actual price level.

### 4.5.1 Wind turbines

As mentioned, the cost of the turbines is something which is decided during the procurement and could vary greatly. The authors have therefore used the average cost approximations from the crown estate, NVE, the research committee of Norway and the Scottish Enterprise with an average cost of 12.2 MNOK/MW (1.5 MEuro/MW) [7]. With 48 turbines á 6 MW this result in a total turbine cost of approximately 3513 MNOK.

### 4.5.2 Foundations

The cost of the foundations is estimated given a large-scale production in a somewhat mature industry with the estimated material costs and their corresponding manufacturing costs. The authors realise that using approximate costs of a mature market assumption is misrepresentative, as the market is all but mature. This is however used due to the limited amount of available data for existing foundations and as a mass production of foundations likely would give more realistic costs per unit compared to the single prototype at a time, which is the only thing that have been built so far. The cost of foundations does however therefore remain as an uncertain part of the cost estimations and might therefore be considerably higher. The approximations are shown in Table 9 and further described in the digital appendix.

*Table 9. The costs associated with the production of the different floating foundation concepts to support the weight of a 6MW turbine. [7]*

| Floating foundation costs | TLP | Spar | Semi-submersible |
|---|---|---|---|
| Production costs per turbine [MNOK/turbine] | 10.4 | 36.6 | 73.4 |
| Total production cost, all foundations [MNOK] | 501.2 | 1757.9 | 3525.1 |

The costs of the foundations are highly related to their size, whereas the size is dependent on demanded stability of the turbine and the level of acceptable risk from the turbine manufacturer and the project developer. With a higher acceptable risk level the foundations can likely be manufactured with a reduced size and thereby reduced cost.

### 4.5.3 Mooring and anchoring

The cost estimates for anchoring and mooring materials and installation are displayed in Table 10. As can be seen, the anchoring and mooring for the TLP system is considerably higher. This is due to the use of fibre ropes and suction pile anchor needed for the TLP system due to higher vertical loads.

*Table 10. The anchoring and mooring material and installation costs for the different concepts. [7]*

| Cost | TLP | Spar | Semi-submersible |
|---|---|---|---|
| Anchor and mooring material cost [MNOK/Turbine] | 15.6 | 3.8 | 5.1 |
| Total anchor and mooring material cost [MNOK] | 748.5 | 180.6 | 244.8 |
| Mooring installation cost [MNOK/Turbine] | 1.6 | 1.4 | 1.8 |
| Total anchor and mooring installation cost [MNOK] | 75.2 | 65.4 | 87 |

### 4.5.4 Inter-array cables, export cables and substations

The cable costs are highly volatile depending upon market supply and demand but approximated to an average price of 2.29 MNOK/km [7]. The costs for installation of the cables are also difficult to quantify as there are various factors and aspects to be taken into consideration e.g. seabed conditions, route lengths, physical environment conditions (weather, currents etc.), chosen supplier (transport of cable), landing sites, cable and pipeline crossings, cultural/natural environment etc. The authors have decided to use a range of cost for a single cable in a single trench 2.98 – 6.97 MNOK/km [20]. With a total inter-array cable length of 53.8 km, the cable materials and installation cost will result in a total cost of approximately 284 – 498 MNOK. The full calculations are displayed in the digital appendix.

The cost of the export cable is estimated to a cost range of 4.98 – 7. 47 MNOK/km [20] while the cost of installation is assumed to be about the same cost per kilometre as the inter-array cables. Given the 39.5 km export cable, this result in a total cost of the export cable and installation of 314 - 570 MNOK.

The HVAC substation together with the required floating foundation and the installation has been estimated to 682 – 865 MNOK. As a comparison, using an HVDC solution would result in a cost of the offshore substation of approximately 1307-1664 MNOK together with the onshore HVDC converter costing approximately 980 – 1205 MNOK [7].

*Table 11. Cost estimations of different components for the power transmission of the test park.*

| **Materials and installation** | **Cost [MNOK]** | |
|---|---|---|
| | **Low** | **High** |
| Internal -array cables | 284 | 498 |
| Export cables | 314 | 570 |
| HVAC substation | 682 | 865 |

### 4.5.5 Installation of wind turbine and foundation

The installation costs of the wind turbine and the foundation could perhaps be considered as one of the phases with highest cost uncertainty. Partially since there have only been a few installations worldwide, and even more as the costs of these has been difficult to get a hold on. The installation methods of the different components depends on the various conditions of the different sites. For instance, water depths determine whether it is possible to assemble the entire turbine and foundation in the harbours and towed out into position or if both foundation and turbine will have to be transported with installation vessels. Furthermore, as the harsh weather condition of the winter season with high waves and strong winds generally limits the time suitable for installation of foundation, mooring and turbines, the installation cost will depend on whether the installation of all turbines can be accomplished in one season or not. This could depend on e.g. the number of turbines to be installed, the availability of ports and vessels as well as weather conditions.

The cost estimates are based on a set of assumptions on personnel usage, operational windows, transit capacities and speeds, and are displayed in Table 12. [7] These approximations are originally estimated for the specific prototypes of Hywind, WindFloat and TLB B/ TLB X3 but has been used as a simplification to represent the costs of their respective foundation concept.

*Table 12. The cost estimates for installation of the turbines foundations for the different concepts. [7]*

| **Cost** | **TLP** | **Spar** | **Semi-Submersible** |
|---|---|---|---|
| Foundation and turbine installation [MNOK/Turbine] | 6.3 | 6.4 | 5.3 |
| Total foundation and turbine installation [MNOK] | 301 | 308 | 252 |

### 4.5.6 Decommissioning

There are large uncertainties in terms of the decommissioning costs for offshore wind power plants as few turbines have passed the end of their lifetime. Even more so for floating turbines although the decommissioning for stable floating offshore turbines with a low draft are expected to be less costly due to simply disconnecting from the mooring lines and towed back to shore. [4] Due to discounting, the impact on the cost of energy is not significant [86]. The cost of decommissioning is assumed to be average 65 percent of the total installation cost by BVG associates although different parts of the segments take different times, e.g. removal of the array cables take 10% of the time. [86].

The scrap values varies greatly both on a monthly and yearly basis and due to this volatility it is difficult to estimate the prices in 20-25 years ahead in time. Based on the development of scrap value prices, the scrap value has been estimated to 5785 NOK/ton [7]. Based on the different concepts' consumption of steel, the following estimations for costs has been used.

*Table 13. Estimated decommissioning costs and values for the different foundation concepts. [7]*

| **Decommissioning costs** | **TLP** | **Spar** | **Semi-submersible** |
|---|---|---|---|
| Decommissioning costs [MNOK] | 1.7 | 1.7 | 1.6 |
| Scrap revenue [MNOK] | 1.1 | 2.5 | 3.5 |
| Total DECEX [MNOK/MW] | 0.6 | -0.9 | -1.9 |
| Total DECEX [MNOK/Turbine] | 3.3 | -5.3 | -11.3 |
| Total DECEX [MNOK] | 158.6 | -253.8 | -542.9 |

As seen in the figure, due to the relative inexpensive installation costs of the floating concepts they are also expected to be associated with low decommissioning costs. The heavy foundation of the Spar and the Semi-submersible concepts are expected to gain considerable scrap steel values that exceeds the small decommissioning costs resulting in negative total decommissioning values.

### 4.5.7 Other key parameters

There are several other parameters, including contingency, project development costs, project lifetime, discount rate and insurance that are necessary in order to decide the LCOE and NVC values of different projects.

#### *4.5.7.1 Contingency*

Contingency is a sort of backup capital to cover uncertainties to all procurement and installation related costs. The contingency cost is usually set at a percentage of CAPEX. The contingency is set as 10% of the total capital cost, excluding the insurance. [92] The contingency cost will increase the estimated LCOE, even if the resources are never used. However, due to the immature nature of the technology this is a very uncertain cost factor.

#### *4.5.7.2 Project development cost*

The project development cost has been estimated to approximately 180 MNOK. These costs includes the MET-mast, environmental impact assessment, project management and additional required studies. As the Utsira Nord area already has been designated by NVE as suitable for floating wind power, there should be an increased chance of receiving concession to build the test park.

#### *4.5.7.3 Discount rate*

The required return of equity varies in between companies and countries. The commercial discount rate is often set to be around 10% and is therefore used in this thesis. As the purpose is to establish a test park with a probable large share of public funding, it could however be debated that there will be no high demand for rate of return and that the discount rate could be set to approximately 5%.

#### 4.5.7.4 *Lifetime and reinvestment.*

The lifetime of the test park is set to 25 years which is the common design life for offshore wind turbines. Some replacements and reinvestments would likely be necessary during this time, included in the O&M costs. Many projects are not decommissioned after this lifetime however, but rather repowered if the site has good wind resources and it makes more sense to replace turbines than remove the entire facility. This would however require a new concession process, although it usually goes faster compared to the first concession.

#### 4.5.7.5 *Insurance*

The insurance cost is estimated to 0.41 MNOK/MW [7] resulting in a total insurance cost of 117.5 MNOK.

### 4.5.8 Total cost and levelised cost of energy

The total CAPEX for the different concepts can be seen in Figure 40, displaying the different cost segments of the three concepts.

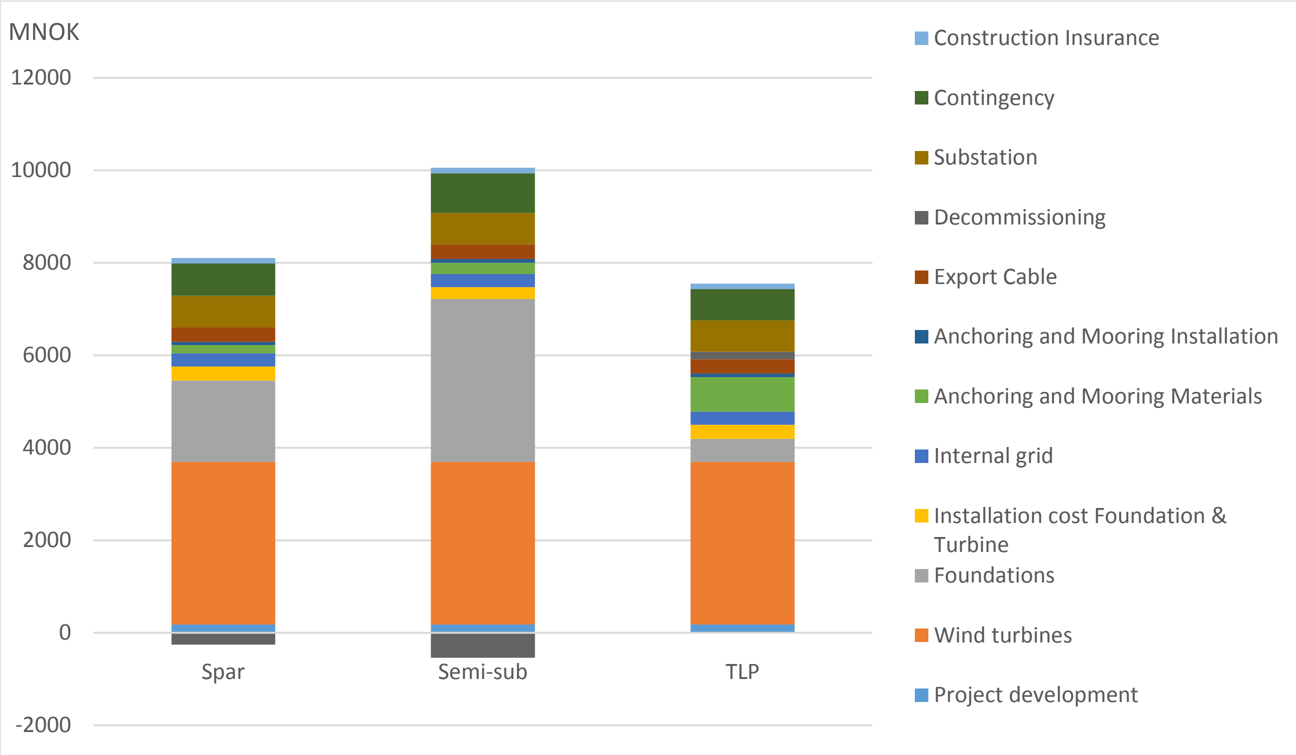


*Figure 40. The total CAPEX using the different foundation concepts.*

As seen in Figure 40, using the semi-submersible requires the highest investment cost. This is mainly due to large cost variations for different foundation concepts and their installation methods. A full cost comparison is displayed in appendix 6, while the full calculations for these can be seen in the digital appendix. As shown in the figure, the cost segment of the different stags varies greatly. This difference is further displayed in Figure 41, Figure 42 and Figure 43 to make it easier to view the particular differences.

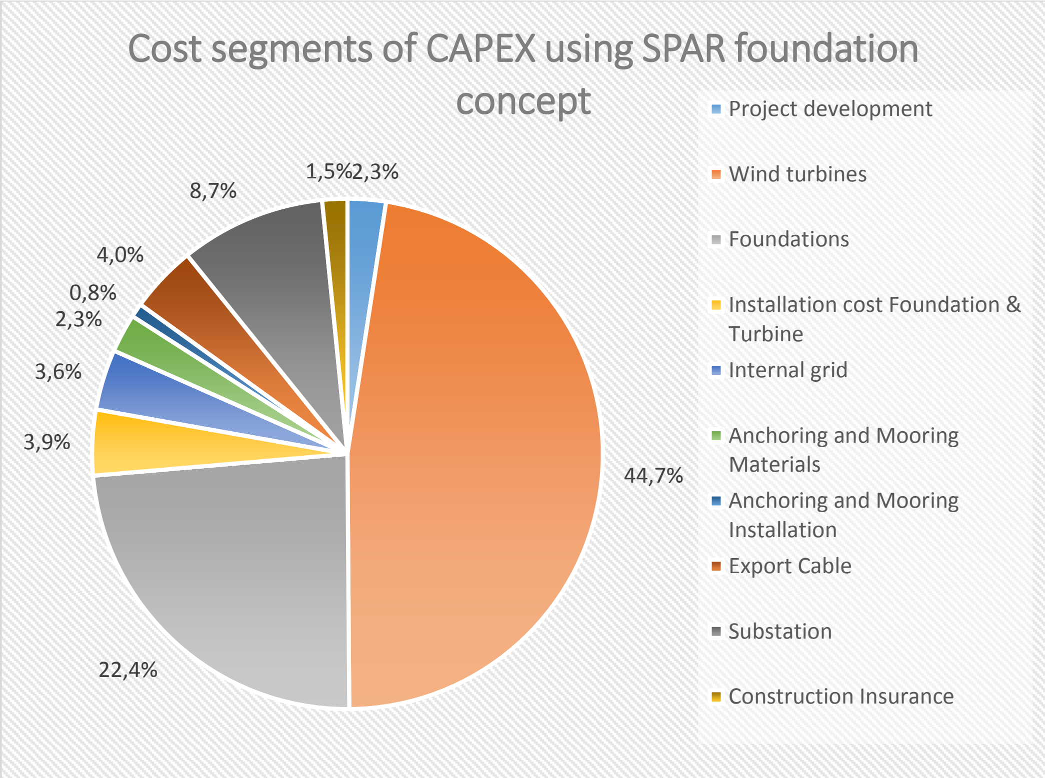


*Figure 41. Cost segment of the CAPEX from the different components and services using the Spar concept.*

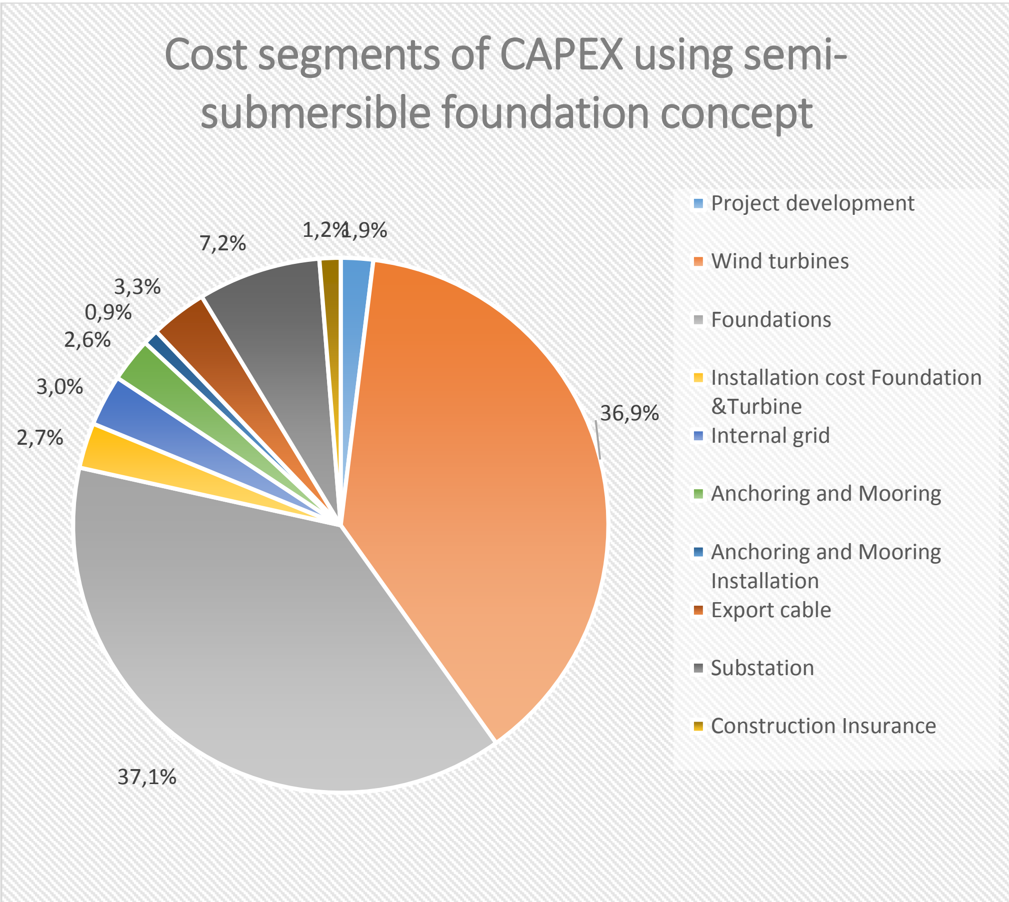


*Figure 42. Cost segment of the CAPEX from the different components and services using the Semi-submersible concept.*

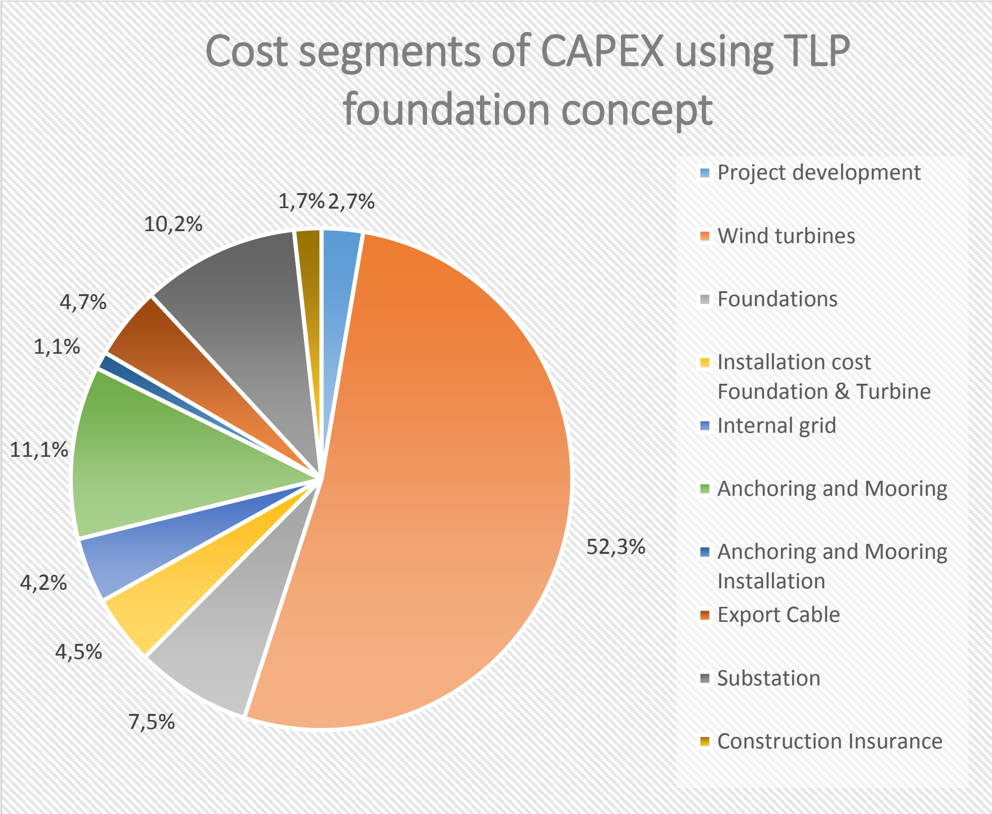


*Figure 43. Cost segment of the CAPEX from the different components and services using the TLP concept.*

With the total cost and the power production, a few of the key economic parameters can be determined. The calculations can be seen in the digital appendix, and the results are displayed in NOK in Table 14 and in Euro in Table 15.

*Table 14. CAPEX. NPV and LCOE using the different floating foundations concepts displayed in NOK.*

| | Capex [MNOK] | | NPV [MNOK] | | LCOE [NOK/kWh] | |
|---|---|---|---|---|---|---|
| **Concept** | **Low** | **High** | **Low** | **High** | **Low** | **High** |
| **Spar** | 7031 | 10213 | -5752 | -8350 | 1.03 | 1.26 |
| **Semi-Submersible** | 8539 | 12868 | -7577 | -11270 | 1.19 | 1.53 |
| **TLP** | 6757 | 8885 | -5421 | -6890 | 1.00 | 1.13 |

*Table 15. CAPEX, NPV and LCOE using the different floating foundations concepts displayed in Euro.*

| | Capex [MEuro] | | NPV [MEuro] | | LCOE [Euro/MWh] | |
|---|---|---|---|---|---|---|
| **Concept** | **Low** | **High** | **Low** | **High** | **Low** | **High** |
| **Spar** | 962 | 1252 | -705 | -1023 | 126.3 | 155.0 |
| **Semi-Submersible** | 1165 | 1577 | -929 | -1381 | 146.4 | 187.2 |
| **TLP** | 925 | 1089 | -664 | -844 | 122.6 | 138.8 |

# 5 Benefits of establishing offshore wind in Norway

Establishing a test park for floating offshore wind power in Norway could generate several considerable benefits stated below. This chapter aims to describe these possibilities and opportunities.

- Export of supply chain
- Value and job creation
- Diversifying from and O&G 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

## 5.1 Export of supply chain

In Europe the development of offshore wind power has accelerated and as the expansion is heading towards deeper waters there is an increasing need for deep water offshore knowledge. The European National Renewable Energy Action Plans states that offshore wind energy will be a major part of the future European energy system [51]. Norway's extensive maritime and O&G expertise leaves a great opportunity for a new large industry development in Norway. By building a test park of floating wind power, Norway can demonstrate their "know how" knowledge and become a key player in the business. It will also highlight the outstanding wind resources of the Nordic region towards the rest of Europe. If Norway takes the lead in setting up the first offshore wind power plant, it may attract foreign countries that are struggling in achieving their national goals for renewable energy for 2020. Through joint projects mechanisms European countries with significantly poorer wind resources can develop projects in the Nordic region [93]. The test park is then not only needed to display the great energy yield, but also to prove the feasibility of developing a floating offshore wind power plant in the area.

A test park of this kind will require public funding, and private investors willing to provide further capital. The investment for such a park will however most likely be very low in comparison with the value of future benefits [51].

A key barrier for the offshore wind industry to overcome is cost reduction [43]. A test park could involve maritime and O&G companies with previous little or no knowledge of the wind power industry. With an abundance of ports and harbours well suited for offshore wind deployment, there is a possibility for Norwegian companies to not only become a strong competence exporter but also manufacture and export parts such as floating foundations. This could not only lead to increased export but also increase employment, less volatility towards the international O&G market and potentially cost reduction.

The development of a strong supply chain is crucial for further expansion of the offshore wind sector [94]. A considerable part of the 150 GW of offshore wind that is expected by 2030 in Europe are in deeper waters and Norwegian expertise for floating structures could be a strong export product. Since no larger projects of floating wind are deployed there is a strong need for a solid supply chain. But the development is rapidly taking hold, and with a potentially enormous new line of offshore wind industry, investment actions should not be delayed for too long in order for Norway not to miss out on becoming a key player within the industry. With Norway's extensive knowledge within deep offshore industry they have a possibility of becoming an important player and lead the development of this niched part of the wind industry [44].

## 5.2 Value and job creation

A significant benefit that comes with new industry development is the value and job creations. For offshore wind in Norway a considerable part of this could be developed locally where there today at many places are a very high dependency of the oil industry. Labour creation in these areas can therefore act as a smooth transition and insurance policy for the O&G industry both locally and on a national level.

Multiconsult and NVE have put together a report [52] where value creation for the different 15 zones targeted by NVE is considered. Figure 44 displays some of the results of the report indicating that the value creation can be achieved nationally to a very high degree. The foreign part of approximately 40% seen in the figure is mostly due to that the turbine supply will likely be handled by international turbine suppliers. According to Multiconsult it is however likely that national turbine developers like SWAY and Blasters could supply a small part of the total installed power due to the interests for these companies to test and prove their technologies. If they decide to step up their production, this will however most likely result in new facilities closer to larger markets and cheaper labour costs. [52] All other major parts of offshore wind projects could in theory be handled by existing Norwegian industry, as seen in Appendix 8 - Value creation. [52]

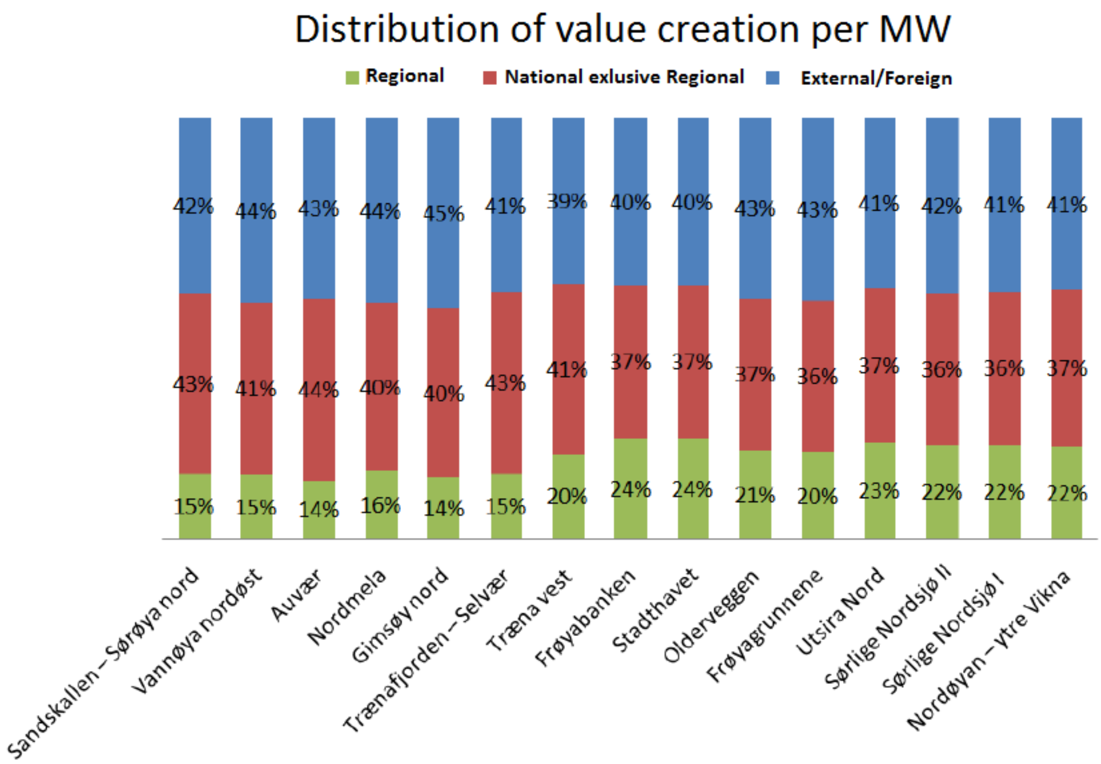


*Figure 44. Value creation distribution [52]*

In the report it is assumed that measurable effects on employment and business can be estimated by measuring job creation in FTE (Full-Time Equivalent) and value creation in GDP (Gross Domestic Product). The employment effects can mostly be viewed as temporary job opportunities and if labour is taken from other business or actually created is not investigated. Employment connected to O&M

can however be viewed as long term. The value creation measured this way corresponds to the operating profits of the company and its labour costs. This is the same approach as the income approach within national accounting. The value and job creation is then levelised per MW for each of the 15 zones. As seen in Figure 45 approximately 60 MNOK of value is created per MW in each area. The value creation is especially high for the deep sea zones using floating substructures. This can be explained knowing that Norwegian suppliers will have an advantage compared to foreign suppliers by using the offshore O&G expertise and therefore can account for a larger share of the value creation compared to the fixed turbines. [52]

A good measurement of the productivity and value creation of a business is to investigate its value creation multiplication. The multiplicator tells how much the activity is rising in Norwegian economy for every invested NOK. In the Multiconsult study the multiplicator is divided into one for the construction phase, which is considerably higher, and one for the O&M. The multiplicator for the construction phase was estimated to 3.25 and 1.76 for O&M. This can be compared to the multiplicator of 4 that is used by the Statistical central bureau in their macroeconomic model for O&G value creation in Norway [95].

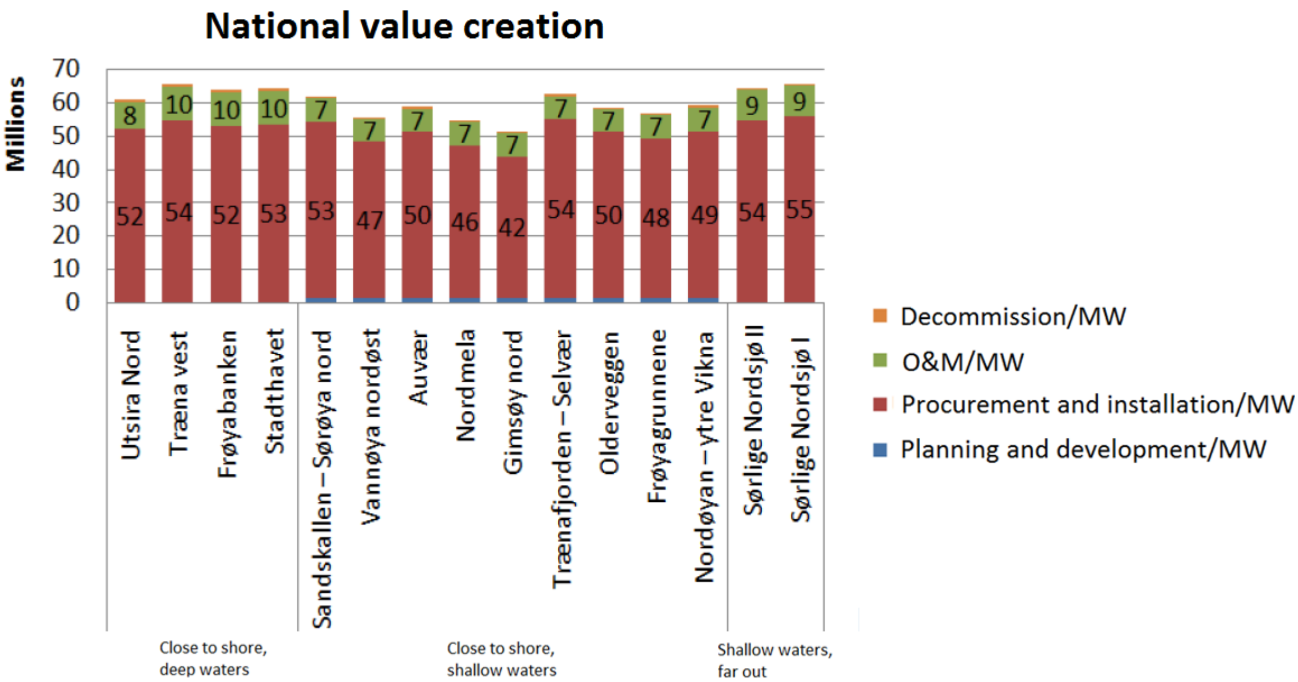


*Figure 45. National value creation by area in MNOK. [52]*

The current unemployment rate in Norway is in an international perspective relatively low [96] and especially so in oil industry influenced cities along the Norwegian coastline. However this also makes these settlements extra volatile for changes in the Norwegian economy [44]. A drop in oil prices could result in decreased activity for many oil companies and therefore set many into unemployment. With the high regional penetration from offshore wind, this new industry can act as an insurance policy for exposed communities in Norway. As seen in Figure 46 the national job creation for every area is approximately around 50 FTE/MW.

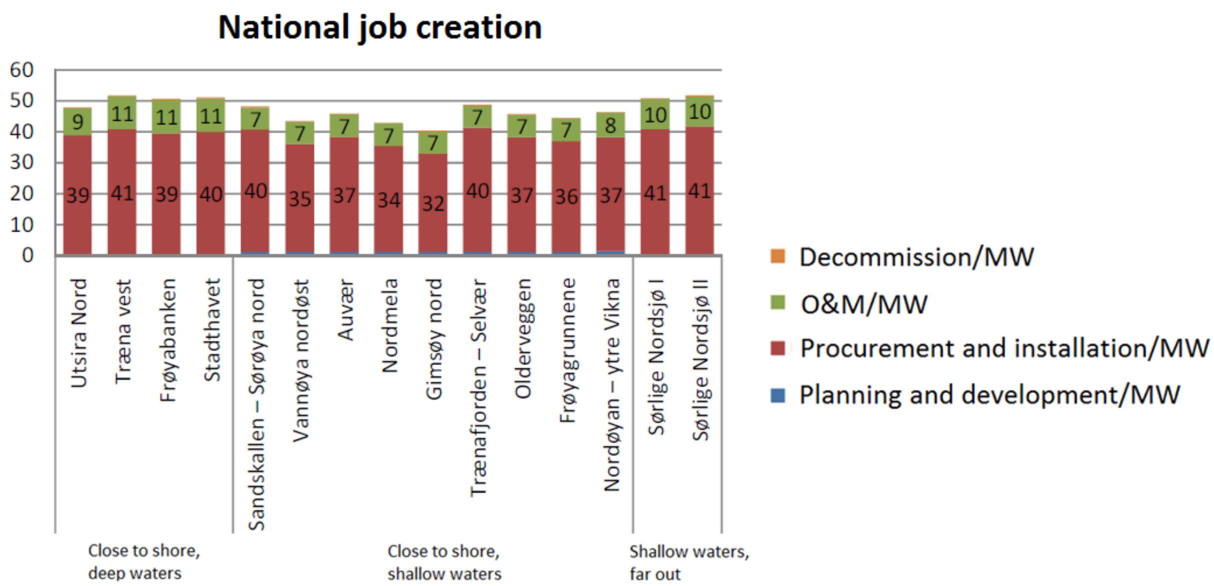


*Figure 46. National job creation by area in FTE [52]*

Norwegian industry has a strong potential to compete within the offshore wind industry, but to what degree this will actually happened is dependent on political will and free capacity within Norwegian industry, mostly dependent on the activity in the O&G industry [52].

The Multiconsult study also investigate the aggregated job and value creation if all the 15 zones would be developed. In Figure 47 the aggregated job creation for each area can be seen. The areas with significantly higher job creation are 1000 MW areas and the other ones are 200 MW. Together the development of all these zones results in approximately a total of 600000 FTE.

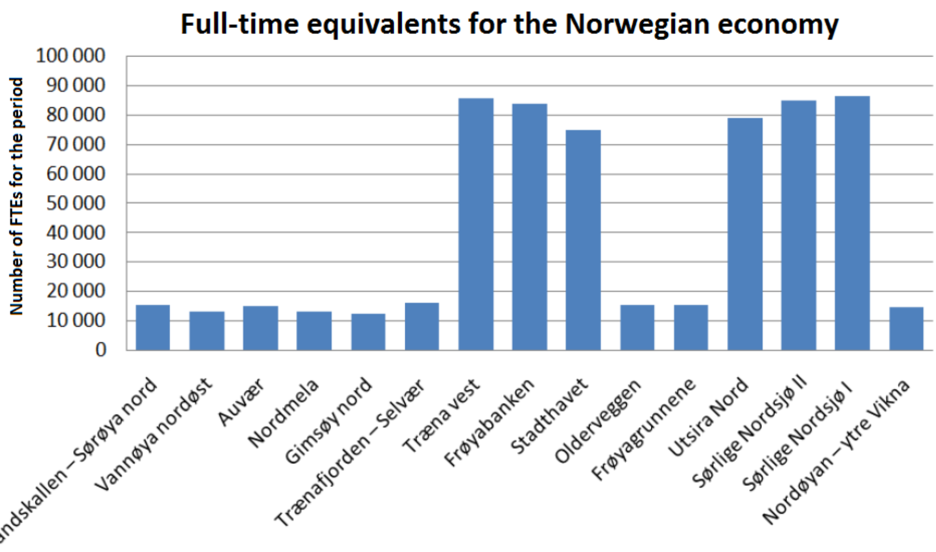


*Figure 47. Full-time equivalents of development of the different offshore wind power areas [52]*

A major increase in value creation of sectors in Norway outside the oil industry is of great importance to the country since the revenues from domestic O&G production is expected to decrease [96]. It is expected that the value creation in competitive sectors other than O&G needs to increase significantly in the coming years in order for Norway to maintain its welfare developments [96].

It is also expected that the increase in labour force will steadily slow down [96]. Therefore Norway's ability to meet new market demands will decrease as a result of shortage in qualified labour force. By engaging in offshore wind power development, Norway could however take advantage of the already established offshore competence that the O&G industry has developed. Shifting the labour force in this way would therefore not only diversify Norway's economy but also reducing the risk of future labour force shortage within major upcoming markets.

Increased value creation have for long been a primary goal for Norway's industrial policy [97]. With this in mind the situation with huge potential for value creating within the offshore wind industry and energy intensive industries, should be kept in mind by the Norwegian policy makers when considering offshore wind.

As Norway is shifting from an oil driven economy, the competitiveness of other Norwegian industries are of great importance. The Hywind project was a great start for Norwegian offshore wind power, but as the industry is growing worldwide, so does the knowledge. A continued clear Norwegian focus on floating wind turbines is therefore necessary in order for Norway to maintain and increase its competitive niche within the offshore wind industry.

## 5.3 Diversifying from an oil and gas driven economy to mitigate future challenges

The petroleum industry have had a great impact for the economic growth in Norway and for financing the Norwegian welfare society. With over 40 years of operations, the industry have created values for more than 12 000 billion NOK in today's money value. In 2012, the petroleum industry stood for 23 % of the value creation in Norway which is more than twice the size of the value creating from the manufacturing industry on land and about 15 times the collected value creation in the other primary industries [98]. Needless to say, there have also been enormous sums invested in the petroleum industry for exploring, building the platforms, transporting infrastructure and land facilities which as of the beginning of 2013 was valued to about 3000 billion NOK in today's value. In 2012 alone 175 billion NOK was invested which correspond to 29% of the total investments in Norway. [98] The production of oil has decreased over the last years as can be seen in Figure 48 while the gas production has increased as seen in Figure 49.

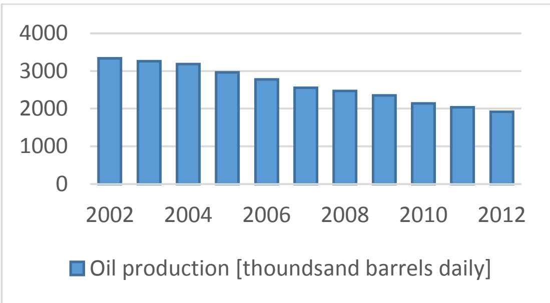


*Figure 48. Oil production in Norway year 2002-2012. [99]*

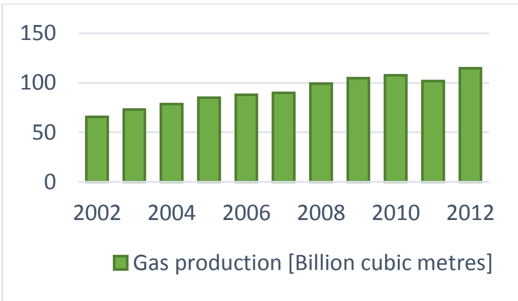


*Figure 49. Gas production in Norway year 2002-2012 [99]*

In august 2013, several political parties argued that no further areas should be opened for oil operations in Norwegian Sea which would mean that about 30 billion barrels would remain untouched. Without additional areas to operate at, the Norwegian oil industry would still be able to produce oil at a high level until about 2022 where it would begin to fall rapidly unless the industry have moved to international markets. As the time from finding oil to producing it usually is about 10 years, there wouldn't be a large immediate effect of not handing out any new licenses. However, in 2025 this would result in reduced incomes of about 10 billion dollar each year. In 2050, these unopened areas would correspond to about 70 % of the production and would therefore lead to drastically reductions in both production and income for the state if remaining unopened. [100]

The consequence of completely relying the economy on natural resources could however be catastrophic as was seen in the Netherlands when they found major natural gas resources in the 1960. The discovery lead to high revenues which in turn dramatically increased the public spending and cost levels [101]. The country experienced an appreciation of the currency, leading to problems for the manufacturing industry.

Norway is experiencing something similar today with increasing wages and price levels making it harder for manufacturing industry to stay in Norway. This has led to that several companies have moved their production abroad, e.g. the shipping giant Frontline [102]. The increasing wages in Norway induced by the oil revenues is driving companies out of Norway and pushing the labour force to the oil industry to a higher degree. When the prosperity of the oil ends or significantly decreases Norway risk having a weak base industry to rely on [102]. Engaging in offshore wind can be a solution, where a lot of the expertise achieved from the O&G industry can be transferred. However, as new industry takes time to develop and optimize a diversification should start now.

Today, around 150 000 people are working directly connected to O&G industry in Norway and an additional 100 000 works indirectly towards it through other services e.g. transport, property, IT, revision etc. [103]. Although a small population and oil wealth have always given Norway the luxury of being a welfare nation, these oil resources will not last forever. As the fields of Norway continue to mature and the natural resources are depleting, it will likely be necessary to diversify the economic outlook as the economic wealth of Norway today is almost exclusively based on its resource wealth [104]. With the ongoing globalization, this could become a risk for Norway if disregarded further as the country has invited few foreign industries into its domestic markets, except in the hydrocarbon sector [104]. The worldwide market is expanding rapidly and Norway has to join in to endure in a world of globalized competition by increasing its global influence within the energy sector as a whole [104]. With Norway's extensive expertise and knowledge within the offshore industry, floating wind power opens a path for excessive opportunities and possibilities to diversify from the O&G sector.

During the last 20 years, the expansion of offshore wind power has been fairly slow, but is finally taking off. In 2011 a total of 140 GW of projects at various stages have been identified throughout Europe. The floating wind power technology is developing rapidly and opens a path for many opportunities for Norway as they have a unique energy, offshore and maritime heritage [51] as a leading nation in shipping industry with:

- 40 years of offshore exploration and production
- 100 years of renewables with hydro and wind power
- Yards and port facilities suited for the deep offshore market
- Both onshore and offshore including interconnectors

With Norway's world leading offshore and energy experience, Norway has gained competitive advantages within the offshore wind supply chain where the technological and operational expertise are considered the most valuable. Besides the expertise of supplying components and services, Norway also has great knowledge in the development of technologies and the management of offshore risks [51]. By applying their skills and supply chain assets in the segment of offshore wind, Norway has great potential for diversifications and new value creation. As the floating wind power industry has just come to life, Norway could use its already existing offshore expertise to become a world leading nation for projecting and constructing floating wind power all over the world. However, with the Hywind project of five 6MW turbines being planned for a demonstration park in Buchan Deep outside Scotland, UK might already be a step ahead in the competition for floating power development, leading the way with ambitious plans and strong policy support schemes.

Norway needs to act soon to avoid falling behind and miss the chance to use the competition advantages they have in the development of this new technology, ranging from technology development and construction to offshore services and risk management. It includes stakeholders in offshore O&G industry, shipping, yards and port facilities, grid connections, etc. By applying Norway's skills and supply chain assets in the new offshore wind market segment, the potential for diversification and new value creation in the supply chain, services, research and development is considerable. [51] Although Norway currently may not have any large wind turbine manufacturers, they have a unique foundation manufacturing segment from constructing steel and concrete foundations for the O&G industry which represents a market in the range of NOK 45 billion per year towards 2020 in Europe alone. Norway also have a great position considering their yards and access to deep fjords providing suitable locations for sheltering the fabrication and assembly of future innovative pre-assembled units [51]. The seabed conditions of Norway is similar to the ones of Japan, US, Korea and China, which creates opportunities for Norway to develop deep offshore technologies which could be exported to these huge markets. [44]

Independent of if the new areas will be left untouched or not, the oil resources in Norway are limited while the vast wind resources of the deep oceans lies untouched. Sooner or later, Norway has to diversify from the O&G industry and the opportunity to use their already existing expertise within the offshore industry and apply it to the offshore wind power industry is a great way to begin.

A test park would result in new work opportunities, both directly in development, construction and operation as well as indirectly in forms of transport, IT, revision, and hotel and restaurant services. With approximately 250 000 people working directly or indirectly within the O&G industry, a decline in oil demand could result in an increased unemployment rate over time. However, as a large part of the companies and employees have considerable expertise and experience from technologies and knowledge applicable for offshore floating wind power, establishing a larger industry around it could greatly mitigate the problem. The huge worldwide markets awaits to be exploited by the Norwegian expertise within the offshore and maritime industry.

Moreover, new power production in Norway would in the long term enable a steady growth of energy intensive industries. Norway is already a world leading producer of aluminium and with the recent implementation from the Norwegian government to compensate energy intensive industries for the $CO_2$-tax cost, there is an increased interest in expanding the industry in Norway [105]

The enabling of growth in energy intensive industries could enhance the mentioned "insurance policy" for Norway in order to minimize the effects of a drop in demand of Norwegian Oil. Norway could thereby become a key player both within offshore wind and energy intensive industry, securing future employment rate and economic growth and further diversifying the economy.

To summarize, Norway's extensive unique heritage, expertise and knowledge within the offshore industry has given them opportunities and competition advantages to become a world leader within the floating wind development. It is essential for Norway to take part in the early development to guarantee its ability to exploit this vast potential for value creation with this new large export industry and at the same time diversify from the depleting resources of the O&G industry. This would both mitigate the losses of incomes from the oil industry and employee opportunities over time.

## 5.4 Reduce impact of dry years and enable export of hydro power

Given that the electricity production in Norway is almost entirely hydro power based, there is a risk connected to years with low level of precipitation. Large amounts of wind power could reduce the risk of insufficient power supply in dry years, and would be especially beneficial in combination with pumped hydro storage [18].

More wind power in Norway could also make hydro power in Norway available for export to other European countries [106]. The hydro power could then be sold at a higher electricity price, when demand is high, in times of low renewable power production, compensating the higher development cost of offshore wind.

The North Sea area could be viewed upon as one market, with a potential future shared power grid. In such a scenario, Norwegian hydro power plays a vital role. Increased power production in Norway is however necessary in order to enable the hydro power for export to a higher degree.

## 5.5 Reduce greenhouse gas emissions

The GHG emissions from the Norwegian electricity production are among the lowest in the world with approximately 16 $gCO_2$-ekvivalents per kWh [107]. The low average $CO_2$-emission is due to the predominant role of hydropower in the electricity generation, covering about 98% of the production. Even though the average amount of $CO_2$ per kWh produced has increased in recent years following the commissioning of gas-fired facilities, from 3 $gCO_2$ per kWh in 2008 [108], the emissions is still significantly lower compared to the average emissions of other areas seen in Figure 50.

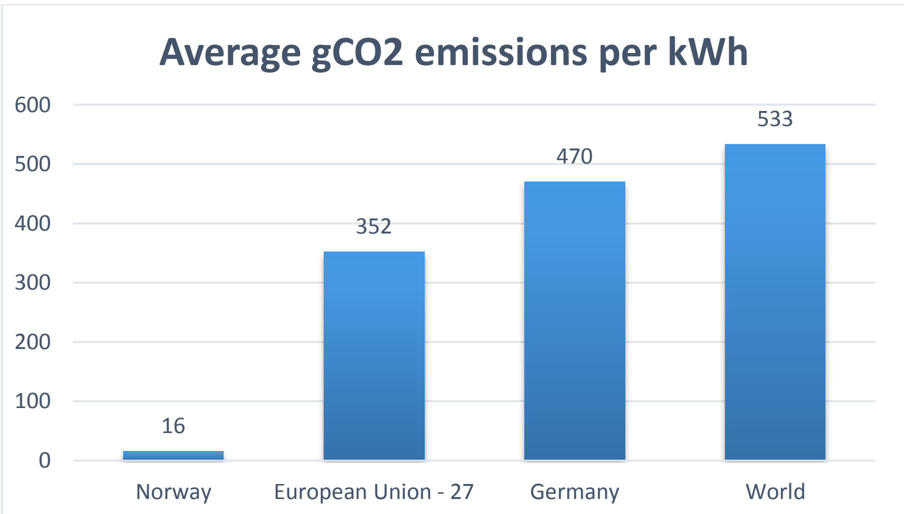


*Figure 50. Average CO2 emissions per kWh from electricity production [108].*

In this aspect, some might consider it unnecessary to continue to build renewable energy and that it rather should be built somewhere else, i.e. in a country with higher emissions. However, Norway has one of the highest energy usage per capita in the world [99] and due to the high energy use in other sectors, have a rather high total emissions per capita compared to other European countries. The average Norwegian emissions per capita is 8.01 tonne $CO_2$-emissions/capita while the EU (European Union – 27) average is only 7.29 tonne $CO_2$-emissions/capita. [107]. The O&G extraction generate a large part of the Norwegian emissions with about 13.7 million tonnes of $CO_2$-equivalents corresponding to roughly 26 % of Norway's total emissions in 2012 [109]. An electrification of the O&G fields could therefore dramatically reduce the $CO_2$ and $NO_x$ emissions and thus provide significant environmental advantages to help battle climate change.

Additional renewable power production also enables additional export potential of hydro power to e.g. Germany and other countries on the continent with significant higher emissions and therefore reducing the average emissions in Europe and the world. As mentioned earlier, building a large test park increases the expertise and experience of floating wind power as well as it has the potential to decrease the LCOE further. This knowledge could then both be used to continue building offshore wind power decreasing the global emissions as well as increase the possibilities for Norway to electrify the O&G platforms in the North Sea at a lower cost.

# 6 The Norwegian industry perspective

The following chapter is a compilation of an interview study and a web-based company survey carried out in the thesis. The results are displayed in two sections both graphically and in free text and should highlight the industries point of view for issues concerning a Norwegian offshore wind industry.

## 6.1 Company Survey questionnaire

In order to get the industry perspective of the Norwegian offshore wind market, a questionnaire was sent out to Norwegian companies involved in offshore wind business in Norway. A list with these companies were provided by *Norwegian Energy Partners (INTPOW)*. The full question list and introduction text can be seen in Appendix 7 – Company survey and interviews. The main purpose of the survey was to highlight the industries point of view for the future of the Norwegian offshore wind sector.

The questionnaire was answered by totally 50 different individuals from Norwegian companies and interest groups involved within the offshore wind sector. These participants are displayed in "Acknowledgements" at the beginning of the thesis. The questionnaire was firstly sent out to 230 companies, however as the company list was a few years old, some of them had shut down or quit the offshore wind business. As no questions were obligatory in order to complete the survey, there are some questions that have been skipped by several participants. Some questions have a relatively high rate of skipped answers but this is mostly due to an automatic function of the survey, where some questions only will turn up for participants if they answered a certain way in a previous question.

The survey comprised 28 questions with the first two identifying the name and company name of the participant. Thereafter a couple of questions were categorising in which area the company is active both nationally and internationally within offshore wind. These questions also involves the participant's belief of Norway's national and international role within the industry. Following these questions, the participants were asked about their company's future strategy for offshore wind and the importance of diversifying from the O&G business. The participants were then asked for a free text answer of what they think is necessary to reduce the risks associated with investing resources in offshore wind in Norway. The last questions concerns possible subsidy options and cost reductions pathways for offshore wind.

### 6.1.1 Analyses of the company survey results

The answers of the questionnaire are hereunder condensed to some of the most common denominators and thoughts given. However, there are many other interesting opinions mentioned in the free text answers and these should therefore be studied separately. The questionnaire figures not displayed in chapter 6 and all of the free text answers are instead displayed in Appendix 7 – Company survey and interviews.

#### *6.1.1.1 Supply chain*

Starting studying the first few questions of the survey which are highlighting the supply chain of the Norwegian offshore wind industry, it can be seen in Figure 51 and Figure 52 that the entire value chain is covered among the participating companies. However, it is a clear focus on research and development among Norwegian stakeholders both nationally and internationally. The spread of services supplied by Norwegian companies shows great potential for a high national part of value creation if developing an offshore wind project in Norway.

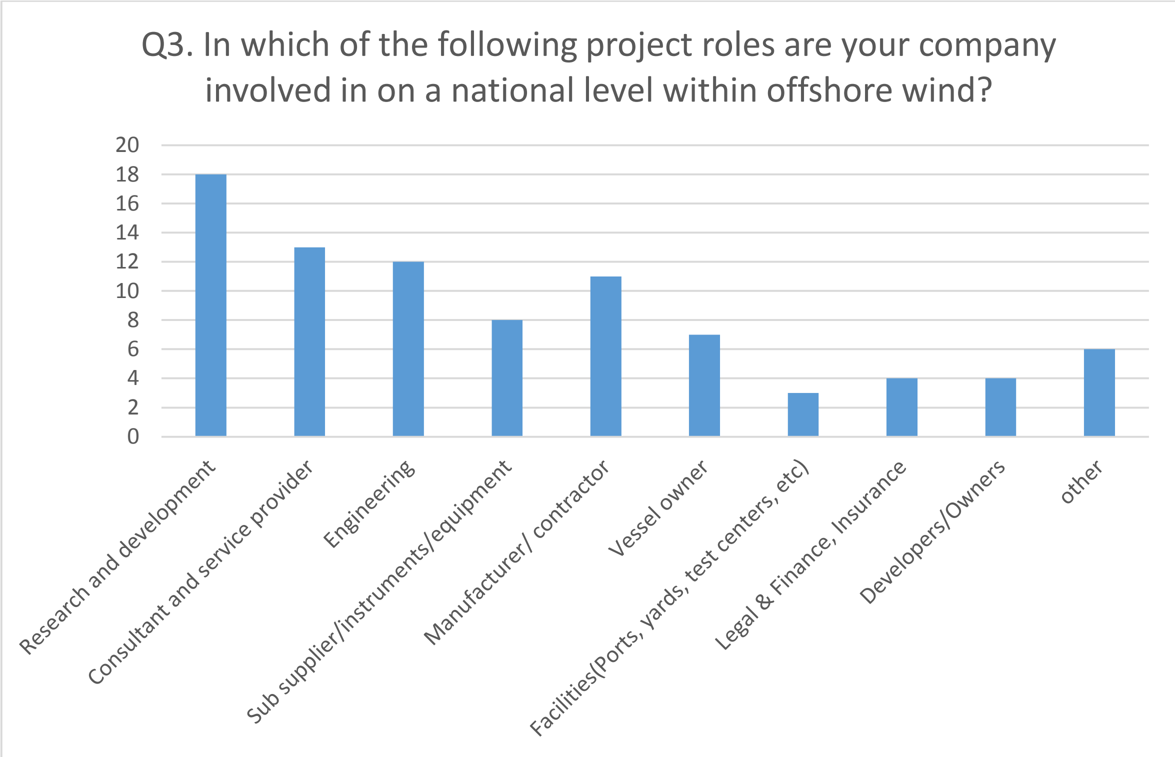


*Figure 51. Number of participants involved in different project roles on a national level, covering the entire offshore wind supply chain.*

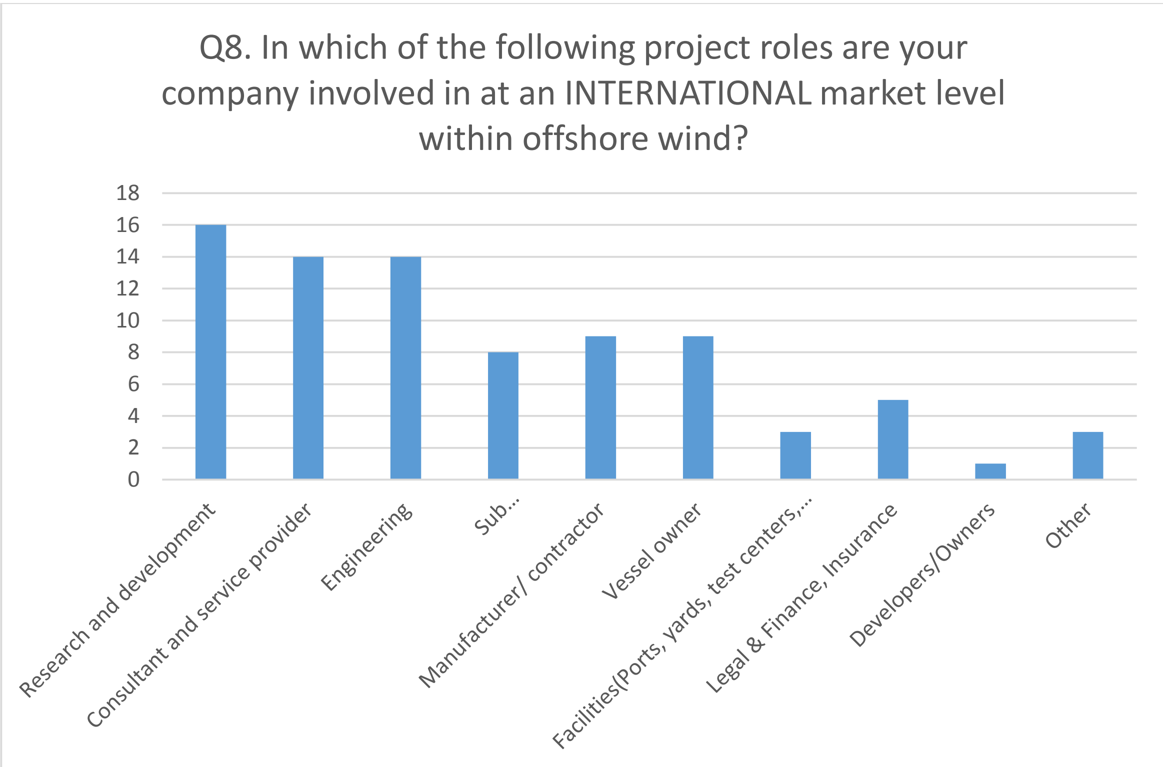


*Figure 52. Number of participants involved in different project roles on an international level, covering the entire offshore wind supply chain.*

#### 6.1.1.2 Future outlook

There is a strong belief among the participants concerning a future national offshore wind market, as seen in Figure 53, where 80% stated that such a market would be possible within 15 years. Furthermore, as seen in Figure 54, roughly 75% of the participants believe that Norway can become a key player on the international offshore wind market within the next 15 years. On the other hand, as seen in Figure 55, as much as 86% declared that offshore wind in Norway will not be developed without a change in the subsidiary system. Comparing these two answers indicate that Norwegian companies considers that Norway has the potential and possibility of realizing a national offshore wind market, but that it will require some further governmental aid.

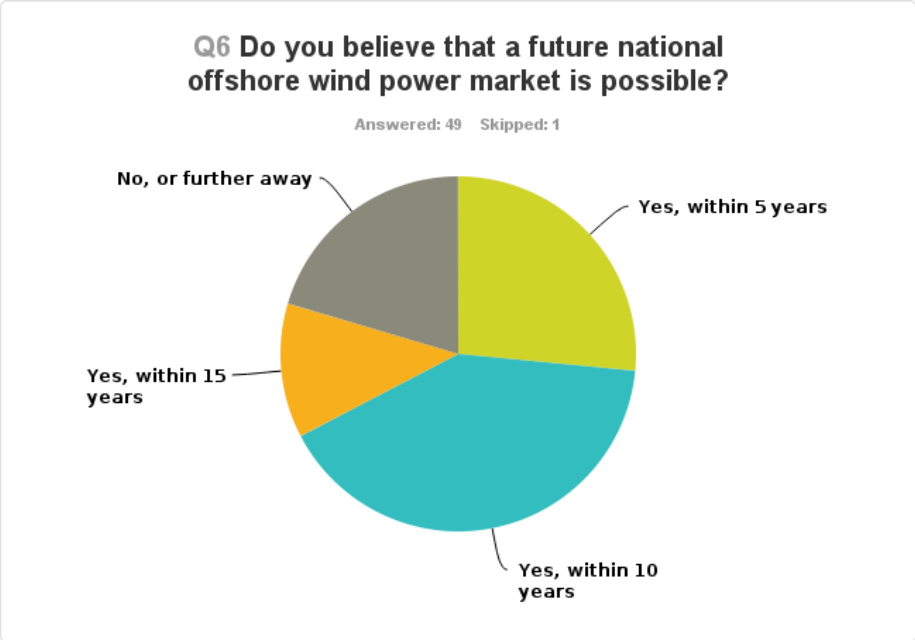


*Figure 53. Question investigating the possibility of realizing a future offshore wind market in Norway.*

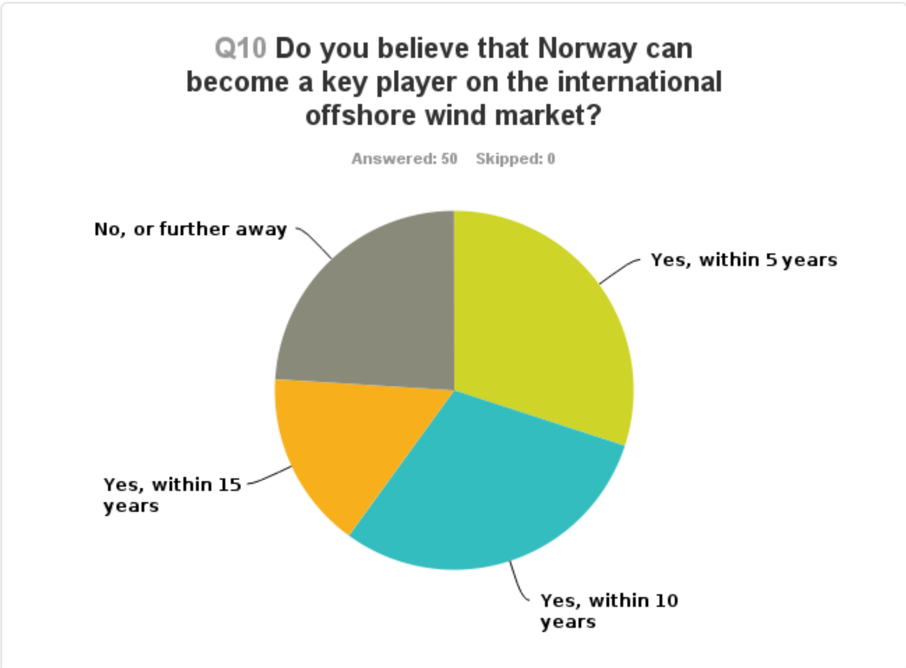


*Figure 54. The possibility for Norway to become a key player on the international offshore wind market.*

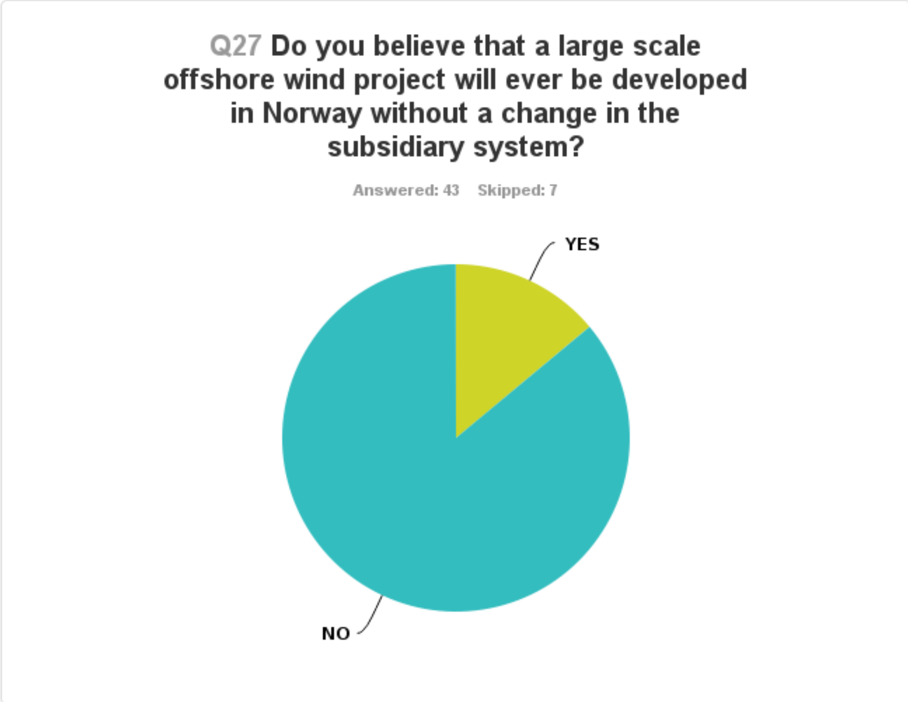


*Figure 55. The belief of a future offshore wind market in Norway without a change of the current support scheme.*

#### 6.1.1.3 International market and competition

Figure 56 indicates that 76% of the companies are involved in offshore wind at an international level. However, Figure 57 shows that as many as 43% believes that the competition makes it difficult for them to establish their companies on an international level. All the larger offshore wind nations competing can rely on a solid home market in order to deliver their competence internationally, for example UK, Germany and Denmark. The fact that 76% of the companies state that they are involved internationally and some of them still thinks that competition is a barrier indicates that it might be difficult to stay in the market without a reliable home market.

As seen in Figure 58, many companies plan to expand the business segment offshore wind, and several of these strategies, seen in Table 23 in Appendix 7, are to take their business international. A national test park could help these companies to better establish their business internationally by providing a possibility to showcase and test their product and services.

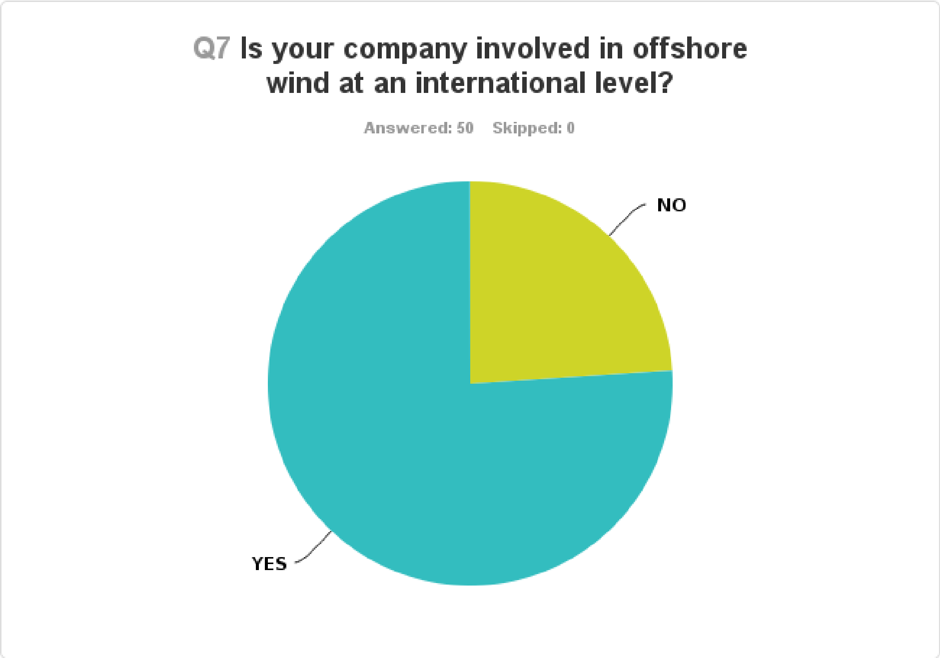


*Figure 56. The participants involvement on the international offshore wind market.*

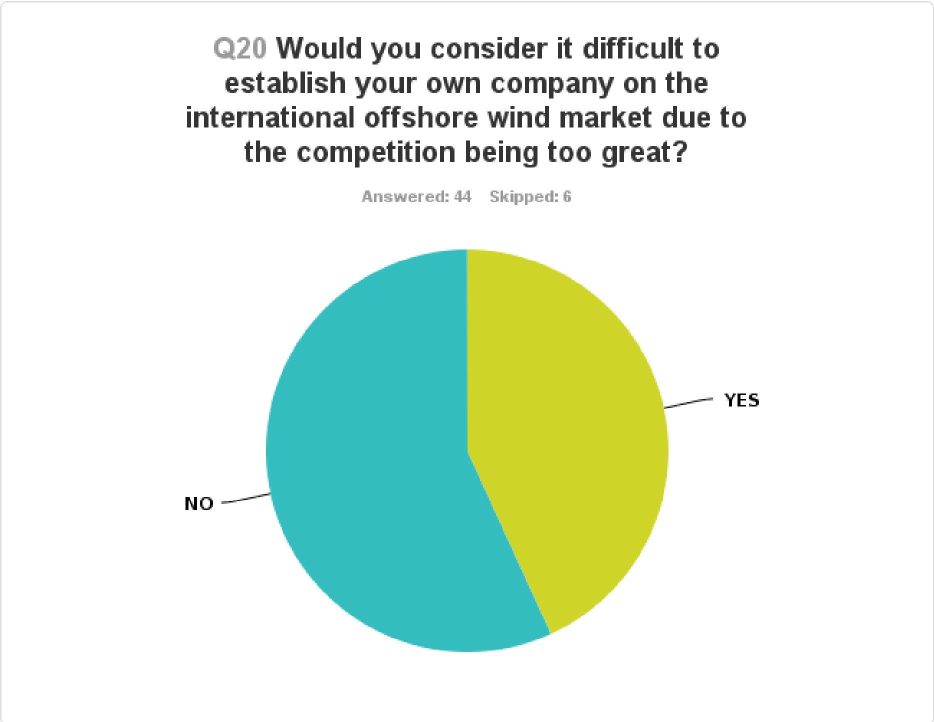


*Figure 57. The participants thoughts of if the competition makes it difficult to establish the company on the international market.*

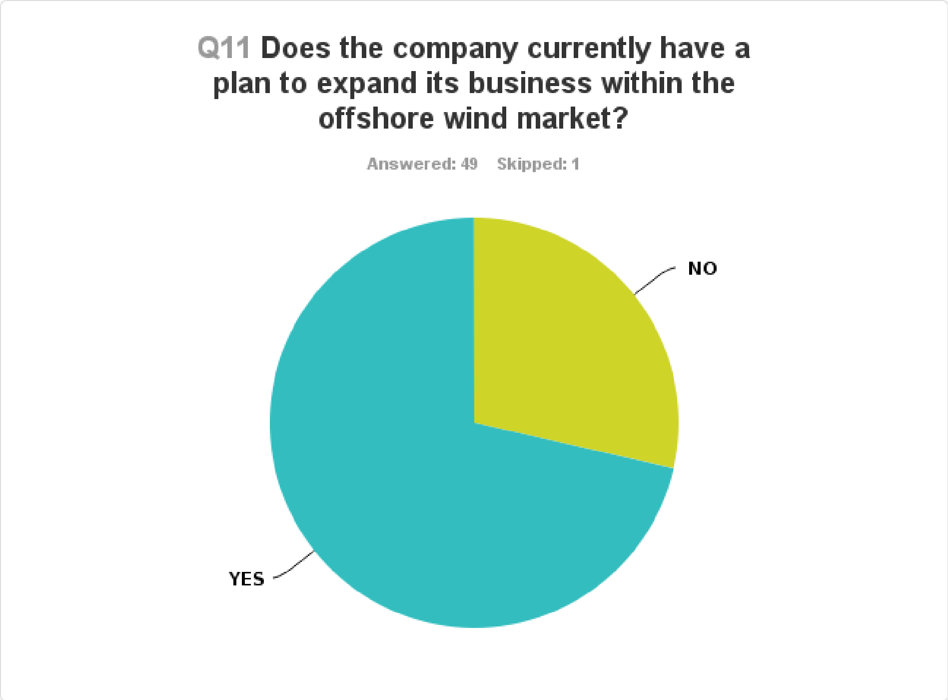


*Figure 58. The answers to the question if the participants are planning to expand the bussiness segment offshore wind*

#### *6.1.1.4 Norwegian offshore wind policy*

Figure 59 shows that 80% of the companies that had no current plans on expansion of the offshore wind sector stated that this was either due to the lack of a clear national policy or the lack of clear incentives from politicians. Moreover, the participants were asked what is needed in order to lower the risks associated with investing resources in offshore wind and the answers can be viewed in Table 24 in Appendix 7. It can be seen that many of the suggestions are similar to each other, where the need of a clear long term policy and plans for offshore wind are the most reoccurring aspects by the participants. These are expressed in a somewhat different way, but in general the companies seems to be implying that Norway needs to have more clear goals and plans for offshore wind in order for suppliers to plan their business and feel confident in engaging in the offshore wind industry. The answers of the survey indicates that current interest in offshore wind is great among Norwegian suppliers, but there is a possibility that these suppliers will lose their interest if no further incentives are provided by Norwegian government in the next couple of years [56]. An argument supported by the answers of the survey, which could erase the possibility of a future national market for offshore wind.

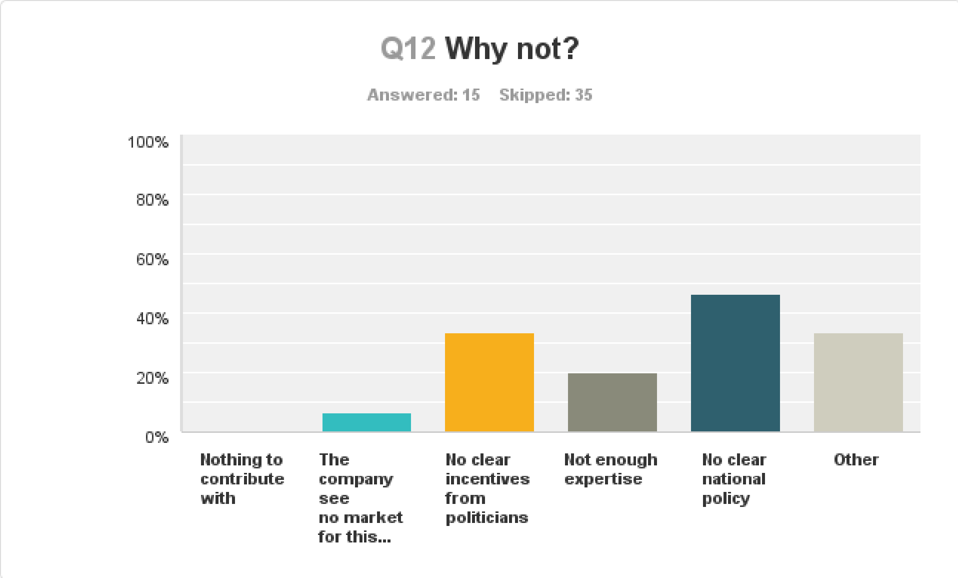


*Figure 59. Participants asked why they are not planning to expand their offshore wind bussiness*

#### 6.1.1.5 Diversifying from oil and gas

One key benefit of developing offshore wind in Norway discussed in this thesis is the potential for Norway to diversify their economy from the nation's very high economic O&G dependency. The participants were asked how important they experienced this and the results are shown in Figure 60 show that 98% of the participants thought it was either important or very important. Moreover, the companies that had stated that they almost exclusively worked towards the O&G industry were asked about the importance to diversify their business. The result shown in Figure 61 shows that all these companies thought that it was either "important" or "very important" to diversify from the O&G sector. The results indicates that they believe there is a risk in relying too much on the O&G industry and that it's positive to have a diverse industry in Norway.

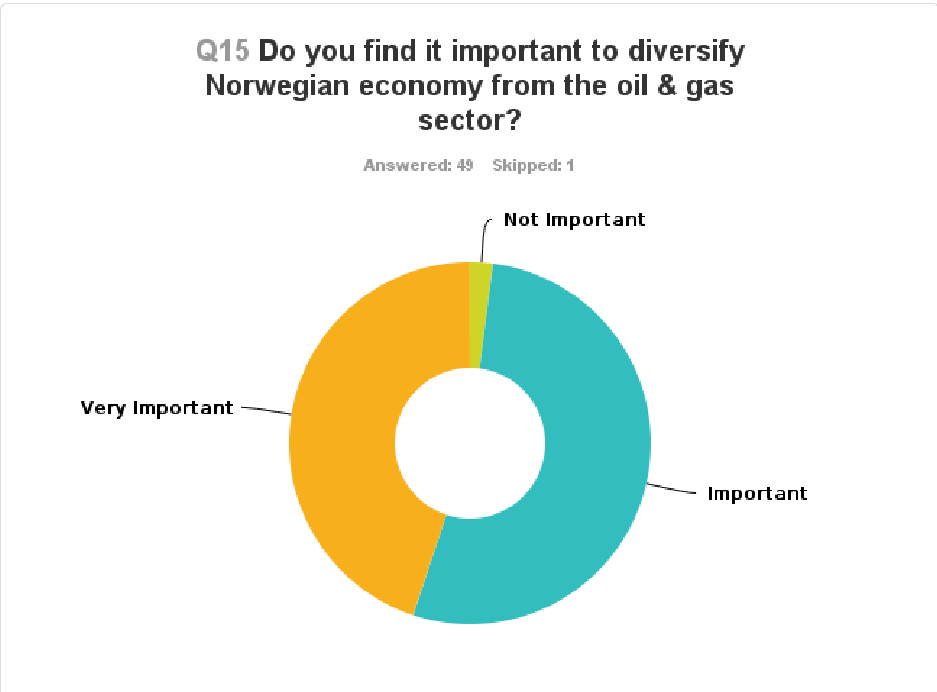


*Figure 60. The importance of diversification of Norwegian economy*


*Figure 61. The importance of diversification within the company*

### 6.1.1.6 Subsidy

When the survey participants were asked what type of subsidy that would be most suitable for offshore wind in Norway, there was a clear spread among the answers as seen in Figure 62. However, all the alternatives stated in the question meant a change compared to today's subsidy scheme. Together roughly 70% thought that either a feed in tariff, investment subsidy, increased green certificates or project bidding would be suitable for Norway. On the other hand, 27% stated that they did not know which form of subsidy that would be suitable.

Participants were also asked what total price (paid electricity price + subsidy aid) that is required in order to develop offshore wind projects in Norway. Almost half of the companies gave the answer "Don't know", which could be explained by that this is a question that require a deeper knowledge of the power market, and that many of the participants are only sub-suppliers to offshore wind, with little knowledge of the electricity price dynamics and its correlation to the profitability of the project.

Among the rest of the answers, as shown in Figure 63, 84% stated that a total price of 0.8-1.1 NOK/kWh or higher is needed for offshore wind power development in Norway. If compared with the current situation with a total price of 0.51 NOK/kWh [110, 111] it is a clear gap between the price needed according to the industry and the market price. Clearly no larger offshore wind projects are being developed in Norway and if Norwegian government wants a national offshore wind market in Norway, a change of the subsidy system is needed. An argument further backed by the answer of question 27 which implied that Norwegian stakeholders have no belief in a national large scale offshore wind project without a change in the support scheme.

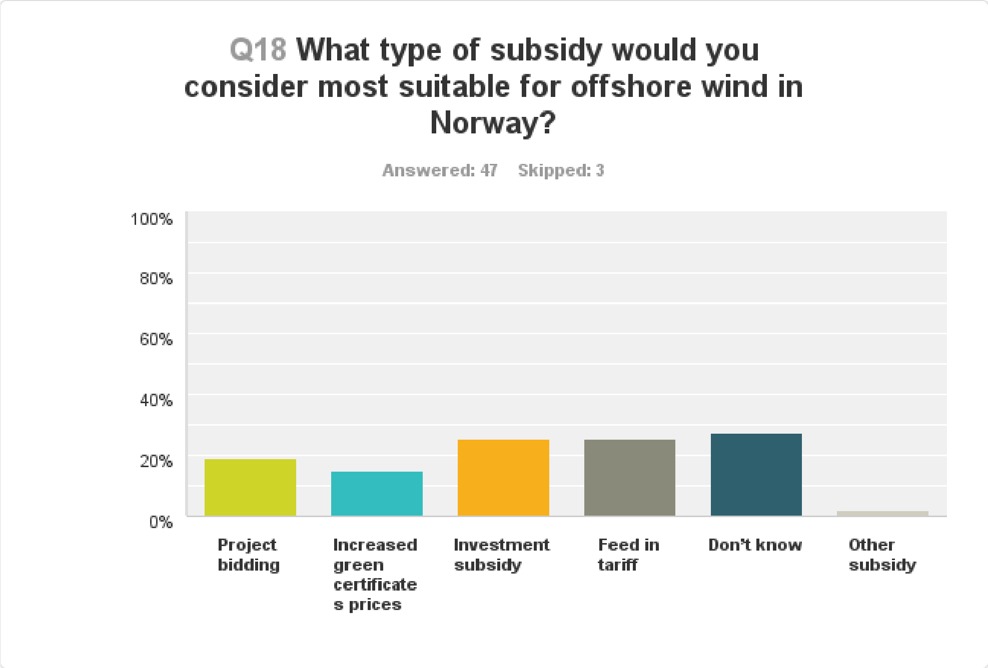


*Figure 62. Potential suitable support schemes for offshore wind in Norway*

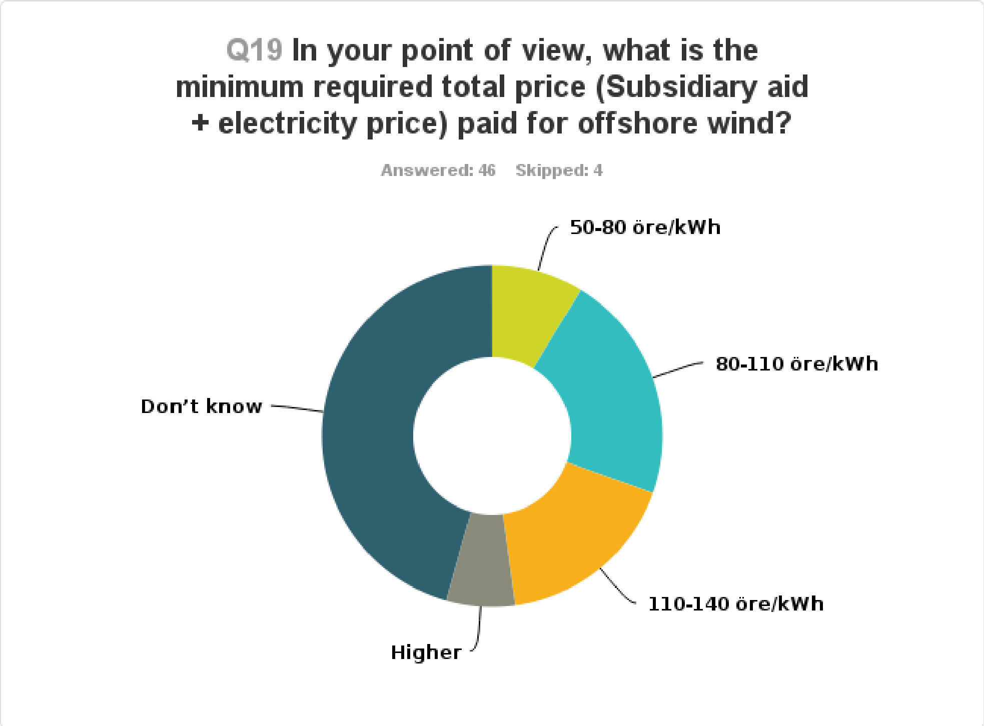


*Figure 63. Required system electricity price for offshore wind power development in Norway*

#### 6.1.1.7 New international transmission lines

The participants were asked if they thought that new international transmission lines are required in order to get the national offshore wind market going. The results displayed in Figure 64 shows that 84% believed that new transmission lines, including the planned cables to UK and Germany, are "important" or "very important" in order for Norway to establish a home market.

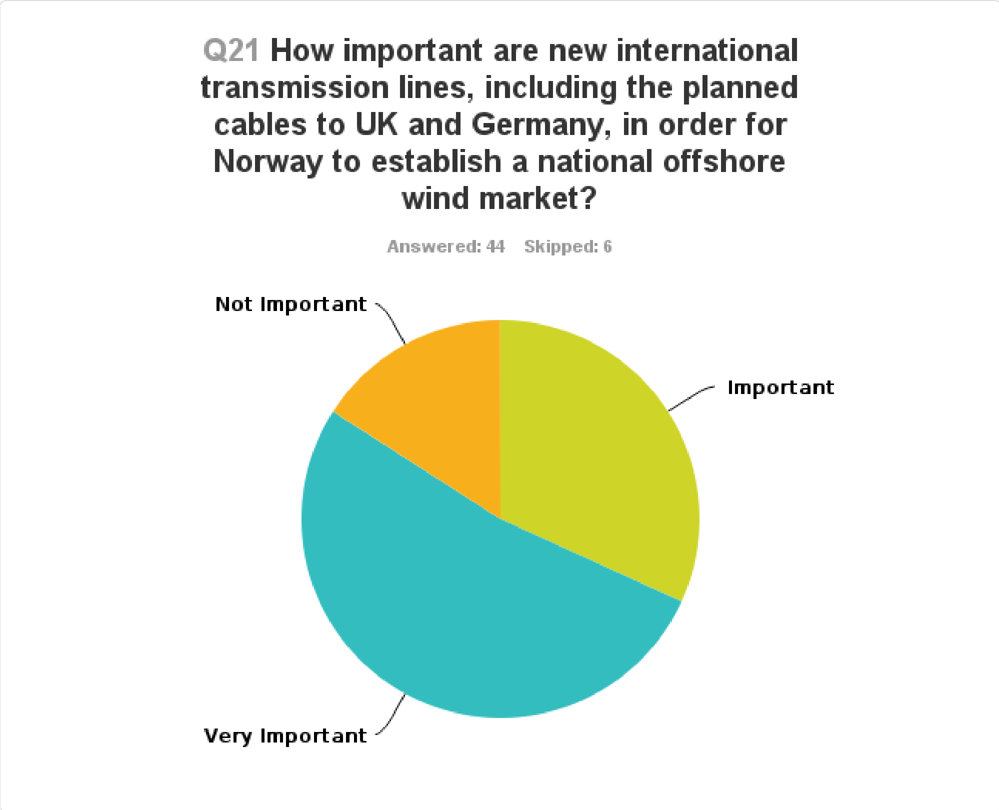


*Figure 64. The importance of new tranmission lines for the development of Norwegian offshore wind*

#### 6.1.1.8 Cost reduction for offshore wind

The participants were asked how and to what extent they thought cost reduction were possible, both for their actual service and for offshore wind as a whole. The quantitative results displayed in Figure 65 and Figure 66 shows that the cost reduction estimates are ranging from 0-40% for the 5 years alternative, 0-50% for the 10 year alternative and 0-60% for the 15 years alternative. 31% cost reduction of the overall cost connected to offshore wind was believed as and average result among the participants in the 15 year ahead alternative. Given the industry estimates of cost reduction, expected future electricity price should be compared with this to investigate if it is likely that offshore wind will be developed at all within such a time frame.

Specific actions from each company in order to lower the costs can be seen in the free text answer sheet in Table 25 in Appendix 7. Many ideas and solutions for cost reduction were e.g. using existing knowledge and technology, better standardization of production and development, simplifying all processes, larger wind turbines, economies of scale, more effective installation vessels, and better park optimization. Several other more detailed solutions were mentioned, but these are the most stated pathways for cost reduction in the survey.

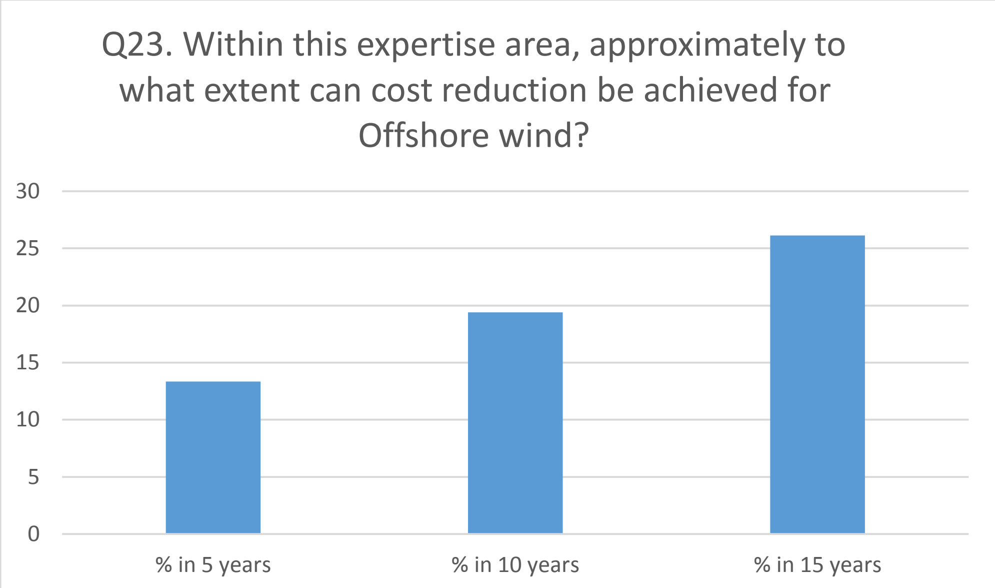


*Figure 65. Cost reduction potential for company specific services*

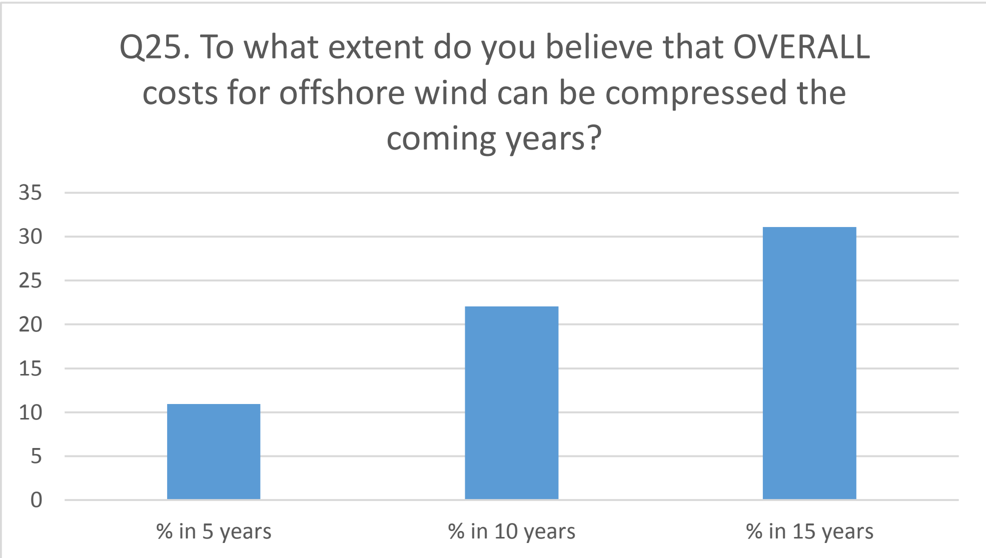


*Figure 66. Participants belief of overall offshore wind cost reductions in 5, 10 and 15 years ahead.*

#### 6.1.1.9 Floating offshore wind power

The companies were asked if it was important for Norway to establish either a test park or a stronger policy towards offshore wind power in order to become an industry leader within the area of floating wind power and the results is shown in Figure 67. The results show that 57% of the companies believed that a stronger policy is needed and 50% thought that developing a test park for floating wind power was important. 20% suggested other alternatives and thoughts considering floating wind power, where a few companies stated that floating wind should be developed abroad where it is needed and are better incentives. As shown in Table 26 in Appendix 7, another idea was the development of "Statwind" (similar to Statoil) with responsibility of development, choosing and installation of new innovative wind technology.

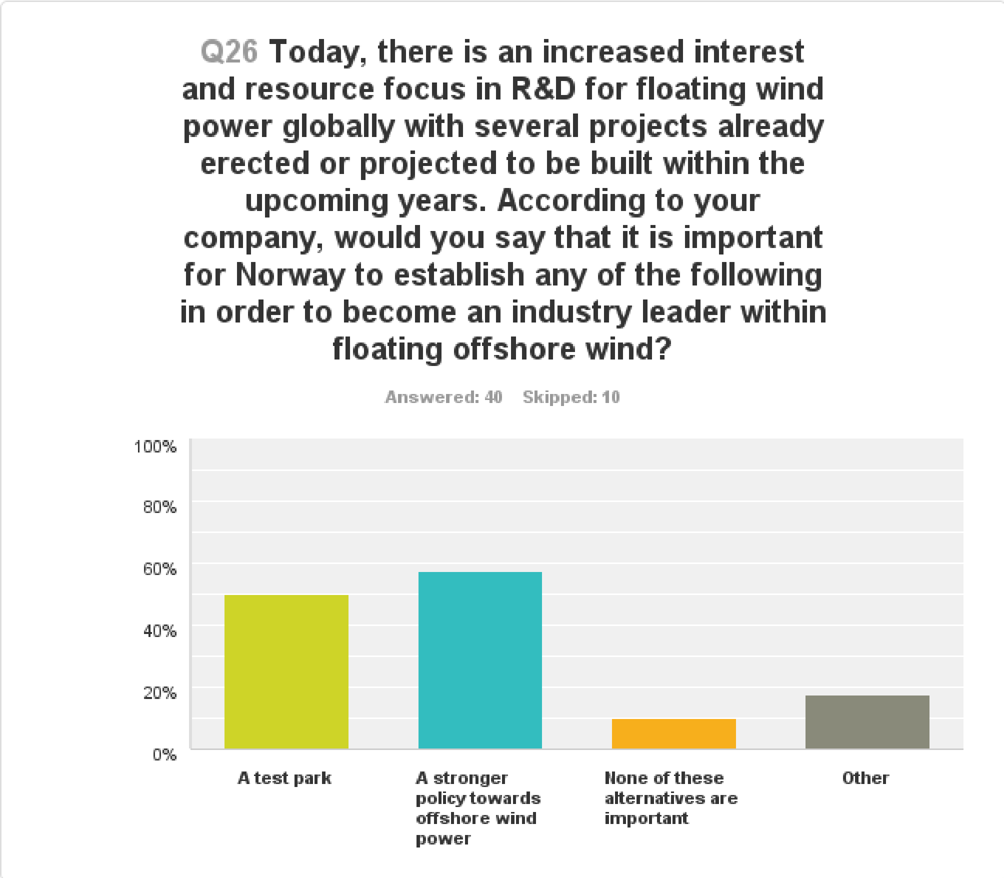


*Figure 67. Important actions for Norway in order to become an industry leader within floating offshore wind*

## 6.2 Interview study

The following section is a summary of 8 interviews [56] conducted during the thesis. Some of the interviewed persons have wished for anonymity and the companies are therefore referred to as Ref 1-8. The interviewed persons all represent key stakeholders and leaders within offshore wind in Norway, but according to the method of the thesis, each interview has been conducted in a certain manner. It is therefore important to keep in mind that several of the statements listed below are thoughts of individuals even though there are some common denominators. The material is however condensed hereunder to a few key aspects of offshore wind in Norway:

- **The future and potential of Norwegian offshore wind**
- **What needs to be done**
- **Pathways for cost reduction**

### 6.2.1 Future of Norwegian offshore wind

Several companies indicates that they previously worked almost exclusively with O&G, but have started to adopt offshore wind business, which show that the knowledge is transferable making Norway suitable for offshore wind business. This is something that is backed by the rest of the interviewed persons which all have a very strong belief in Norwegian offshore competence. In fact Ref 5 means that Norway already has the experience and potential to develop a large scale demonstration park within the next five years, but in order for this to happen the government needs to take a lead and show the way for the industry. A large amount of resources and time have already been invested in offshore wind in Norway and industry still holds a rather large interest, but if no further incentives are set into play, there is a risk that Norwegian suppliers will quite the business. According to Ref 7 this would be devastating since he means that Norway has a great potential to use the first mover advantage for floating wind power and all the benefits that comes with it. Ref 5 thinks that both a floating wind power test park and a bottom fixed could be valuable options since Norway has the expertise to deploy both of these and has a great potential for export within both areas. However if one were to choose between them, Norwegian investment should be focused on a floating wind power demonstration park.

According to Ref 1 and 8, when it comes to offshore wind in the short term for power production in Norway it will mostly be used for electricity export and potentially for integration and electrification of the O&G platforms. The latter part is dependent of that the O&G companies would actually see this as a good economic alternative. When it comes to the export, new transmissions lines are needed if Norway would expand its renewable power production. This would also allow for Norway to a higher degree export its balancing power resources, which could be exported to a very beneficial price level. Ref 8 lifts the mentioned power export as the new "Oil" for Norway.

The possibility to use existing knowledge in Norway is tremendous and the market value of offshore wind is expected to 100 billion NOK/year towards 2020. According to Ref 5, Norway's part of this could be 10 %, which means a relative export potential corresponding to the size of today's fishery and aquaculture.

Ref 2 and 6 believes that it will be difficult for Norway to export the actual foundations since the cost of the transportation will never make it profitable. They mean that these costs are high due to the very large size of the structures. Furthermore they all believe in concrete as a future construction material for mass production. Ref 6 notes that one of the key benefits with concrete structures is that it can pretty much be produced everywhere which, according to Ref 2, means that the costs for concrete structures are connected to the labour cost to a much higher degree compared to steel. They all believe that Norway has a very strong tradition and competence in building large offshore concrete structures, but due to the reasons noted, this expertise should be used to construct the foundations near deployment. Furthermore they all state that the harbours and yards of south west Norway could be used for production of foundations for a test park as the one investigated in this thesis.

There is a common consensus among the interviewed persons that wind power could be used to electrify O&G production to some degree. Many of the offshore installations in Norway are in deep water, hence floating wind power would be the most attractive solution. Ref 5 however, means that the O&G companies often see this investment as unnecessary and would instead rely on a complete electrification from the mainland with a cable, but using wind power would be more valuable for Norway in terms of social economic benefit. He does however state that such an installation would be more complex and therefore result in a higher risk, something that the O&G companies always tries to minimize.

### 6.2.2 What needs to be done

There is a clear consensus that cost needs to be reduced in order to attract developers to offshore wind. However according to Ref 1 the cost reductions will not happen without a change towards a more long term subsidy plan. A clearer policy could attract investments that is needed in order to achieve cost reduction. Ref 1 further indicates that "they are both dependent of each other and clearer policy is needed in order to increase investment within the industry that can result in cost reductions.

It will be hard to develop the industry in right direction and a sufficient supply chain without either of them."

New transmission cables are mentioned several times as a way to induce the development of offshore wind in Norway. Such new connections to Europe would expose Norway to foreign energy markets and most likely raise the electricity price. The total value for Norway could however be great since the hydropower could be used for export when prices are high on the continent. The other way around Norway could import cheap electricity when there is an abundance of power supply in connected markets, storing it in pumped hydro storage. Ref 7 however, states that this potential is great, but that the window of opportunity is now, and if investment in such projects are held up for too long, concerned countries might look for other alternatives.

One of the main positive effects of renewable energy development in Norway derived from new transmission lines is that it will increase the electricity price which would make it more profitable for such an industry in Norway. Another major reason is that the common counter argument against renewable power in Norway that the Nordic region is heading for a power oversupply, would be less viable since times with oversupply could be used for export or hydro storage for future export. This argument is further supported with the fact that several of the interview participants means that wind power and hydro power is a great match when considering a larger system. New transmission lines can also act as a connection hub for offshore wind power plants and O&G installations, which could reduce the cost for offshore wind development and the electrification of O&G platforms.

Several interviewees indicated that a test park would be needed in order to develop a home market and to be able to compete on the international market. Even if some larger Norwegian companies like Statoil and Statkraft already are involved in large offshore wind projects without an existing home market, several of the interviews highlight that many companies are rather small and would be more dependent of a solid home market in order to go international with its business.

A test park could be of different layouts, either focusing on one concepts or be a test facility for different innovative concepts and ideas. Ref 5 means that both these alternatives have their corresponding advantages and disadvantages. If a smaller test park with different concepts would be erected this would enable an operator to charge foreign technology developers to test their products. However this park could have a problem in not being large enough to be able to develop a strong supply chain in Norway for export. A large scale park would be able to handle this, but would also mean a higher risk as this would be a larger investment as well as a more narrowed investment.

In order to reduce the financial risk, several subsidy types are discussed in the interviews. However interviews indicate that a feed in tariff could be a possible long term subsidy plan, but that a direct investment support might be a better option for a test park, in order to attract investors since the cost of such a project are very uncertain. Ref 5 means that the already implemented green certificate system could be used, but instead offer maybe two or three certificates for offshore wind instead of only one.

### 6.2.3 Pathways for cost reduction

As mentioned above cost reduction is one of the key barriers in order to get the offshore wind industry going in Norway. Question concerning different pathways were therefore discussed with the participants. Commonly mentioned areas for cost reduction were as follows:

- More effective installation process, assembly and transportation
- More effective O&M and changing of large components
- Standardization within all parts of the value chain
- Industrialization of foundation production

Several solutions for these areas were mentioned by some of the participants. For some floating wind turbine concepts, special purpose vessels needs to be developed in order to lower installation costs but these are large investments, therefore vessel producers need to be certain of a future market. This means that floating wind turbines must come first, and a clearer policy.

Concrete has a large potential for cost reduction if the units are mass produced, but for single turbines it's usually easier to use steel. However Ref 5 thought that Steel would be very suitable for mass production in Norway as well and not necessarily more expensive, since for Spar concepts, it resembles the turbine towers a lot and the same kind of construction method and facilities could be used.

## 6.3 Summary of industry thoughts

Chapter 6 highlighted some thoughts of the Norwegian offshore wind industry which was acquired from several interviews with key stakeholders and a web based survey. The general opinion is that Norway has a great possibility of using existing maritime and O&G expertise to develop a national supply chain within offshore wind. Due to the great international competition a home market is needed, that could be developed by establishing a test park for offshore wind in Norway. The potential for export of supply chain is great and the development of new offshore wind power production in Norway could be used for electricity export and electrification of O&G facilities.

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 force up the electricity price, making it more profitable with new power production, and serve as the start of a European super grid, with offshore wind power plants as nods.

Connecting offshore wind to offshore O&G production is an important step in reducing the Norwegian greenhouse gas emissions and making the technology commercial.

# 7 Future outlook

The future of the offshore wind development is very uncertain and will depend on several factors where the cost reduction is a vital part, and the development of the Nordic electricity price level another. Both these parameters in turn are influenced by a tremendous amount of underlying elements, making these kind of estimates extremely uncertain. However in this chapter the probability of an offshore wind development in Norway is investigated, with the assumption of an unchanged subsidy scheme.

## 7.1 Price development prognosis on electricity and green certificates

The revenues for offshore wind are depending on both the system electricity price and the green certificate price. The electricity price is a highly complex system. In the short term, the system price is driven by a large number of parameters, e.g. hydropower availability, temperature/weather conditions, export opportunities and other fuel costs. In the Nordic region, the yearly average electricity prices have fluctuated mainly due to the variations in catchment inflow to the hydro power plants. [112] In the long term, the electricity prices also depends on policy decisions, new transmission lines, energy efficiencies, the level of electrification of transport system etc. Moreover, it is very difficult to estimate the future production and consumption levels.

The green certificates system is a market based subsidy scheme driven by supply and demand. Prognosis are done using different programs and tools based on historical developments and future scenarios to estimate the electricity price in the future. In a forecast made by the management and energy trading company Neas Energy, the electricity prices in the Nordic countries will continue to rise as shown in Figure 68.

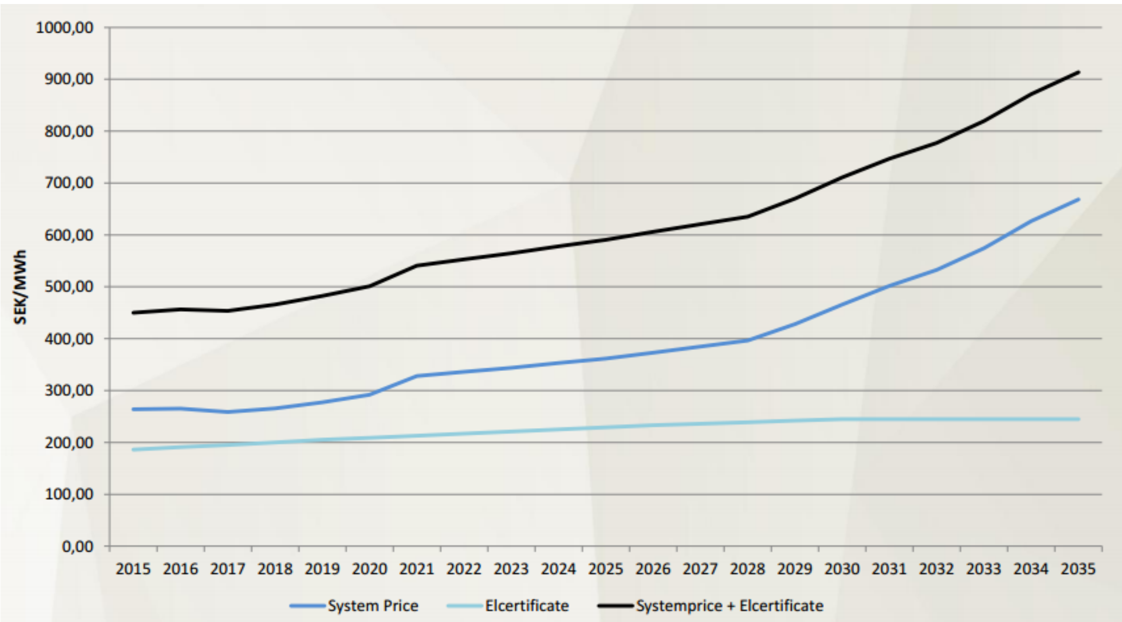


*Figure 68. The prognosis of the system electricity price and green certificate price from 2015-2035 by Neas Energy. [113]*

After converting the numbers in the figure to NOK, it can be seen that the system price together with the green certificate prices will estimated to be 0.45 NOK/kWh in 2020, 0.54 NOK/kWh in 2025 and about 0.63 NOK/kWh in 2030. The Swedish Energy Agency has done fairly similar estimations of about 0.44 NOK/kWh in 2020 and 0.56 NOK/kWh in 2030 [114]. Moreover, Profu's prognosis shows a similar range of the total price, shown in Figure 69. As seen, all these prognoses shows an interval of estimated total electricity system price ranging from 0.41 - 0.50 NOK/kWh in 2020 and 0.45 - 0.63 NOK/kWh in 2030.

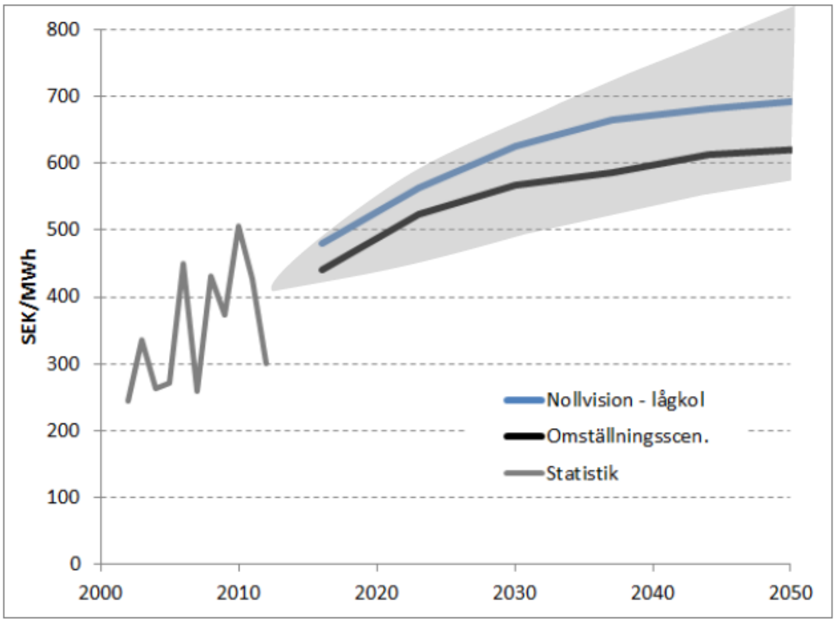


*Figure 69. The prognosis of the system electricity price and green certificate price from 2015-2035 by Profu [115].*

## 7.2 Cost reductions

As a very immature technology, floating wind has many areas where a great deal of cost reduction could be achieved. Even conventional bottom fixed offshore wind is an area where major cost reduction possibilities exists. There are several different ways to achieve cost reductions, although some of them may be counterproductive towards the other.

Learning rate is a key driver to push down the costs and is closely correlated to the capacity build-out, e.g. the LCOE for onshore wind turbines has fallen 14% for every doubling of installed capacity between 1984 and 2011 [116]. Although the same reduction hasn't occurred for the offshore wind industry where the LCOE has in fact increased over the last years, the early market of offshore wind power also revealed considerable cost reductions. With a strong political will to bring down barriers and enable industry growth, the costs can be brought down. The floating wind power technology is currently in a very early phase in its development and will therefore be able to double the capacity quickly and could hence acquire a steep cost reduction. The LCOE also depend on the specific site conditions, where optimal depths and distance to shore together with considerable wind resources could reduce the LCOE significantly. Some floating wind turbine system developers have shown estimates of future LCOE which under optimal conditions approaches 60 Euro/MWh corresponding to 0.49 NOK/kWh already in 2030. [117]

Innovations can lead the way to find new methods and solutions to reduce the costs of different segments of the supply chain. However, the innovations can also lead to a decreased learning rate due continuously new concepts and technology being developed hence counteract the development of an industrialization of the industry. Furthermore, O&M costs could increase due to a rise in maintenance and offshore operations because of new untested technology. This ratifies the need for innovations to have a long term vision and the industry needs to be confident in the market before investing in new technologies. [118] The innovative technologies requires to demonstrate clear advantages such as cost reductions to avoid being counterproductive. Moreover, industry collaboration is important to accelerate the de-risking, demonstration and acceptance of new technologies by sharing costs and risks, learning from each other and pooling sites and resources [118]. The right balance is therefore needed between long term confidence and attractive incentive systems to maintain the benefits of the learning rates.

Carbon Trust is one of the organizations trying to achieve cost reduction through innovation and technology development together with their nine large industry partners. Carbon Trust is currently studying five different areas for technology innovations for cost reductions in their flagship collaborative R&D program "The Offshore Wind Accelerator", focusing on the following areas [119] :

- Foundations - Developing new turbine foundation designs for 30-60m water depths that are cheaper to fabricate and install
- Access systems - Developing improved access system technology and vessels to transfer technicians and equipment onto turbines for operations and maintenance in heavier seas
- Wake effects - Vision to increase energy yield and reduce financing costs by improving the accuracy of wake effect models
- Electrical systems - Developing new electrical systems to reduce transmission losses and increase reliability with a significant focus on higher voltage arrays e.g. 66kV inter-array cables [118]
- Cable installation - Improving cable installation methods, e.g. cable entry system, free hanging cables and cable burials [118]

As seen, these are similar to the cost reduction factors identified by the companies participating in the survey and interview study presented in chapter 6, trying to reflect Norwegian possibilities for cost reduction. One of these cost reductions factors mentioned is the use of concrete as a foundation material.

The majority of the floating offshore wind prototypes being developed today are using steel as the construction material. Due to high steel prices and eager need to reduce cost of the technology, some developers are now looking into concrete constructions. One of them is the Norwegian construction consultancy company Dr. Techn. Olav Olsen who has developed a prototype as a complete concrete solution called the OO Star Wind Floater [120]. Olav Olsen means that concrete foundations will be cost effective for larger turbines, which are mass produced in an industrialized process. The concrete material also implies that these structures will have better fatigue properties and design life relative to steel [120]. As the foundation is a main driver for the investment cost of floating wind power, the long design life is interesting as this changes the economics of the entire floating unit. Olav Olsen means that the design life could be 100 years or more [120], if this becomes reality, exhausted towers and turbines could be towed to shore and replaced, eliminating the cost of a new foundation. This is especially interesting for semi-submersible concepts, where towing is easily done and the substructure could account for roughly 50 percent of the capital cost [121].

Another concrete structure being tested is the semi-submersible 1:8 scale prototype outside Maine. When deployed in the summer of 2013 it was the first offshore floating wind concrete substructure in use. Now a full scale Spar concrete prototype has been deployed at Kabashima in Japan. Using concrete for simple structures could enable mass production with casting onshore in dry-docks, which could result in an overall cost reduction for floating wind power [120].

According to Andreas Lervik, senior engineer within concrete structures at DNV GL, it's possible to glide cast structures similar to both Hywind, Windfloat and Pelastar in concrete [122]. Lervik also mentions that existing facilities and dry-docks along the Norwegian west coast could be used for this purpose. This would enable mass production and possibly cost reduction of the floating foundations for use in Norway.

In the company survey, offshore wind stakeholders were asked about their belief of future cost reductions for offshore wind in 5, 10 and 15 years. The results are displayed in Figure 66 in chapter 6, indicating mean values of cost reductions of 11% in 5 years, 22% in 10 years and 31% in 15 years. As seen in chapter 4.5.8, the case study in this report identified the low case LCOE for a floating offshore wind of semi-submersible type to 1.19 NOK/kWh, SPAR to 1.03 NOK/kWh and TLP to 1.00 NOK/kWh with an average of 1.08 NOK/kWh. Using this as the base case LCOE, the cost compression estimates displayed in Figure 70 is obtained.

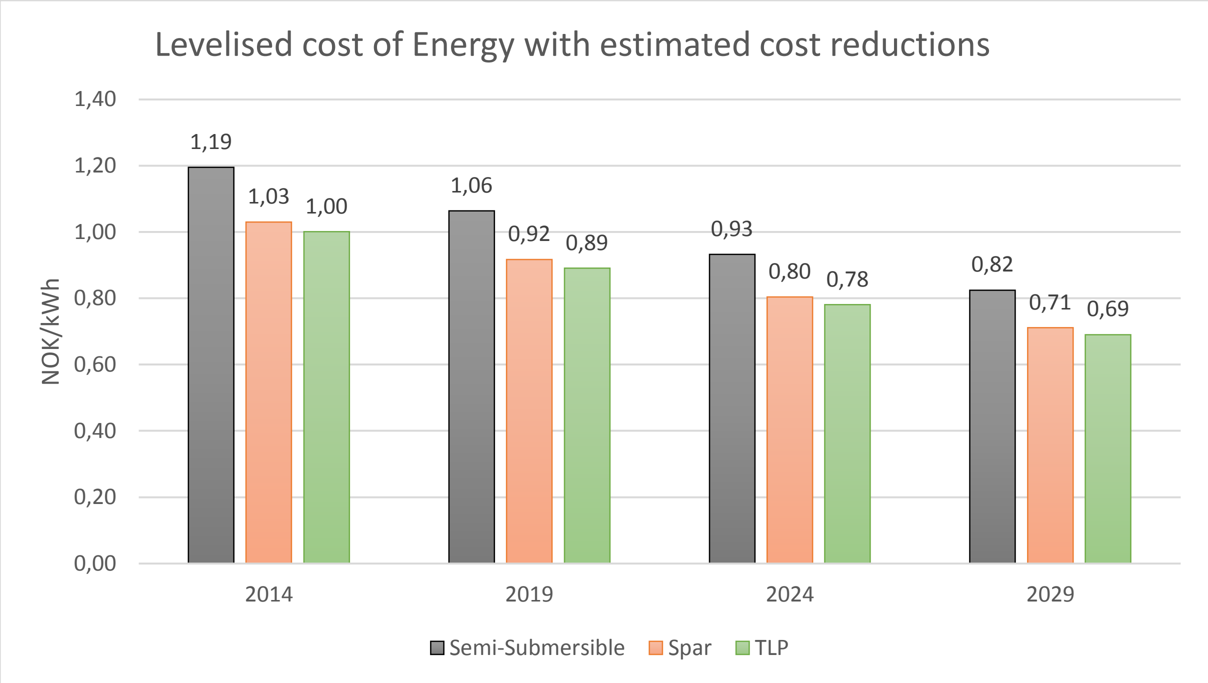


*Figure 70. The LCOE for the three different concepts with the estimated cost reductions from the company survey of 11%, 22% and 31 % in 5, 10, and 15 years.*

## 7.3 Required actions for offshore wind development

Given the expected development of the electricity price in the Nordic region in combination with the expected cost reduction for offshore wind in this thesis, showed in Figure 70, there is still a significant difference in LCOE and revenue of 0.51 NOK/kWh in 2019 and 0.30 NOK/kWh in 2024.

*Table 16. Estimated development of the electricity system price and the LCOE for floating wind*

| Year | Estimated system price and green certificate prices [NOK/kWh] | Average estimated LCOE [NOK/kWh] | Difference [NOK/kWh] |
|---|---|---|---|
| **2014** | 0.5 | 1.08 | 0.58 |
| **2019** | 0.45 | 0.96 | 0.51 |
| **2024** | 0.54 | 0.84 | 0.30 |
| **2029** | 0.63 | 0.74 | 0.11 |

Based on the estimations of LCOE and system electricity price it appears that offshore floating wind power would require additional cost reductions, than ones derived from the company survey in this thesis, or new support schemes raising the incomes for project developers. Governmental actions could induce more offshore wind to be built in Norway which could lead to further cost reductions. It is however important to remember that there are great uncertainties associated with these values, both for the LCOE and cost reductions. Both the LCOE and the cost reductions could in reality be both considerable higher or lower e.g. due to progress in R&D and how much capacity that is actually built.

As mentioned in chapter 3, about 84 % of the companies giving an estimate, stated that the required income for offshore wind projects would have to be around a total of 0.8-1.1 NOK/kWh or higher to be profitable. As can be seen for floating wind 0.8-1.1 NOK/kWh wouldn't be enough as of today.

Other than the green certificates currently used in Norway to support offshore wind power there are various forms of support systems used in other countries with offshore wind in the North Sea basin, showed in Table 17.

*Table 17. Support systems for offshore wind in the North Sea basin*

| Country | Main support mechanism | Support level (€/MWh) | Additional incentives | Responsibility for grid connection |
|---|---|---|---|---|
| **Belgium** | Quota obligation | Minimum payment of 107 €/MWh (over 20 years) for first 216 MW installed, thereafter 90 €/MWh | Lower balancing cost if real production stays within 30% of nominated production | Developer, support provided by TSO for 25% of cable connection cable cost, max 25M€ |
| **Denmark** | Tender + feed-in premium | 1.05 DKK/kWh (approx. 13 4€/MWh) for first 50,000 full load hours (result of the last tendering process) | | TSO |
| **Germany** | Feed-in tariff | 150 €/MWh for a minimum of 12 years (of which 20€/MWh is bonus for projects initiated before 2015), 35 €/MWh for next 10 years. Alternatively a so-called squeezed FIT of 190 €/MWh which is granted for 8 years can be chosen. | To accelerate investment in OWE, the public German KfW bank is providing a total of €5 bil. loans for the first 10 parks (at market based interest rates) | TSO |
| **Netherlands** | Tender + feed-in premium | Average expected premium of 110 €/MWh (over 15 years) above the average yearly electricity price on the day ahead market | Tax incentives | Developer |
| **Norway** | Capital grants | Currently no support incentives for development of offshore wind parks. Joint Norwegian-Swedish certificate scheme will be introduced on 1 January 2012, however, it is expected that the certificate price will be too low to be attractive for OWE developers. Additional support for OWE not yet identified. | Capital grants for demonstration projects | Developer |
| **UK** | Quota obligation[3] | 1.5 ROCs, temporary increase to 2/1.75 ROCs for projects with financial closure by March 2010/2011, average ROC price £50 (approx. €56) (April 2011), certificates to 2037. | Climate change levy Capital grants | Developer |

These support levels for offshore wind varies greatly in different countries, ranging from almost nothing to generous feed in tariffs. E.g. the German offshore tariff offers 1.22 NOK/kWh (150 EUR/MWh) for 12 years, or 1.55 NOK/kWh (190 EUR/MWh) for 8 years, plus an extra period of 1.22 NOK/kWh (150 EUR/MWh) depending on distance from shore and depth. [123] This indicates that floating wind power projects could be economically feasible already today or in a few years for some countries depending on the required discount rate and their wind resources. This being said, if Norwegian politicians would consider a required financial aid to be too comprehensive, a test park could still trigger the development of a national supply chain used for export to more profitable markets.

Since support schemes often have complex market dynamics, Norway could learn from the experience gained in other North Sea countries, when considering their own support system.

# 8 Possible Pathways for Norway

The projected development of cost reduction and electric price indicates that governmental actions are needed in order for an offshore wind power industry in Norway to take hold. A potential increased engagement from Norwegian government in offshore wind will require several major decisions. The amount and comprehensiveness of such decisions and investments mostly correlates to the desired outcome of the engagement. Therefore a roadmap, shown in Figure 71, has been developed to help correlate decisions to desired outcome.

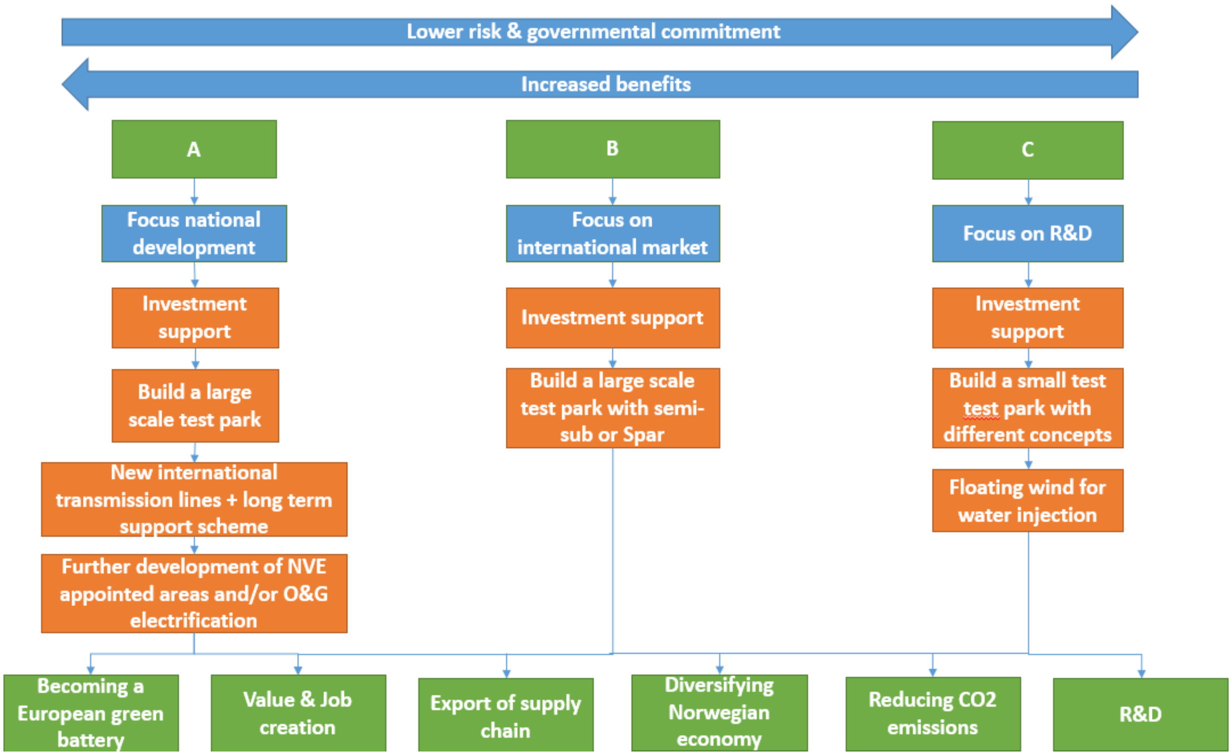


*Figure 71. Flow chart of different pathways and actions for Norway starting from potential outcomes.*

The green areas in the figure above are the main advantages of an offshore wind investment identified in this thesis. How the different floating wind concepts and layouts of a potential test park corresponds to these have been recognized using several SWOT-analysis in the thesis. When suggesting possible pathways for Norway, the thoughts of the industry have also been taken into account.

When it comes to a suitable subsidy scheme, investment support has been suggested for the actual test park independently of what the preferred outcome of the park will be. Due to the uncertain nature and costs of such a project many of the interviewed persons in this thesis thought that a direct investment support would be required in order to lower the risk to an acceptable degree. However in the long term there is a need for a clear policy and subsidy scheme. As stated in chapter 5, the company survey identified that feed-in-tariff, project bidding or increased green certificate all would be possible options, but the strongest support was however for a feed-in-tariff system. The company survey also recognized that new international transmission lines are important in order for Norway to develop a home market for offshore wind.

Following is a consideration and explanation of the different possible pathways for Norway given in Figure 71 which comprises the choice of floating wind turbine concepts and most suitable test park layout.

## 8.1 Pathway A- Building a test park for large scale national deployment

Even though the most likely future scenario of the Nordic power system is an oversupply, there are still factors that can change this picture dramatically which can lead to a re-evaluation of the Norwegian offshore wind market.

One potential game changer is the future of the Swedish nuclear reactors. A complete shutdown would leave a very large gap in the Nordic power supply. With already built connections between Sweden and Norway, the system could be balanced with an increase in hydro, CHP and wind power. Offshore alternatives would therefore be interesting in this case since the nuclear shut down might lead to an increase in the electricity prices as has been seen in Sweden after the shutdown of German reactors [124].

Another factor that could change the view of the offshore wind power market in Norway is if more HVDC cables are connected to countries in northern Europe. If this is realized, Norway could utilize its offshore wind resources and enable export of its hydro power when needed in high renewable energy penetration markets such as Germany and the UK [106].

Building offshore wind will increase the power supply in Norway leading to lower electricity prices and support the competiveness of energy intensive industry in Norway [44]. This in turn will give further incentives for such industries to expand their production in Norway generating a higher demand for electricity. One example is Hydro's planned aluminium production facility at Karmøy.

Taking all these outcomes into account, there can be a domestic market for offshore wind in Norway. A spar solution like Hywind could in this case then be the most promising solution, as experience is already gained with the Norwegian test project. However as mentioned in Pathway A, the semi-submersible do have ha higher international market penetration for the time being and could therefore result in higher export potential. If large scale Norwegian development is demanded, analysis of the different deployment areas should be further studied to investigate the most suitable concept.

## 8.2 Pathway B- Building a single test park for international export

Norway with its well established expertise and knowledge within the offshore industry has a clear potential to be a part of an international offshore wind market. However since the domestic market is limited and the Nordic countries are heading towards a power oversupply by 2020 [44], R&D and development of test parks in Norway might be better of focusing on technologies most suitable for an international market rather than the Norwegian. According to Table 4 where the planned floating offshore wind projects are listed, the semi-submersible concept is the one with the highest international potential. With this in mind, the Semi-sub floating wind turbine concept is considered the most suitable for the Norwegian location.

## 8.3 Pathway C - A combination of different types of floating foundation

A third option for the test park could be erection of several different types of foundations, e.g. one row with each concept. This would enable testing of the different concepts and individual designs against one another in the same conditions to evaluate their respective challenges and opportunities for improvements and development. Moreover, it could be made available for various global concept developers to add their new and innovative concepts for floating wind to the test park, potentially making it a global rally facility for testing and development.

Using different foundation concepts for the test park would not likely impact the power production to a great extent compared to using the same concepts, however, it would likely result in a cost increase per MW. This would be partly due to the fact that the concepts can vary greatly in installation methods, mooring and anchoring, vessels etc. and thus not receive the same benefits of scale as using the same concept for the entire park. Therefore a test park of a more modest size could be used as the purpose of such a park would mainly be testing and development of new technologies and not actual power production.

Building such a park could enable research and testing of connecting floating wind turbines to O&G processes like water injection described in section 3.2.

## 8.4 SWOT-analysis of different layouts

For both scenario A and B a test park of full scale size would be appropriate since a main advantage of this is developing a strong national supply chain which would be needed both for the export scenario and for the national deployment. For scenario C however, a somewhat smaller test park is being considered, as a park of full scale size and different concepts and technologies could be hard to operate. To highlight the different advantages/disadvantages of erecting a test park of mentioned types, a SWOT-analysis has been setup for the two layouts shown in Figure 72 and Figure 73.


*Figure 72. SWOT analysis of building large scale test park using only one floating wind turbine concept*


*Figure 73. SWOT analysis of a small test park using several floating wind turbine concepts*

### 8.4.1 Choice of test park layout

The opportunities and advantages of building a large scale test park in Norway are many. Such a park would enable the development of a national supply chain within offshore wind that could be used for export or to develop projects within Norway, with a high national value creation content. The large scale development will also mean scale effects in production and offshore operations, which can lead to cost reductions for the technology with a high learning rate. Since it's likely to believe that no large scale floating wind power park in the 300 MW range will be built in the next couple of years, there is an opportunity to become a first mover. However, being a first mover also means that Norway might experience higher costs, compared to following projects, due to the "breaking trail" effect. This higher cost could in the worst case act counterproductive on further development if the deployment will show much higher costs than expected.

Many of the weaknesses and threats for a large scale floating wind power plant are directly connected to the advantages of a multiple concept small test park such as; testing of different concepts, lower investment and lower risks. An opportunity with a small test park with different concepts is to become a European test centre for floating offshore wind which gives the possibility to share the risk with other countries and developers in joint projects.

To decide the most appropriate test park, Norway should first evaluate what their long term goals for offshore wind are and thereafter compare these to the opportunities and threats of different concepts and different layouts to find the most suitable solution.

# 9 Discussion

## 9.1 Evaluation of the report

The future is filled with uncertainties of how the power systems will develop both in Norway and in the rest of Europe depending on politic policy making, development of the market and prices on electricity and green certificates. In the Nordic countries, this will partly depend on the future of Swedish nuclear power and goals for reduced emissions and expansion of renewable energy. It is truly a challenge to estimate how much additional power production that will be built until 2030-2050 as this depend on numerous parameters. As mentioned in previous chapters there are many factors that could change the outcome of the projected power oversupply in the Nordic region, where offshore wind power might play an important role in order to achieve climate goals. The consequence of not investing in offshore wind today could result in the lack of a national supply chain and the missed possibility of local value creation in future projects within the Norwegian borders. An energy system transition does not happen overnight, it is important to start early to reduce the risk of future power scarcity which could generate higher electricity prices and induce outsourcing of energy intensive industry.

There are great uncertainties coupled with the future expansion of the Nordic power grid to the European market. In a longer time perspective it could be possible to connect continents with high voltage cables, which could completely change the current electricity market dynamics that many of the future projections of the electricity price are depending on. Several other very uncertain parameters are hard to predict, for instance a potential shut down of the Swedish nuclear power. It is therefore hard to find rationale in that Norway should not build offshore wind because of the projected Nordic power oversupply. Instead Norway should view the future of the power system as a very uncertain factor, and instead seize the market opportunity for offshore wind, and in this way also hedge Norway for dramatic changes within the power system. This would also enable Norway to perform as the often spoken “European green battery” if the possibility will arise.

In the interview and company study several companies indicated that new incentives will be needed soon in order for Norwegian companies not to give up on an engagement towards offshore wind. The current low electricity price is making it increasingly difficult to find profitability of offshore projects in Norway. Moreover most participants had a very pessimistic view of a future development of offshore wind in Norway, since they found it currently unrealistic to believe that Norwegian policy makers would dramatically change the support scheme in the near future. If Norway have plans on a future offshore wind contribution within the power supply, then a commitment must start now before already established companies and organizations move on towards other business opportunities.

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 to establishing a large scale development of either bottom mounted or floating 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. Establishing an offshore wind market in Norway could e.g. aid to become a well needed diversification from the O&G industry with national value creations, new job opportunities and a potential large global market. 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 O&G sector. The additional power production could be used to increase the renewable power export to countries with a greater demand and with higher emissions, where the opportunities are further boosted with additional export cables. How these benefits will turn out is difficult to determine as of today due to several uncertainties. It will however likely greatly depend on the future decisions and commitment of the Norwegian politicians:

- If the politicians conclude that the benefits of establishing a test park and a national supply chain outweigh the costs of doing so, then the possibilities are considerable with the chance to become a world leading nation within offshore wind using Norway's substantial expertise and resources. Moreover, being first to establish a large scale project of floating wind power have the potential to give significant first-mover benefits and market opportunities. This would however also come with the moderately high cost of this innovative technology in an immature market and would require governmental support and commitment. It could however prove to be an invaluable investment to diversify the Norwegian industry.

- If the politicians consider the costs of establishing a Norwegian test park for offshore wind to outweigh the benefits and decides not to develop one, a national supply chain for export can still be formed. This would require less governmental support and involvement. However, without a national market and with the existing international competition, such a development will be difficult and highly unlikely.

- If the politicians decide that it might be worth to establish floating wind power in Norway, but decide to wait several years for further cost reductions, they risk to fall behind on the international market as other players are already mobilizing. Since the Fukushima accident, the high electricity prices and the high demand for new energy sources has resulted in increasingly Japanese attention towards offshore floating wind power. Moreover, the US, the UK and other European countries are also on the move with floating wind concepts, although it seems Japan has far higher ambitions in the years to come.

- If the politicians do not aim to establish a new large Norwegian industry in offshore wind, the industry might still consider to implement floating wind turbines for water injection at O&G platforms, which could already today be cost-effective and can help to reduce the emissions of the oil and gas sector. The establishment of floating turbines, could be a stepping stone in achieving expertise enabling further electrification of the O&G platforms. This in turn could lead to another global market opportunity for Norway as well as considerable reduced GHG emission.

What level of commitment the Norwegian politicians ultimately decides is the best for Norway is difficult to predict. However, if they decide to aim for a commitment in a reasonable future, they will have to implement some sort of support scheme to provide incentives for developers to build offshore wind in Norway. To be able to choose a suitable support scheme for offshore wind in Norway, policy makers should study the experience and lessons learned from other offshore wind nations. Several types of subsidies would probably be effective for a Norwegian long term perspective. With a test park in mind however some key aspects should be addressed with the support scheme. One is that the development of the test park is performed in a way that will minimize problems under operation and installation. It is also necessary to support a project at a good spot where it will achieve a high energy yield and thereby highlight great performance. Therefore a pure investment support alone might not be the best, but a combination of this and some kind of tender process. This way the government can choose the location for a test park where they would consider it to be most suitable. One idea is to have a direct investment subsidy compensating for a large part of grid connection and the cost of the installation, contingency and other of the most uncertain costs, reducing the risk for the developers. Other costs are easier to estimate and therefore a relatively accurate bidding process in NOK/kWh can be held after the cost of installation, contingency and grid connection are taken away.  Having two different support schemes may however complicate the situation further. This support system could mainly be used for the first test park, as such a park would display the actual cost, and a subsidy scheme for further offshore wind development could be evaluated after this. In fact a long term predictable support scheme is what most companies and investors are requiring according to the company survey and interview study carried out in this thesis.

Since one of the key goals with building a test park is to develop a strong national supply chain, agreements in the tendering contract to favour the use of Norwegian suppliers could help achieving this.  Another alternative is to start a state-owned company like Statwind or GreenStat which has been mentioned by several companies in the company survey and interview study. This could be done the same way as Statoil was started, and could be supported by the oil fund.

The purpose of the case study part of the thesis was to highlight the excellent conditions and possibilities coupled with the development of an offshore wind project in Norway. As demonstrated in the Havvind report, there is a considerable potential for building floating wind power in Norway due to vast wind resources and deep waters at close distances from shore. However, the costs of establishing floating wind power are still determined as considerable with an investment cost of about 26.1 - 45 MNOK/MW.  However, the LCOE is ranging from 1.00 – 1.52 NOK/kWh which isn't differing much from the LCOE of bottom-mounted offshore wind. This might partly be explained by the ideal conditions of the site at Utsira Nord. With a short distance to shore and with vast wind resources providing a capacity factor close to 50% together with low impact on other interest, the Utsira site has great potential for floating wind power development.

For the designed test park in this master thesis, the most technical feasible and economic solutions - as of today – have generally been chosen. For a future floating wind park located considerable further out from shore in significant deeper waters, different solutions could be more attractive. In one of those alternatives, solutions using a HVDC connection to shore to avoid the reactive power conversion and electric losses would likely be the best alternative. Moreover, the great distance to land might make it suitable to keep a platform for O&M personnel to live on in periods with access to O&M vessels, reducing the need for long, costly and time consuming travels back and forth to shore. Due to the depths it might have been feasible to use high capacity anchor capable of connecting several wind turbines and 66kV semi-floating cables for the inter-array system. Thus, one alternative for the test park could be to apply one or several of these solutions to showcase and test the capacity for future large scale projects which likely will use some of these alternatives. However, the immature technology of high capacity anchors and semi-floating cables could both result in high costs and technical complications. Together with the additional high cost of the HVDC substations and export cable, the test park might/would become considerable more expensive. Even if it would be acknowledged as a test park, the investment cost and LCOE might worry future investors and developers for investing in floating wind power.

## 9.2 Uncertainties

### 9.2.1 Company questionnaire

The questionnaire which was sent to over 200 companies were answered by 50 individuals which could be seen as a rather low reply frequency and not display the actual overall thoughts of the industry. Studying Figure 51 in chapter 6 however indicate that the entire value chain is represented among the participants. It should also be noted that some answers were neglected due to the fact that these persons had switched jobs which would otherwise have given dual answers from the same company and thus misrepresentative. Several individuals also replied that the company did not have any business within offshore wind anymore.

Another aspect worth mentioning with this kind of study is that the thoughts of different individuals could vary greatly between individuals within the same company and would not necessary represent the overall values of the actual company. Moreover, as many of the participants represent companies that have an interest in an expanded offshore wind market in Norway, some of their answers could be exaggerated and give the impression of a more positive outlook compared to companies not working towards offshore wind.

The industries thoughts of the future cost reductions of offshore wind together with projections of the electricity price indicates that a support system will be needed for several years. These results should however be viewed with some respect, since the cost reduction potential is a very uncertain factor where various organisations have made different projections. Many of the companies that answered this question, may have limited knowledge of such a development and hence their response might lack appropriate background understanding. A more detailed estimated would be to use these projections together with other estimates.

### 9.2.2 Case study

The determined LCOE is linked to great uncertainties as there are no large offshore floating wind power projects in the world which makes it difficult to estimate the genuine cost of several parts of the value chain. Moreover, a great quantity of the values used for the economic calculations are taken from the same report which could lower the credibility of the calculations. Other cost estimates for floating wind have been done by other sources, but are usually more general where floating wind power as a concept is compared with bottom fixed. These values did however correspond relatively well with the results of this thesis, indicating some accuracy. Furthermore the costs of the test projects erected in the world should not be used to determine future costs, as these are pilot projects which are usually faced with considerably higher costs. Thus, they would not represent units produced and deployed in larger scale. How much this cost would be reduced for a full scale development is however difficult to estimate. It is important to note that the simple cost estimation done in this thesis was only to receive a general estimate for a test park at this location. A deeper analysis would have to be done to acquire more accurate estimates.

It could also be added that most of the values set for the cost calculations are set in a quite conservative manner due to the uncertain and immature nature of the technology. Some of the costs are therefore likely to be shown considerably lower when a test park will actually be built. For instance, the required rate of return (used as the discount rate) was set to 10% which is comparatively high, especially when considering a test park which main focus would not be to achieve a high profitability. A 5 percent lower discount rate will greatly reduce the LCOE.

On the other hand, as the costs of the foundations is estimated based on the possibility for mass production they might be underestimated due to limited possibilities to do this as of today. However, the costs of the turbine and O&M may be somewhat overestimated and together with the high contingency and discount rate, the inaccuracies may cancel each other. The resources set as contingency may never be used which would result in almost 10% less CAPEX and as it is a test park, the discount rate should perhaps not exceed 5% which would have reduced the LCOE dramatically.

It should be remembered however, that the financial analysis should only serve as an indication of the actual price level due to the uncertain cost associated to the youth of the technology and limitations in availability of data. The costs associated with a project will always depend on the site specifics and the timing. For instance, the cost of turbines, foundations, cables and additional electric equipment are all decided during the procurement and could fluctuate greatly depending on the timing, number of components being procured and the number of alternative providers available. Moreover, the choice of e.g. components and vessels could vary greatly depending on the location and availability. The total cost of the test park and the LCOE varies greatly based on these assumptions and cost estimates used for the different concepts and phases of the life cycle of the wind park. Furthermore, to receive the most accurate financial evaluation of a wind park, a vast number of parameters would have to be established as input in a financial cost model, to account for future cost variations in upcoming years. This would have to include projections for the development of inflation, electricity price, costs of O&M, stockpile management and reparations of components.

### 9.2.3 Interviews

The interviews conducted in this thesis comprise an important part of the final conclusions drawn. One should however discuss if eight interviewees can provide a complete picture of the industries thoughts, since representatives from all supply chain parts haven't been interviewed. The persons interviewed have however been identified as individuals with great knowledge of the area and their thoughts could therefore be viewed in relationship to the company survey results.

One should keep in mind that the interviews are picked by the authors themselves and since its people who have actively worked towards an offshore wind development, the thoughts may be more positive compared to other industry representatives. In fact wind power is a debated area and there are many voices working against a development, especially for offshore wind since these costs are higher. According to us it was however more relevant to focus the interviews on people involved in offshore wind since these persons could provide more valuable information than someone who's not working actively with it.

## 9.3 Future work

This report has displayed the great potential of an offshore wind development in Norway. As many developers believe that the future plan for the Norwegian power system is very uncertain, a first step could be to perform a detailed analysis of the future development of the Norwegian and Nordic power system. Thereafter, Norwegian policymakers should try to implement a clear plan and support system to realize the goals for the future power system. The Norwegian power grid should be evaluated and upgraded in weak areas in order to enable a higher flow and future export through new international transmission lines.

Further studies should be done to analyse the actual effects on the potential benefits that a large scale commitment to offshore wind could offer. For instance the impact on the national economy of establishing a large quantity of offshore wind power and exporting more power to the European continent with new export cables and/or establishing a large supply chain for export. It might also be worth to deeper analyse the Norwegian possibilities to succeed to establish an industry for floating wind power, depending on when/if the Norwegian politicians decide to commit to this. This could e.g. consider different scenarios of ongoing R&D progressions in UK, the US and Japan together with their already existing offshore wind supply chain and the future global market.

A future study of interest would be to develop a benchmark study of building floating wind power in Norway compared to other European countries. This would clarify specific challenges and opportunities coupled with a Norwegian development, which could be very interesting when discussing the European future energy system. Such a study could highlight the potential benefits for Europe and not solely the Norwegian.

A detailed study of the entire electrification development of the O&G industry would be highly relevant as a follow up study to this thesis. Such a report could in-depth investigate different alternatives for electrification for each platform and area. This is important and interesting since it is likely that the appropriateness of different solutions such as floating wind power, bottom fixed wind power, onshore cables and so on will greatly differ between different geographical areas and existing technical equipment.

Further studies should also involve analysis of the parameters given in section 1.4 Limitations which are considered highly relevant and necessary to investigate. This include the Norwegian fishery perspective and a more detailed sensitive analysis of the costs of floating wind power. Moreover a detailed analysis of an appropriate offshore wind support scheme should be analysed, where knowledge could be taken from other North Sea nations.

# 10 Conclusion

It is clear that the potential for the future of floating offshore wind is great and that many nations will rely on this new technology as a part of their transition towards a greener energy system. If Norway wants to be a part of this development a stronger commitment is needed in forms of economic support and long term planning. The benefits of doing so are many including the following:

- Diversification of the Norwegian economy
- Value and job creation
- Export of supply chain
- Reduced impact of dry years
- Reduced greenhouse gas emissions

Norway holds a great possibility to utilize its petro-maritime expertise to become a world leader within floating offshore wind. As a result of this the national value creation of offshore wind development could be very high. Furthermore the industry believes that it is of great importance that Norway diversify its economy from the oil & gas sector, and engaging in offshore wind is a great way of doing so. The development should however proceed in collaboration with existing oil & gas industry, where floating wind turbines connected to oil platforms for partly electrification can be the stepping stone for the technology and enable a great reduction of the Norwegian $CO_2$ and $NO_x$ emissions.

The possibility for cost reduction is great concerning floating offshore wind. As it is an immature industry, the learning effects are likely to result in steep cost reductions and in the years to come floating wind power may be more cost effective than bottom fixed offshore wind. Some potential aspects that could greatly reduce the costs are, onshore assembly, industrialized mass production and the use of different foundation materials as concrete.

The case study displayed the superb wind resources of Norwegian waters, where almost 50 % capacity factor for an offshore wind power plant could be reached. The common trend of the European energy systems is the transition towards a more intermittent renewable energy production. A great window of opportunity arise for Norway to both benefit from a new industry, and become significant exporter of renewable energy to the continent, where the Norwegian hydro power is used to balance the European power system.

Norway has several decades of experience within the petro-maritime industry and has established significant knowledge and a broad expertise of offshore development. Moreover, Norway possesses some of the best wind resources in the world. This has given Norway a unique opportunity to achieve a world leading role as initiative taker for the development of floating wind power and enable export of expertise and knowledge. The possibilities and potential to use the existing knowledge of Norway's industry is tremendous, but to be a part of this new business opportunity, Norway should act soon before other countries gets too far ahead in the competition.

By engaging in the offshore wind power sector Norway could take advantage of the experiences drawn from the North Sea oil adventure and simultaneously diversify its heavily oil driven economy and avoid the effects of the Dutch Disease. The time has come to stop drilling for resources in the depths of the ocean and instead harness the vast resources above it.

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# 12 Appendix

## 12.1 Appendix 1- List of Figures

## 12.2 Appendix 2 – List of Tables

## 12.3 Appendix 3 - Inter-array structure

Several inter-array structures was considered and analysed for the case study test park. A few shown of these are presented in Figure 74 and discussed in here.

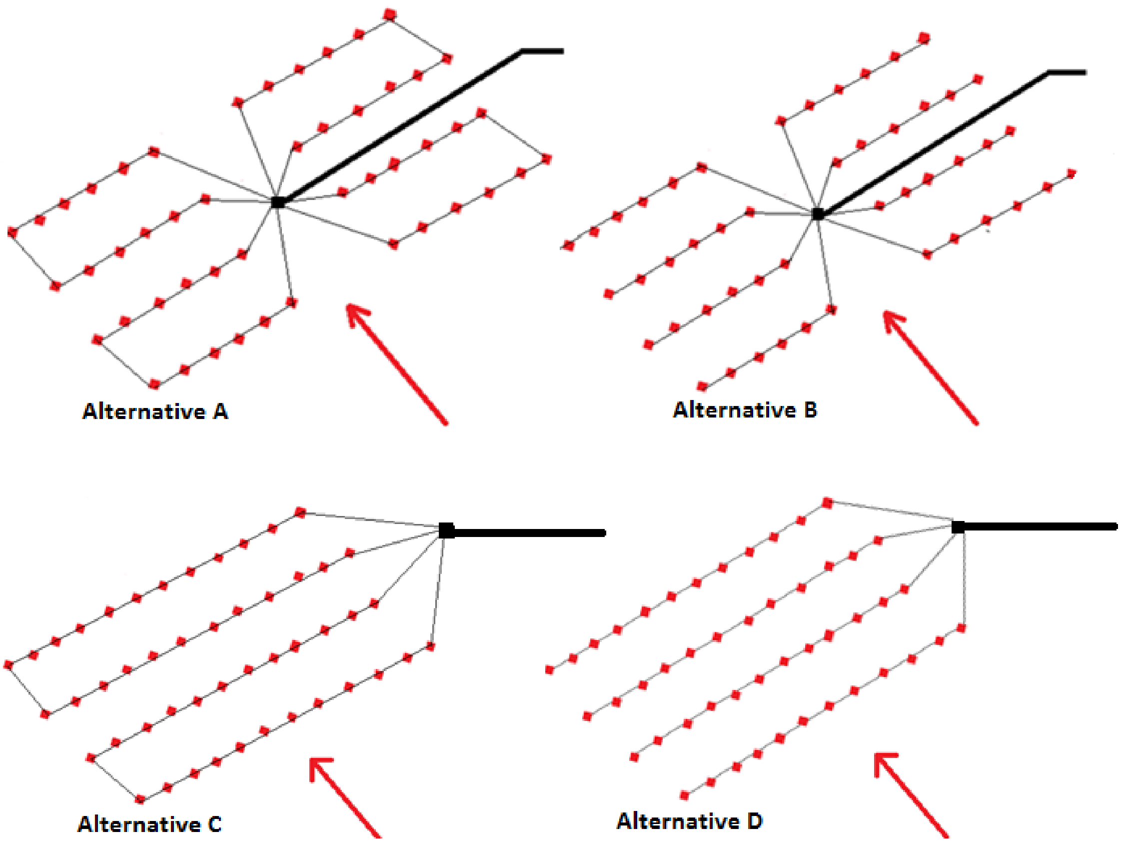


*Figure 74. Different alternatives for inter-array structures displaying the locations of the 48 turbines á 6 MW, where the red arrows mark the prime power rose direction. The thicker black lines represent the external cable to shore, and the black box represent the transformer station.*

In alternative B and D, a cable failure in between two turbines in one of the rows would result in the subsequent turbines in the row to lose their ability to submit power to the grid. If the failure occurs close to the transformer, a large part of the production capacity can be lost for quite some time until the cables are repaired. In contrast, alternative A and C have circle-solution inter-array structure which could increase the reliability of power production. If the cable in between two turbines would fail, the power could simply transmit in the other direction. However, to support full power, this would require the cable in the two rows be support the power of all the turbines in the two rows connected, i.e. 72

MW for alternative A and 144 MW for alternative C. 33kV cables which are used today are however both highly complex and expensive to exceed 800mm$^2$ which can only transfer about 50 MW making this an unrealistic choice for rows with 6MW turbines. Alternative D as well would require the cables connecting to the turbines closest to the transformer in each row to support 72 MW which isn't feasible. The voltage level of 66kV cables has been studied which could 800mm$^2$ to support up to 100 MW and would open for a higher degree to use the ring formation to reduced lost revenue due to increased availability as well a reduction in number of substations. Even though there would be some penalty in terms of wind turbine equipment i.e. transformers and switchgear, it should still increase the NPV of offshore wind parks [118]. The solution has however not yet been implemented for inter-array structures and will not be considered further for this case study. Ultimately, alternative B was considered as the most feasible as test park layout due to still high production reliability at fairly low cost for internal cables. The transformer station in the middle is assumed to have little or no impact on contributing to additional wake effect or turbulence to affect the turbines.

## 12.4 Appendix 4 - Wind power theory

Wind is created by the differences in atmospheric pressure induced by the sun. The difference causes the air to flow from the high pressure area to the low pressure area, resulting in winds with various speeds. The kinetic energy E in the wind can be described with the following equation:

$$E = \frac{1}{2}mv^2 \tag{2}$$

Where m is the mass in kg and v is the velocity in m/s. Power, in turn, is defined as the change or transfer of energy over time as described by equation 3.

$$P = \frac{dE}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) = \frac{1}{2} * \frac{dm}{dt}v^2 \tag{3}$$

The mass flow of this wind can be expressed with the mass conservation equation:

$$\frac{dm}{dt} = \rho vA \tag{4}$$

Where $\frac{dm}{dt}$ is the mass flow of air flowing through an area A with the velocity U and density ρ. By combining equation 3 and 4, the kinetic power of this flow can be described with equation 5.

$$P_{kinetic} = \frac{1}{2} * \frac{dm}{dt}v^2 = \frac{1}{2}\rho Av^3 \tag{5}$$

The energy which can be extracted by the rotor is however not equal to the kinetic power of the flow, as this would lead to a wind speed equal to zero after the wind turbine and thus work as a wall, stopping all following air through the rotor which would then stop. Instead, the mechanical energy which theoretically is extractable from the wind is defined by the Betz's coefficient, $C_{p,Betz}$ =59.3%. Furthermore, there is also mechanical losses, generator losses which roughly gives a total efficiency factor $C_p = 0.45$ expressing how much power the turbine generates in correlation to energy available in the wind. Thus, the expression for the power generated by the turbine is:

$$P_{generator} = \frac{1}{2}\rho A v^3 C_p \tag{6}$$

As shown in equation 6, the power and thereby the profits is proportional to the cube of the wind speed within the speed limits which it is operational, commonly between around 4 m/s and 25 m/s. As the average wind speed increases and the turbulence decreases with height above the ground, turbines with high towers usually can generate more electricity. However, higher towers also increases the cost of the turbines which could then require a cost analysis to determine the optimal height of the turbine. As the offshore wind generally have a higher average wind speed and have less turbulence due to less obstacles, the turbines are normally higher onshore than offshore, especially if built in a forest.

## 12.5 Appendix 5 – Matlab calculations

The following commands was used in MatLab to display the wind speed distribution and the power rose where Winddata.txt contains the wind data provided by Kjeller Vindteknikk at the nacelle height of 100m.

```
close all; clear all; clc;
load Winddata.txt %Loading the wind data received from Kjeller Vindteknikk
A=Winddata;
figure
hist(A(:,2),0:39) %Creates a histogram of the wind speeds
title('Totala vindhastigheter')
figure
polar((0:10:360)*(pi/180),hist(A(:,1),0:10:360))  %Creates a polar diagram showing the distribution of all wind speeds and their corresponding wind direction.
title('Total vindros vid 100m');

lim =[5 25];
f=logical((A(:,2)>=lim(1)).*(A(:,2)<=lim(2))); %Create a condition to sort out all the values under 5m/s and over 25m/s

A = A(f,:); %Creates a new matrix with only the wind speeds available for production.
figure
polar((0:10:360)*(pi/180),hist(A(:,1),0:10:360))   %Creates a polar diagram showing the distribution of all wind speeds and their corresponding wind direction for wind speeds higher than 4m/s and lower than 25m/s.
title(' Vindros vid 100m 5-25m/s');

figure
hist(A(:,2),0:30),
DIR = A(:,1); % All wind speed directions values
SPD = A(:,2); % All wind speed values
dirs = unique(DIR); % All unique wind direction values
spds = unique(SPD); % All unique wind speed values

B = zeros(numel(dirs),numel(spds));  % Wind direction in the columns and wind direction in the rows.
```

```
for i=1:numel(spds)
B(:,i) = hist(DIR(SPD==spds(i)),numel(dirs)); % Creates a matrix displaying
the amount of all wind speeds and their directions.
end

P = repmat(spds',numel(dirs),1).^3; % Created a matrix with the wind speed
^3 to receive the corresponding "power production potential".
E = B.*P; % Multiplies matrix B with matrix B to receive the power
relationship.
C = fliplr(cumsum(B,2)); % Creates a matrix to display the "different" wind
speeds in a wind rose
F = fliplr(cumsum(E,2)); % Creates a matrix to display the "different" wind
speeds impact on the power production, for a power rose.
t = repmat((1:1:360)*(pi/180),numel(spds),1);
figure
F = fliplr(cumsum(E,2)); % Creates a matrix to display the "different" wind
speeds impact on the power production, for a power rose.
t = repmat((1:1:360)*(pi/180),numel(spds),1);
figure
polar(t',C) % Creates a wind rose
title('Wind')
figure
polar(t',F) % Creates a power rose
title('Power')
export(dataset(F)) % Exports the matrix to display the "different" wind speeds
impact on the power production, for a power rose. This is then used in the
excel document
```

## 12.6 Appendix 6 – Cost estimations.

This section gives an overview of the full economical estimations and results. The overall test park information used for all cases and both in the high and low case are shown in Table 18. The LCOE and NPV calculations for the Spar, Semi-submersible and the TLP concepts are shown in Table 19, Table 20, Table 21. The full calculations can be seen in the digital appendix.

*Table 18. Overall test park information and parameters.*

| | | |
|---|---|---|
| **Wind park information** | **Utsira** | |
| Rated power | 6 | MW |
| Number of Turbines | 48 | Turbines |
| Total Rated power | 288 | MW |
| Annual energy production | 1222 | GWh/year |
| Electricity price | 38 | Euro/MWh |
| Green certificates | 25 | Euro/MWh |
| Revenue | 62.73 | Euro/MWh |
| Full load hours | 4244 | hours |
| Lifetime | 25 | Years |
| Euro Conversion | 9.1 | SEK/Euro |
| Euro Conversion | 8.16 | SEK/Euro |

*Table 19. Capex, LCOE and NVP calculations using the Spar foundation concept.*

| Concept | Spar [MNOK] |
|---|---|
| Project development | 179 |
| Wind turbines | 3513 |
| Foundations | 1758 |
| Installation cost Foundation & Turbine | 308 |
| Internal grid | 284 |
| Anchoring and Mooring Materials | 181 |
| Anchoring and Mooring Installation | 65 |
| Export Cable | 314 |
| Decommissioning | -254 |
| Substation | 682 |
| *Pre capital Cost* | 7031 |
| *Contingency* | 703 |
| *Construction Insurance* | 118 |
| *Capex [MNOK]* | 7851 |

| ***Economics*** | | *NOK* |
|---|---|---|
| Average annual Return [MNOK] | | 625.6 |
| | | |
| *Net present value (NPV) [MNOK]* | | |
| Investment | | 7851 |
| Loan | | 0 |
| O&M | | 2794 |
| Reinvestment | 10% | 785 |
| Total costs, NPVc | | 11431 |
| Sold energy, NPVi | | 5679 |
| *Total. NPV* | | *-5752* |
| | | |
| **Levelised cost of energy [NOK/kWh]** | | **1.03** |
| | | |
| Series of payments factor (Y) | | 9.08 |
| Discount rate | | 10% |
| Capital recovery factor (CRF) | | 0.110 |
| | | |
| Investment [MNOK/MW] | | 27.3 |
| Investment [NOK/year kWh] | | 0.26 |
| Operating cost [NOK/kWh] | | 0.09 |

*Table 20. Capex, LCOE and NPV calculation using the Semi-submersible foundation concept.*

| **Concept** | **Semi-sub [MNOK]** |
|---|---|
| Project development | 179 |
| Wind turbines | 3513 |
| Foundations | 3525 |
| Installation cost Foundation & Turbine | 252 |
| Internal grid | 284 |
| Anchoring and Mooring Materials | 245 |
| Anchoring and Mooring Installation | 87 |
| Export Cable | 314 |
| Decommissioning | -543 |
| Substation | 682 |
| *Pre capital Cost* | 8539 |
| *Contingency* | 854 |
| *Construction Insurance* | 118 |
| *Capex [MNOK]* | 9510 |

| ***Economics*** | | *NOK* |
|---|---|---|
| Average annual Return [MNOK] | | 625.6 |
| | | |
| *Net present value (NPV) [MNOK]* | | |
| Investment | | 9510 |
| Loan | | 0 |
| O&M | | 2794 |
| Reinvestment | 10% | 951 |
| Total costs, NPVc | | 13256 |
| Sold energy, NPVi | | 5679 |
| *Total, NPV* | | *-7577* |
| | | |
| **Levelised cost of energy [NOK/kWh]** | | **1.19** |
| | | |
| Series of payments factor (Y) | | 9.08 |
| Discount rate | | 10% |
| Capital recovery factor (CRF) | | 0.110 |
| | | |
| Investment [MNOK/MW] | | 33.0 |
| Investment [NOK/year kWh] | | 0.31 |
| Operating cost [NOK/kWh] | | 0.09 |

*Table 21. Capex, LCOE and NPV calculations using the TLP foundation concept.*

| Concept | TLP [MNOK] |
|---|---|
| Project development | 179 |
| Wind turbines | 3513 |
| Foundations | 501 |
| Installation cost Foundation & Turbine | 301 |
| Internal grid | 284 |
| Anchoring and Mooring Materials | 749 |
| Anchoring and Mooring Installation | 75 |
| Export Cable | 314 |
| Decommissioning | 159 |
| Substation | 682 |
| *Pre capital Cost* | 6757 |
| *Contingency* | 676 |
| *Construction Insurance* | 118 |
| *Capex [MNOK]* | 7550 |

| ***Economics*** | | *NOK* |
|---|---|---|
| Average annual Return [MNOK] | | 625.6 |
| | | |
| *Net present value (NPV) [MNOK]* | | |
| Investment | | 7550 |
| Loan | | 0 |
| O&M | | 2794 |
| Reinvestment | 10% | 755 |
| Total costs, NPVc | | 11100 |
| Sold energy, NPVi | | 5679 |
| *Total, NPV* | | *-5421* |
| | | |
| **Levelised cost of energy [NOK/kWh]** | | **1.00** |
| | | |
| Series of payments factor (Y) | | 9.08 |
| Discount rate | | 10% |
| Capital recovery factor (CRF) | | 0.110 |
| | | |
| Investment [MNOK/MW] | | 26.2 |
| Investment [NOK/year kWh] | | 0.25 |
| Operating cost [NOK/kWh] | | 0.09 |

## 12.7 Appendix 7 – Company survey and interviews

Appendix 7 displays the email sent to companies, inviting them to participate in the questionnaire in order to get the industry perspective of the Norwegian offshore wind market. Moreover, it present the full list of questions asked in questionnaire as well as some figures displaying results which was not presented in chapter 6.

**Questionnaire participation invitation:**

“Dear,

We would like to invite you to participate in a voluntary research survey in order to gather information and thoughts of the existing Norwegian industry linked to offshore wind. The survey will take approximately 5-10 minutes to complete and will be an important part of a master thesis carried out by the two students Anders Westin and Daniel Nilsson at Lund institute of technology. The thesis is written under the supervision of DNV GL in Oslo, and aims to highlight the possibilities of creating an offshore wind market in Norway, identify cost reduction potentials and investigate key benefits of utilizing Norwegian maritime and oil & gas expertise.

Your answers will highlight the current supply chain within offshore wind in Norway and its limitation. It’s also important to acquire your point of view of the industry and its future to be able to present a roadmap for policy makers in Norway.

If you feel like this document was incapable of providing your thoughts of this topics, we will happily discuss this further over telephone. If this is the case, please mark the box in the end of the document saying “I would like to provide more information to this survey”.

You and your company’s answers will be presented anonymously in the report. However it is required that you provide name and company name in order for us to process the incoming data. To be able to fully process the information acquired in this survey, a response is required before April 18.

Thank you for your cooperation, any contribution is valuable.
As a token of our gratitude participants in this survey will be dedicated a special thanks and receive a copy of the final report.

Best regards,

Anders Westin & Daniel Nilsson

In collaboration with INTPOW”

## Questionnaire

**1. What is the name of your company?**

**2. Your name**

**3. In which of the following project roles are your company involved in on a national level within offshore wind?**

- ☐ Research and development
- ☐ Consultant and service provider
- ☐ Engineering
- ☐ Sub supplier/instruments/equipment
- ☐ Manufacturer/ contractor
- ☐ Vessel owner
- ☐ Facilities(Ports, yards, test centers, etc)

☐ Legal & Finance, Insurance

☐ Developers/Owners

☐ other

**4. Within this role, which/what main components/services do you supply?**

**5. Does this business area have operations in or nearby the following locations?**

☐ Stavanger

☐ Bergen

☐ Oslo

☐ Other

**6. Do you believe that a future national offshore wind power market is possible?**

○ Yes, within 5 years

○ Yes, within 10 years

○ Yes, within 15 years

○ No, or further away

**7. Is your company involved in offshore wind at an international level?**

○ NO

○ YES

Which is /are your main markets (country)?

**8. In which of the following project roles are your company involved in at an INTERNATIONAL market level within offshore wind?**

☐ Research and development

☐ Consultant and service provider

☐ Engineering

☐ Sub supplier/instruments/equipment

☐ Manufacturer/ contractor

☐ Vessel owner

☐ Facilities(Ports, yards, test centers, etc)

☐ Legal & Finance, Insurance

☐ Developers/Owners

☐ Other

**9. Within this role, which/what main components/services do you supply to the international market?**

**10. Do you believe that Norway can become a key player on the international offshore wind market?**

○ Yes, within 5 years

○ Yes, within 10 years

○ Yes, within 15 years

○ No, or further away

**11. Does the company currently have a plan to expand its business within the offshore wind market?**

○ NO

○ YES

In what way?

**12. Why not?**

☐ Nothing to contribute with

☐ The company see no market for this at the time being

☐ No clear incentives from politicians

☐ Not enough expertise

☐ No clear national policy

☐ Other

**13. Does the company currently work almost exclusively towards the maritime or Oil & Gas industry?**

○ YES

NO

**14. How important do you find it to diversify your business, using existing knowledge within the company?**

Not important

Important

Very Important

**15. Do you find it important to diversify Norwegian economy from the oil & gas sector?**

Not Important

Important

Very Important

**16. Does the political insecurity make it a too big of a risk to invest resources in establishing an industry towards offshore wind power?**

YES

NO

**17. What would be required in order to lower this risk to an acceptable degree?**

**18. What type of subsidy would you consider most suitable for offshore wind in Norway?**

Project bidding- The government suggest a project and developers are invited to bid on required electricity price to build and operate the project – Lowest bid gets the project

Increased green certificates prices

Investment subsidy

Feed in tariff

Don't know

Other subsidy

**19. In your point of view, what is the minimum required total price (Subsidiary aid + electricity price) paid foroffshore wind?**

50-80 öre/kWh

80-110 öre/kWh

110-140 öre/kWh

- Higher
- Don’t know

**20. Would you consider it difficult to establish your own company on the international offshore wind market due to the competition being too great?**

- YES
- NO

**21. How important are new international transmission lines, including the planned cables to UK and Germany, in order for Norway to establish a national offshore wind market?**

- Important
- Very Important
- Not Important

**22. In your company’s area of expertise, do you see any possibilities for cost reduction for offshore wind?**

- YES
- NO

**23. Within this expertise area, approximately to what extent can cost reduction be achieved for Offshore wind?**

% in 5 years

% in 10 years

% in 15 years

**24. How can this cost reduction be achieved?**

How can this cost reduction be achieved?

**25. To what extent do you believe that OVERALL costs for offshore wind can be compressed the coming years?**

% 5 years

% in 10 years

% in 15 years

**26. Today, there is an increased interest and resource focus in R&D for floating wind power globally with several projects already erected or projected to be built within the upcoming years. According**

**to your company, would you say that it is important for Norway to establish any of the following in order to become an industry leader within floating offshore wind?**

- ☐ A test park
- ☐ A stronger policy towards offshore wind power
- ☐ None of these alternatives are important
- ☐ Other

**27. Do you believe that a large scale offshore wind project will ever be developed in Norway without a change in the subsidiary system?**

- ○ YES
- ○ NO

**28. I would like to provide more information to this survey**

- ○ YES
- ○ NO

*Table 22. Free text answer of what main components the participants company supply to the offshore wind industry*

Norwegian offshore wind industry

## Q4 Within this role, which/what main components/services do you supply?

Svarade: 47 Hoppade över: 3

| # | Svar | Datum |
|---|---|---|
| 1 | Svp | 2014-04-24 08:17 |
| 2 | Business solutions | 2014-04-23 20:47 |
| 3 | Wind analysis. Production estimates. Production management. | 2014-04-23 15:27 |
| 4 | Sensors for airgap measurement (environmental loads on structures) & radar for wave height measurement (installation vessels and service vessel access) | 2014-04-23 12:42 |
| 5 | Structural monitoring systems | 2014-04-23 12:40 |
| 6 | Project Development, FInance, Transactions and Disputes, including regulatory assistance | 2014-04-23 11:24 |
| 7 | Remote inspection systems | 2014-04-23 10:58 |
| 8 | Influence decision makers, to promote new, renewable (wind, wave tidal) energy production in Norway. | 2014-04-23 10:55 |
| 9 | Complete large wind turbines 3MW + | 2014-04-23 10:48 |
| 10 | Financial guarantees to facilitate long-term financing of offshore wind farms. But GIEK can only provide guarantees in connection With export from Norway. | 2014-04-22 10:15 |
| 11 | None | 2014-04-22 10:01 |
| 12 | Cable solutions for inter array and export cable systems. Also including cable installation and protection work etc. | 2014-04-17 21:56 |
| 13 | Transport of service personnel to the Wind turbines | 2014-04-16 13:54 |
| 14 | na | 2014-04-13 17:15 |
| 15 | Installation contractors | 2014-04-11 21:22 |
| 16 | Transport and installation services including engineering and procurement | 2014-04-11 11:17 |
| 17 | Cable and umbillical installations off shore | 2014-04-11 09:52 |
| 18 | Geerboxes | 2014-04-10 20:41 |
| 19 | Yardstays, engineering, Mobilization | 2014-04-10 13:45 |
| 20 | Technical development related to onshore and offshore wind and marine renewables | 2014-04-10 10:16 |
| 21 | Offshore and marine competence | 2014-04-10 06:39 |
| 22 | WTG's | 2014-04-09 18:19 |
| 23 | Site screening and strategic environmental assessment EIA, consent & planning wind farm design support structure foundation design construction economics ... | 2014-04-09 13:01 |
| 24 | Software for Strategic Sourcing and Contract Lifecycle Management and connected Services | 2014-04-09 12:00 |
| 25 | Offshote WTG foundation design | 2014-04-09 11:32 |
| 26 | Crew transfer systems | 2014-04-09 10:49 |
| 27 | As a cluster WCN has the following strategic areas of work: 1. Supply chain development 2. Increase the collaboration between R&D and Industry 3. Communication 4. Market positioning in defined international markeds | 2014-04-09 10:41 |
| 28 | Cable Condition Assessment Services and LIRA Test Technology & Equipment | 2014-04-08 09:59 |
| 29 | Offshore windmill installation survey support | 2014-04-07 14:55 |

| | | |
|---|---|---|
| 30 | Offshore wind foundations | 2014-04-07 08:02 |
| 31 | We are investigating whether drones can be used for inspections. | 2014-04-06 21:42 |
| 32 | Export financing to the cutomers of the Norwegian supply industry | 2014-04-04 14:40 |
| 33 | Met ocean, wave and wind studies, | 2014-04-04 14:18 |
| 34 | Propulsion Plants for WFSV - consisting of propellers, shaftlines, gearboxes and control systems for propellers & rudders | 2014-04-03 23:52 |
| 35 | Software for analysis, design and simulation of wind turbines (aeroelastic analysis). | 2014-04-03 18:41 |
| 36 | Crew transfer vessels | 2014-04-03 16:07 |
| 37 | Cable protection | 2014-04-03 15:52 |
| 38 | Wind Farm Management system | 2014-04-03 15:50 |
| 39 | Cathodic protection detail design and engineering | 2014-04-03 15:06 |
| 40 | Host NOWITECH, www.nowitech.no, a EUR 40 million research cooperation with industry and RCN funding Research at SINTEF Energy mainly related to grid connection, power system integration and operation and maintenace strategies. Active in five EU projects (FP7 and H2020) | 2014-04-03 15:00 |
| 41 | Services and infrastructure for full scale testing | 2014-04-03 14:46 |
| 42 | Installation services | 2014-04-03 14:13 |
| 43 | 1: Wind Turbine Technology 2: Medium/ Size wind turbine prototype | 2014-04-03 14:11 |
| 44 | Hydrodynamic testing foundations, service vessels, installation vessel and weather stations | 2014-04-03 14:03 |
| 45 | Jack-up vessels & crew transfer vessels | 2014-04-03 14:02 |
| 46 | Motion compensated access equipment | 2014-04-03 13:53 |
| 47 | Fixed and floating substructures including mooring and anchors | 2014-04-03 13:46 |

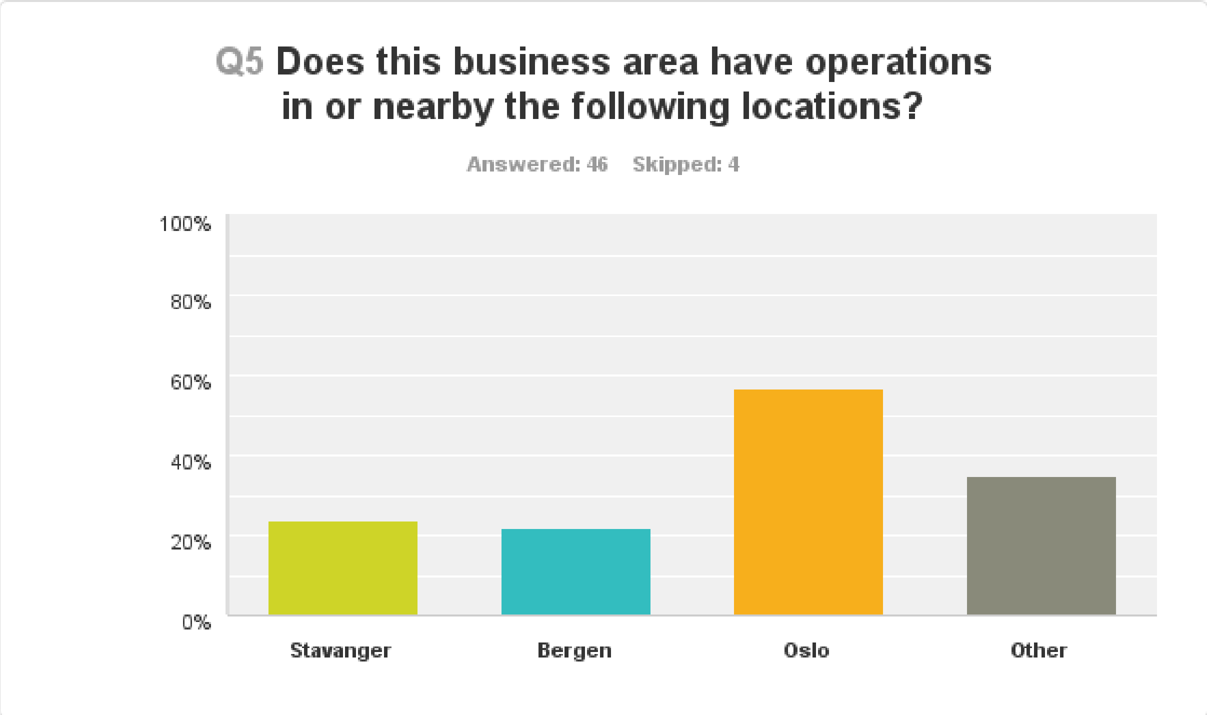


*Figure 75. Question asking for specific areas of offshore wind business for the participants companies*

*Table 23. Connected question to question nr. 11 in Figure 58*

| # | In what way? |
|---|---|
| 1 | Evaluating local presence in central Europe |
| 2 | European marked |
| 3 | Internationally, we see good opportunities for Norwegian companies. However the oil industry is still taking a lot of capacity from potensiell providers if solutions for the offshore wind industry. |
| 4 | Adapting capacity to the development of the wind market |
| 5 | More and advanced vessels |
| 6 | Advising on UK Round 3 |
| 7 | Expand offering in value chain |
| 8 | Production, assembly, service |
| 9 | Utility companies - primarily Northern Europe |
| 10 | More capacity |
| 11 | Wid company in Aberdeenj |
| 12 | Gangway systems on more larger boats |
| 13 | Through an application to and adoption into the NCE program Windcluster Norway plans to increase the cluster´s effort in both offshore and onshore wind. |
| 14 | We will be establishing local partners in those regions where this makes sense from a business standpoint |
| 15 | Find more project for our services |
| 16 | Commercialisation to large volumes |
| 17 | We follow the Norwegian supply industry |
| 18 | Strengthen our relationship to vessel consepte developers within the industry |
| 19 | Sale of software to the offshore wind turbine industry |
| 20 | Produce more vessels |
| 21 | Increased production, enter new markets |
| 22 | Going international, based on maritime and offshore experience |
| 23 | We see a growing interest for our services in the international market |
| 24 | New projects |
| 25 | Build vessels |
| 26 | As a solution provider - light and floating WTGs |
| 27 | By being visible in the marked so that designers know about us |
| 28 | aquisitions and offices abroad |
| 29 | Sell more |
| 30 | Become an internationally well known technology provider and engineering company |

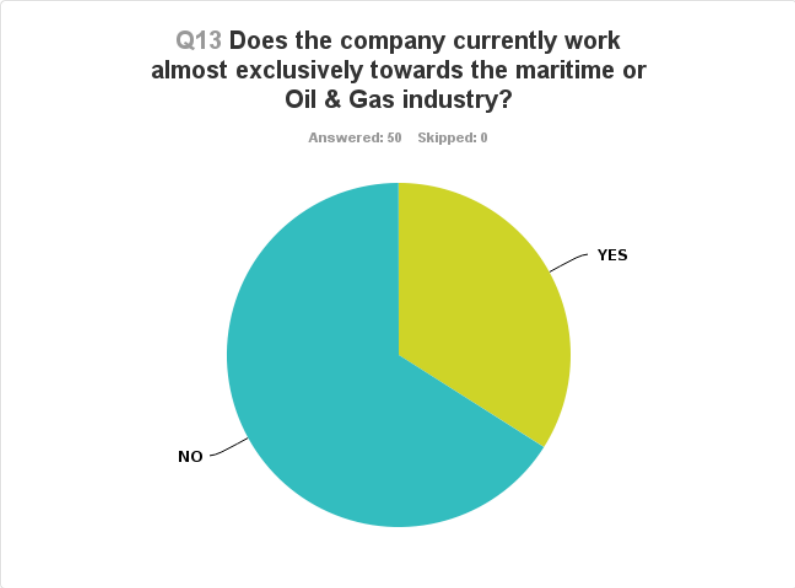


*Figure 76. Question asking if the participants company work almost exclusively towards maritime or Oil & Gas industry*

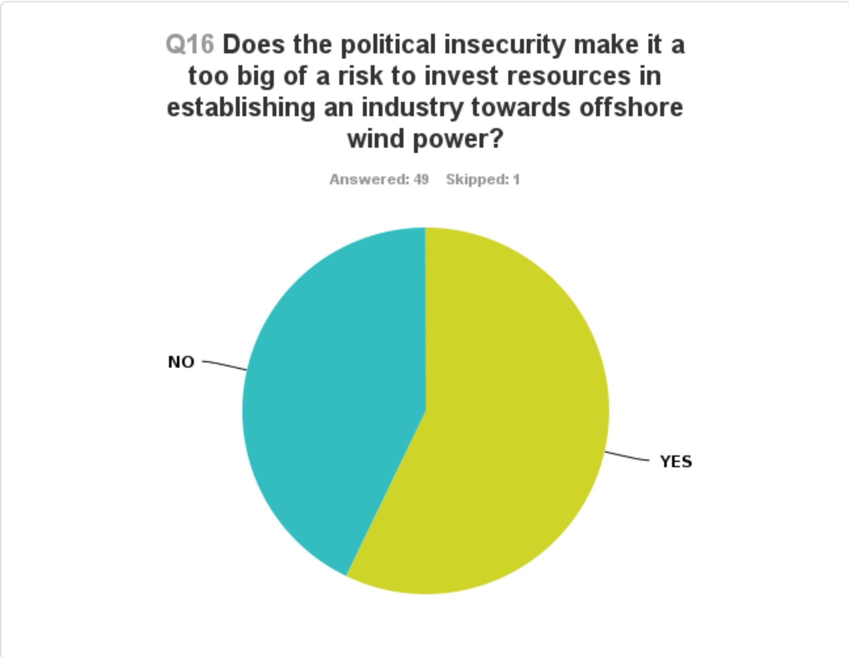


*Figure 77. Question asking the participants if they think that the political insecurity in Norway makes it to big of a risk to invest resources in offshore wind*

*Table 24. Connected question to question nr. 16 in Figure 77*

## Q17 What would be required in order to lower this risk to an acceptable degree?

Svarade: 20 Hoppade över: 30

| # | Svar | Datum |
|---|---|---|
| 1 | I believe the risk for us is mainly connected to the economy in offshore wind it self. The risk is not political. | 2014-04-23 15:37 |
| 2 | National strategy with willingnes and steady suppert system for offshore wind. Create a home marked | 2014-04-23 11:01 |
| 3 | Guaranteed feed in tariff for electricity to the grid and risk fond help in financing due to technical risk in developing the technology | 2014-04-23 10:53 |
| 4 | Stable regulatory framwork | 2014-04-22 10:22 |
| 5 | Subsidy | 2014-04-22 10:03 |
| 6 | More predictability related to future developments. | 2014-04-17 21:59 |
| 7 | Clear national targets More reliable regulations TSO cover cables offshore (as in other countries) | 2014-04-13 17:18 |
| 8 | NA | 2014-04-11 09:55 |
| 9 | Norway has enormous onshore wind resources, these should be exploited to a higher degree before offshore resources are exploited. Market risk must be removed, potentially by building cables to larger markets, agreements with other nations to buy our wind power etc. subsidies. But onshore must come first | 2014-04-10 10:26 |
| 10 | Sustainability in politics | 2014-04-10 06:46 |
| 11 | A political set and supported target. | 2014-04-09 18:25 |
| 12 | Phase out coal quicker, espceially in the EU. | 2014-04-09 12:05 |
| 13 | For us, not easy to say | 2014-04-07 14:58 |
| 14 | Long term political plans | 2014-04-04 12:26 |
| 15 | No idea | 2014-04-03 16:10 |
| 16 | Increased hydropower electricity prices | 2014-04-03 15:15 |
| 17 | Private financing is challenging Partly publicly owned company - Statwind backed by public financing. Ref Statoil history. | 2014-04-03 14:18 |
| 18 | A national pilot offshore wind farm | 2014-04-03 14:15 |
| 19 | due to the length of the development cycle policy needs to ensure security for a longer time | 2014-04-03 14:07 |
| 20 | A long term perspective and plan for how Norway will make commitment towards offshore wind. | 2014-04-03 13:56 |

*Table 25. Free text answer of how cost reductions for offshore wind could be achieved*

**Q24 How can this cost reduction be achieved?**

Svarade: 31 Hoppade över: 19

| # | Svar | Datum |
|---|---|---|
| 1 | Design installables for installation + design installation vessels for installables (purpose builds) | 2014-04-24 09:56 |
| 2 | Through project, reference to uk cost reduction scheme. This is answere to 21 and 23 | 2014-04-24 08:22 |
| 3 | Better understanding of the phisics in the wind and the wakes, making it possible to design the projects more optimal. | 2014-04-23 15:40 |
| 4 | Improved maintenance systems, standarized production | 2014-04-23 11:27 |
| 5 | more mature industry, complete installation on shore/near shore, floating turbines, better O&M, | 2014-04-23 11:02 |
| 6 | Build up dedicated wind power companies not involved in oil&gas business. Wind power can never pay the price level for those exposed to oil&gas price levels | 2014-04-23 10:56 |
| 7 | Industrial Production of standard Foundation solutions. More effective use of installation vessels. | 2014-04-22 10:25 |
| 8 | Better standardized solutions between various developments. More use of frame agreements between developers and key suppliers. New products and technology. | 2014-04-17 22:01 |
| 9 | Through all stages of the developement and operation of the Wind energee | 2014-04-16 14:03 |
| 10 | Better turbines (more yield per unit), less risk, TSO covers infrastructure | 2014-04-13 17:21 |
| 11 | Innovation, make things less complicated, and standardization | 2014-04-10 20:51 |
| 12 | Larger turbines, better logistics, better maintenance solutions | 2014-04-10 10:29 |
| 13 | Transfer experience, not start from scratch | 2014-04-10 06:49 |
| 14 | engineering learning and efficiency | 2014-04-09 14:16 |
| 15 | eEonomies of scale, R&D - New technology/improvements. Cheaper mills (or similar) | 2014-04-09 12:08 |
| 16 | Increased understanding in the market for what are good WTG foundation concepts. Re-use of such concepts with a focus on optimization. The wheel must not be reinvented over-and-over... | 2014-04-09 11:37 |
| 17 | Use more know how form the oil industry | 2014-04-09 10:56 |
| 18 | By implementing Cable Condition Monitoring solutions on both export and inter array cables | 2014-04-08 10:06 |
| 19 | Integrated approach, better concepts and installation methods, reduced O&M | 2014-04-07 08:07 |
| 20 | Industrialized production methods and better logistic. | 2014-04-04 12:35 |
| 21 | By devloping more cost-effective vessels in operation (fuel consumption) | 2014-04-03 23:58 |
| 22 | More effective analysis, design and simulation software will enable engineers to work faster and better. Thus, leading to more cost effective design. | 2014-04-03 18:50 |
| 23 | SImplification, standard products | 2014-04-03 16:12 |
| 24 | See recent reports in Germany and UK | 2014-04-03 15:57 |
| 25 | Reducing offshore operations, minimizing number of claims and repairs in cable field. | 2014-04-03 15:57 |
| 26 | Very important: Alternative choice of main conceptual solution. Saving material and related work Technology today is based on upscaling of technology developed for onshore wind. Technology is no limitation, but financial risk is limiting the development of far better technologies. | 2014-04-03 14:29 |
| 27 | Better installation Equipment, more efficient vessels, more comptence, R&D | 2014-04-03 14:17 |
| 28 | larger windmills. Better solutions gives less maintenance. Better service vessels for doing maintenance mor efficiently. Lighter constructions requires less from installation vessels, | 2014-04-03 14:16 |
| 29 | economy of scale; learning from the current mistakes; development of new technologies | 2014-04-03 14:09 |
| 30 | Clearify and standardise rules and regulations. Improved technical solutions. Minimise offshore operations (Installation & Operation/Maintenance). More robust solutions with long design life. Gain experience on mass production. | 2014-04-03 14:03 |
| 31 | Turbines more accessible for maintenance and repairs | 2014-04-03 13:56 |

*Table 26. Other answers to question 26 seen in Figure 67*

| # | Other | Datum |
|---|---|---|
| 1 | Development of floating wind is a global development | 2014-04-24 08:22 |
| 2 | Don't know. | 2014-04-23 15:40 |
| 3 | long term support system | 2014-04-23 11:02 |
| 4 | build in other countries - where it is wanted - learn and adapt in Norway when/if Norway really wants it | 2014-04-13 17:21 |
| 5 | collaborative innovation & demo framework with other countries. | 2014-04-09 14:16 |
| 6 | Norwegian technology should be deployed abroad | 2014-04-07 08:07 |
| 7 | Establishing of "Statwind" with responsibility of development, choosing and installation of next generation wind technology. New, technology, not modification of old, land based technology. | 2014-04-03 14:29 |

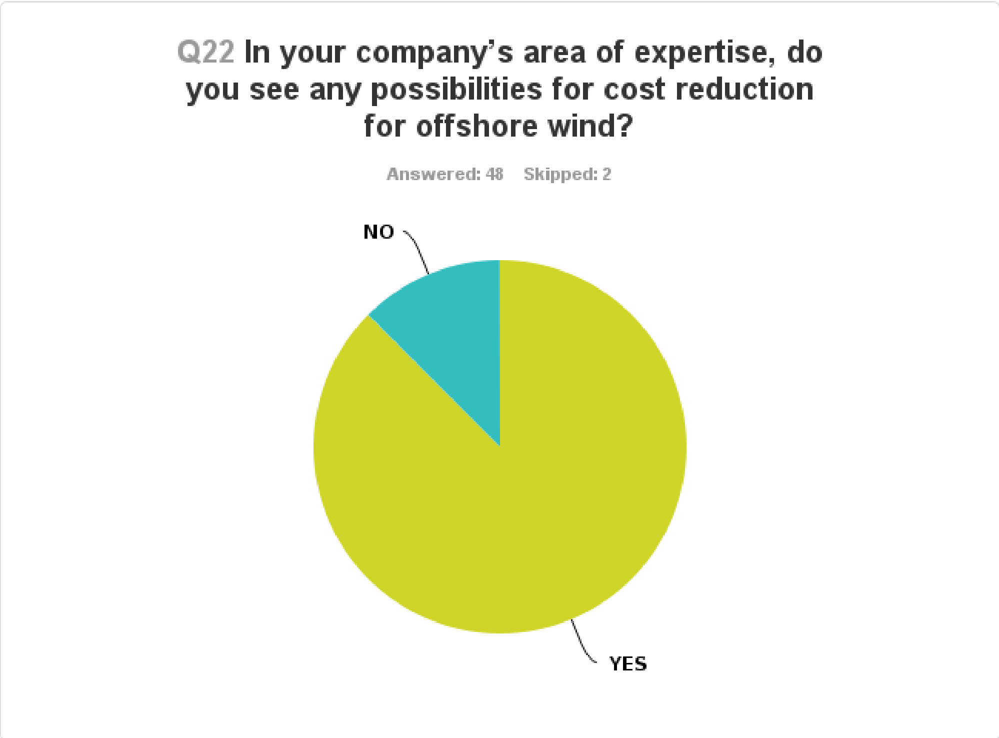


*Figure 78. The possiblity for cost reduction for the companies specfic service within offshore wind*

## 12.8 Appendix 8 - Value creation

Figure 79 displays the percentage of the supply chain for bottom mounted and floating wind turbines which can be supplied by Norway.

| Enhet | Norsk andel av totale leveranser | |
|---|---|---|
| **Fundament** | **Bunnfast** | **Flytende** |
| Planlegging og utvikling | | |
| *Generelle utviklingskostnader* | 90 % | 90 % |
| *Met. Mast* | 70 % | 85 % |
| Bygging | | |
| *Prosjektledelse* | 70 % | 85 % |
| *Komponenter* | | |
| *Vindturbin, ekskl. fundament* | 15 % | 15 % |
| *Fundament* | 80 % | 90 % |
| *Kabler* | 95 % | 95 % |
| Transformatorstasjon, bade land- og havbaserte installasjoner | 70 % | 70 % |
| Installasjon | | |
| *Fundament* | 80 % | 90 % |
| *Vindturbiner* | 50 % | 80 % |
| *Kabler* | 80 % | 80 % |
| Substation, inkl. Onshore- and offshore facilities | 70 % | 70 % |
| Andre kostnader | 75 % | 75 % |
| Drift og vedlikehold | | |
| *Drift* | 85 % | 85 % |
| *Vedlikehold* | | |
| *Planlagt* | 65 % | 75 % |
| *Ikke planlagt* | 60 % | 90 % |
| Dekommisjonering | 80 % | 90 % |

*Figure 79. Norwegian part of supply chain for offshore wind [52]*